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Review Paper

Evaluating methods for detecting and monitoring pangolin (Pholidata: Manidae) populations

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A B S T R A C T

The behaviours, ecologies and morphologies of pangolins make them challenging to survey and monitor, and non-targeted wildlife surveys have not produced robust status assessments, especially where population densities are low because of overexploitation. To inform the development of feasible survey and monitoring techniques for pangolins, we conducted a systematic review of all traceable efforts used to survey and monitor pangolins to date: 87 articles were included in the review. Pitfalls of current approaches are discussed and recommendations made on suitable methods. Recommendations include the use of mark-recapture for burrow-dwelling species, community interviews, sign-based surveys in arid and open habitats, detection dog teams, and targeted camera-trapping. Occupancy sampling using camera-traps could be used to monitor some pangolin populations, particularly ground-dwelling species, but the rarity of all species makes it uncertain whether this would provide enough data for monitoring; combinations of methods used within an occupancy sampling framework are likely to be the most effective. There will be many circumstances where direct monitoring of a population at a site, to a level that will generate precise data, is not financially viable nor the best use of conservation resources. In many sites, particularly in Asia, pangolins are too rare as a result of overexploitation, and/or occur in inaccessible areas where significant resources will be needed to implement a targeted monitoring programme. Under such circumstances, the use of proxy variables, including status of other hunting-sensitive species that are easier to record, in combination with enforcement or patrol data and/or community interviews, is

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likely to be the most cost-effective method for assessing the impact of conservation interventions on pangolin status. The publication of incidental observations and survey 'by-catch' would significantly improve understanding of pangolin status and ecology, and therefore how best to identify, conserve and monitor priority populations.

1. Introduction

Pangolins are one of the most globally threatened mammal groups. All eight extant species, four in Africa and four in Asia, are listed as globally threatened on The IUCN Red List of Threatened Species (IUCN, 2019). The most significant threat to pangolins is overexploitation for the illegal international wildlife trade and local use, which mainly involves the meat of the animals and their scales (Boakye et al., 2015; Heinrich et al., 2017).

The behaviours, ecologies and morphologies of pangolins make this group challenging to survey and monitor. Most pangolin species are small (under 10 kg) and cryptic (Myhrvold et al., 2015), and with one exception (black-bellied pangolin *Phataginus tetradactyla*: Kingdon and Hoffmann, 2013), each species is understood to be primarily nocturnal (Kingdon and Hoffmann, 2013; Gaubert, 2011), though most have been observed to be active during the day. Black-bellied pangolin is understood to be almost exclusively arboreal, Sunda pangolin *Manis javanica*, Philippine pangolin *Manis culionensis* and white-bellied pangolin *Phataginus tricuspis* are semi-arboreal, and the remaining four species are burrow-dwelling. Pangolins are not known to vocalise and do not appear to have markings that would easily enable individuals to be identified from photographs.

Confidently determining the status of pangolins at the site, national and global levels has proven challenging, and has relied on proxy measures. Surveys of sufficient effort that have used methods likely to detect a large portion of ground-dwelling mammals often fail to detect pangolins, even though, based on the confirmed presence of other hunting-sensitive or impacted species, pangolins probably persist (e.g., Moo et al., 2017; Suzuki et al., 2017; Lahkar et al., 2018). Establishing whether these results are non-detections (due to methodological issues) or genuine absences, has made determining pangolin status at sites and within countries difficult. Status assessments have therefore relied on other measures including the status of an area's fauna, levels of observed or reported hunting pressure (including historical unverifiable accounts), information on perceived status from community interviews (e.g., Nash et al., 2016) and market, trade and trafficking dynamics (e.g. Newton et al., 2008).

Difficulties in surveying pangolins, especially where low population densities are suspected owing to overexploitation, have also made it challenging to produce confident status assessments using results of general (i.e. non-targeted) wildlife surveys. This is particularly apparent for populations of the Asian species, where decades of targeted and sustained over-exploitation have resulted in very low population densities (e.g., Duckworth et al., 1999). Given the threats pangolins face, there is a need to develop efficient survey and monitoring methods in order to more robustly determine species status, identify priority populations, and evaluate the impact of conservation interventions on populations. To inform the development of feasible survey and monitoring techniques for pangolins, we conducted a systematic review of all traceable efforts used to survey for or monitor pangolins in the published and grey literature.

There was no empirical evidence with which to precisely assess a method's suitability against. Most assessments are therefore effectively opinion-based. This is an obvious limitation to the conclusions that have been made, however considerable effort has been made to evaluate each method as best possible and to seek expert opinion wherever possible. An additional limitation is that there are pangolin records from 'by-catch' (e.g., from large-scale camera-trapping), that are unpublished and were therefore not included. Although every effort was made to include relevant unpublished records, their inclusion was dependent on the author's networks and knowledge of relevant surveys; there was not the scope in this review to trace every unpublished record.

2. Methods

We systematically reviewed relevant literature using the method developed by the Collaboration for Environmental Evidence (2013). The primary review question was 'how effective have applied methods been at detecting and monitoring pangolin populations?' Peer-reviewed publications and grey literature that had reviewable details on survey or monitoring methods for pangolins were targeted. Grey literature included presentations, donor reports, and unpublished/non-peer-reviewed survey and/or technical reports.

2.1. Search terms, strings and databases

We searched the Thomson Reuters Web of Science database [version 5.27.2] (all years, all databases), Google and Google Scholar for relevant literature using a combination of terms in each, using Boolean queries (Appendix 1: Fig. 1). Searches were conducted between October 2017 and December 2017. Where searches included species names, known synonyms were included. In Web of Science the search terms and Boolean queries included the following: "*Manis crassicaudata*", "*Manis culionensis*", "*Manis gigantea*", "*Manis javanica*", "*Manis pentadactyla*", "*Manis temminckii*", "*Manis tetradactyla*", "*Manis tricuspis*", "*Phataginus tetradactyla*", "*Phataginus tricuspis*", "*Smutsia gigantea*", "*Smutsia temminckii*", "pangolin AND distribution", "pangolin AND ecology", "pangolin AND monitoring", "pangolin AND status", "pangolin AND survey".

Potential country biases in Google were removed by using www.google.com/ncr [ncr = no country region], before searches were conducted. We searched all years (unless specified below), all languages and for specified file types (.PDF,.PPT,.PPTX,.DOC,.DOCX). Search terms that excluded "mine" and "mining" were included after 2005; a mining company was established in this year that has 'pangolin' in its name (see Appendix 2 for a full list of search terms). This did not exclude pangolin records that may have resulted from e.g. environmental impact assessments on mining concessions; visual scans of results from searches that included the term mining, did not produce any such records.

In Google Scholar, search terms within the title of articles (alllintitle) comprised the following: "*Manis temminckii*", "*Manis gigantea*", "*Manis javanica*", "*Manis tetradactyla*", "*Manis tricuspis*", "*Manis pentadactyla*", "*Manis crassicaudata*", "*Manis culionensis*", "*Phataginus tetradactyla*", "*Phataginus tricuspis*", "*Uromanis tetradactyla*", "*Smutsia temminckii*", "*Smutsia gigantea*"; and the following terms that were searched anywhere in articles: "pangolin recorded", "pangolin was recorded", "pangolin survey", "pangolin monitoring", "pangolin detected", "pangolin was detected", "pangolin detection", "pangolin observed", and "pangolin was observed". A number of additional sources were added following email correspondence with people known to be engaged in relevant research, and a review of existing literature databases that are maintained by DW and DC. Surveys for other species or mammal groups, that used methods suitable for detecting pangolins if present, were also included, particularly for camera-trapping and nocturnal (spotlighting) surveys; these were traced based on sources or references known to the authors. Two highly relevant papers were included after the review had been completed: Nash et al. (2018a) and Bruce et al. (2018). Two papers were included during this paper's review: Duckworth (1998b) and Gurung (1996).

2.2. *Article screening*

There were two main stages to article screening: (i) removing duplicates, and (ii) removing articles by applying exclusion criteria (Appendix 1: Fig. 1). All results from internet searches were exported as tables and visually checked; any duplicate articles were removed. For the large set of results from Google, articles were grouped by year to aid this process and each web link was checked for its relevance to the review. For the results from Web of Science and Google Scholar the export files included publication title, year of publication and author, which were usually sufficient to determine a paper's relevance.

Articles were rejected from the final list of sources if there were insufficient details included on the methods used, if on reading the source it was irrelevant, or if they were in a language other than English. Eight papers were not included based on language, seven in Chinese and one in Indonesian; of these, one had an English language equivalent, and one was from a research group that contributed to the development of this review. Of the remaining six, only two were thought likely to include information relevant to this review, but are on pangolin species that are well-represented by other sources. A full list of rejected sources is in Appendix 3. Sources that had an abstract or other reviewable text in English that provided sufficient detail on methods were accepted.

2.3. *Reviewing the effectiveness of methods*

The methods in the final sources were reviewed for: information on pangolin status (though not necessarily to species level), confirming species presence, the generation of ecological information, and/or estimating population densities/abundance. Only methods that have been applied to pangolins are included in this review.

Consideration was given to whether the survey or research had been conducted in an area where pangolin populations are assumed to be at low densities due to overexploitation, or in areas with relatively low hunting pressures, and the impacts of these circumstances on a method's efficiency. No effort was made to assess a method's relevance across a species's range where densities and abundance might vary due to variable factors e.g., habitat, as these data do not exist, and for many populations, overexploitation probably masks any actual changes due to habitat preferences. Sites where pangolins persist are more likely to reflect exploitation patterns and may even be marginal/unsuitable habitat for the species.

Although cost is a major factor in any analysis of effectiveness, only one traced source included detail on the cost of surveys. This prevented any quantitative analysis. However, the cost implications of each method were assessed following discussions with known experts, and the lead authors' first-hand experience with these techniques. No assessment was made of whether the random placement of transect lines, survey plots or similar was truly random or not.

3. Results

Internet-based searches produced 2191 articles, including 230 from Web of Science, 1710 from Google and 251 from Google Scholar. Removing duplicates but adding additional sources resulted in 133 articles that were reviewed (Fig. 1). A further 46 articles were removed based on our exclusion criteria, resulting in 87 articles being included in the review.

Results for each species are included in Appendix 4: Tables 3–9 Results for black-bellied pangolin are not tabulated because there was only one traced effort to survey this species. Burrow-dwelling species are presented first, followed by semi-arboreal and then arboreal.

3.1. Chinese pangolin Manis pentadactyla (Appendix 4: Table 3)

Most Chinese pangolin surveys have used burrow counts to assess its status and distribution (Wu et al., 2003; Bhandari and Chalise, 2014; Thapa et al., 2014; Dorji, 2015; Katuwal et al., 2017; SMRCF, 2017). Burrow counts were used to estimate burrow density in different habitat types, and therefore status, but none estimated populations based on these data. Most research made the distinction between active and old burrows by looking for recent claw marks, freshly dug soil, or the presence of a 'false wall', a wall of earth used by pangolins to avoid predation (see Bao et al., 2013; Trageser et al., 2017). All published telemetry research have been in Taiwan (NOW, 2010; Pei et al., 2015).

3.2. Indian pangolin Manis crassicaudata (Appendix 4: Table 4)

Burrow counts have been used to assess distribution and status, possible habitat associations, and burrow characteristics (Irshad, 2015; Mahmood et al., 2013, 2014; 2015; Nadeem et al., 2015; Pabasara et al., 2015; Anon, 2016; Akrim et al., 2017). There are no published telemetry studies on this species. Burrows were usually distinguished as either feeding digs or burrows, and further categorised as active or old, inactive burrows (e.g. Mahmood et al., 2014). Several of these surveys produced population estimates based on burrow densities (Irshad, 2015; Nadeem et al., 2015; Mahmood et al., 2014, 2015; Akrim et al., 2017).

3.3. Temminck's ground pangolin Smutsia temminckii (Appendix 4: Table 5)

Research on this species has focused on its ecology and home range size (Jacobsen et al., 1991; Heath et al., 1997a; Pietersen et al., 2014), foraging behaviour and diet (Richer et al., 1997; Swart, 1996; Swart et al., 1999; Pietersen et al., 2015), and translocation success (Heath et al., 1997b).

3.4. Giant pangolin Smutsia gigantea (Appendix 4: Table 6)

Only two published studies on wild populations were traced, both from Cameroon (Ichu et al., 2017; Bruce et al., 2018). Other research which included this species focused on pangolin bushmeat markets in Nigeria (Sodeinde and Adedipe, 1994) and a review of pangolin trade data from across Central Africa (Ingram et al., 2018).

3.5. Sunda pangolin Manis javanica (Appendix 4: Table 7)

Targeted camera-trapping has recorded Sunda pangolins in Sabah, Malaysia (Panjang, 2012), Brunei (Fletcher, undated), Vietnam (CPCP, 2014; Willcox et al., 2017) and Thailand (ZSL, 2017). There have been multiple attempts to track animals using telemetry, but none have lasted more than three months due to high transmitter drop-off rates (Lim, 2007; Lim and Ng, 2008; Panjang, 2012; CPCP, 2014; Nash et al., 2018a).

3.6. Philippine pangolin Manis culionensis (Appendix 4: Table 8)

Local community interviews, nocturnal surveys, hunting dogs (Schoppe and Alvarado, 2015a; 2015b, 2015c), targeted camera trapping (Marler, 2016), and snare traps (Acosta-Lagrada, 2012) have been used to detect Philippine pangolins. Telemetry has also been used on this species (Schoppe and Alvarado, 2015a).

3.7. White-bellied pangolin Phataginus tricuspis (Appendix 4: Table 9)

This was the first pangolin species to be researched using telemetry (Pagès, 1975). There is little traceable information on the transmitter design or its success, other than that it was attached to several scales using copper wires (Zimmermann et al., 1976). General bushmeat surveys have also recorded the species (Angelici et al., 1999). Targeted surveys have used observations at local bushmeat markets and information from community interviews in Nigeria to assess pangolin status and threats, including white-bellied pangolins (Sodeinde and Adedipe, 1994; Soewu and Ayodele, 2009). Species status has been assessed using nocturnal surveys and interviews in Benin (Akpona et al., 2008). Ichu et al. (2017) used a combination of diurnal sign surveys, community interviews and camera-trapping; only the latter confirmed the species presence.

3.8. Black-bellied pangolin Phataginus tetradactyla

There is no published ecological research on the black-bellied pangolin. There were no records during the targeted pangolin bushmeat surveys of Sodeinde and Adedipe (1994). The diurnal transects, camera-trapping and community interviews discussed in Ichu et al. (2017) only produced a single record; a carcass found during a line transect. During interviews it was the least well-known pangolin species and the one reported to be least frequently observed (Ichu et al., 2017).

4. Discussion

4.1. Burrow counts

For the purposes of this review, surveys that targeted pangolin burrows are discussed separately. Sign surveys, which include searching for combinations of signs such as faeces, claw marks, tail drag marks and/or burrows are discussed in section 4.3.

Several surveys have produced population estimates based on the density of pangolin burrows (e.g. Mahmood et al., 2014, 2015; Irshad et al., 2015; Nadeem et al., 2015; Akrim et al., 2017). These estimates are dependent on the assumption that one active pangolin burrow equates to one pangolin occupying a surveyed area, that all active burrows are found, and that all burrows identified as active reflect pangolin activity rather than that of any other species; active burrow densities are simply equated to pangolin densities. However, pangolins are known to use multiple ‘active’ burrows, occupying a single burrow for only a few days at a time (e.g. Lim and Ng, 2008; Pietersen et al., 2014; Pei et al., 2015), with as many as 30–80 burrows being used by individual Chinese pangolins in Taiwan (Nick Sun, pers. comm. 2018). It is therefore probable that many of the population estimates derived from burrow count data are inaccurate as multiple burrows in a survey area in a given time period could be utilised by one resident pangolin. Pangolin species that use tree hollows or tree or rock cavities (e.g. Chong et al., 2016) as resting places will mostly go undetected using this method and it will be difficult to determine whether such ‘burrows’ are active. Pangolins have also been recorded resting in more open areas such as grasslands (Lim and Ng, 2008) which will also result in non-detections.

The accuracy of burrow counts is also dependent upon the ability of the surveyor to identify resting burrows from feeding ‘digs’ (sometimes referred to as ‘feeding burrows’), active from inactive burrows, and whether burrows belong to a pangolin or other burrowing species e.g. Aardvark *Orycteropus afer* (Ichu et al., 2017). Separation from feeding digs is relatively straightforward, with depth the main criterion (e.g. Mahmood et al., 2013). However, accurate distinction of inactive from active pangolin burrows is more challenging. Researchers have used freshly dug soil and fresh prints (e.g. feet, tail) at burrow entrances, the absence of leaves, debris or spider webs, and/or the presence of a false wall at burrow entrances to determine activity status. No studies used camera-traps or similar methods to validate burrow occupancy rates and how this may vary over time and space. This has probably caused overestimates of pangolin density; some pangolin species are known to use burrows dug by other species (Pietersen et al., 2014) and other species are known to use pangolin burrows (e.g. travancore tortoise *Indotestudo travancorica*: Deepak, 2011). Additionally, the criteria for identifying a pangolin burrow can be inconsistent across a species's range. Chinese pangolins are reported to create semi-circular (SMCRF, 2017) and circular burrows (Gurung, 1996) in Nepal, and circular burrows in Vietnam (Newton et al., 2008). The former two are based on direct observation, the latter from hunter interviews. No authors that have published population estimates from burrow counts have considered these important caveats, and there has been no estimate of the levels of inaccuracy these factors introduce. In theory some form of ‘correction factor’ could be determined to allow conversion of burrow numbers to pangolin numbers but this commands further research. It is subject to polarised debate for other burrowing species (e.g., gopher tortoise *Gopherus polyphemus*: Nomani et al., 2008; Stober and Smith, 2010), and similar problems will probably affect the application of this method to pangolins.

The sole use of burrow counts to identify potential habitat associations/preferences is also flawed. Burrow detection will vary in different habitats, particularly in areas that are steep and inaccessible to survey teams or where habitat is less open (e.g. presence of a dense shrub layer), and where most/all burrows are in earth as opposed to rocks and/or trees. Additionally, as it is likely that most pangolin species have been overexploited in parts of their ranges, previously occupied habitats are likely devoid of pangolins, therefore creating apparent habitat associations which are likely to reflect habitat associations of hunters, for example, as opposed to pangolins. This is particularly true of lowland areas which tend to have higher human population densities. Some pangolin species are known to be relatively tolerant of habitat loss or modification and have been recorded in secondary forests, commercial plantations, urban gardens and in peri-urban landscapes (e.g. Sunda pangolin; Fletcher undated, Lim and Ng, 2008; Willcox et al., 2017). Absence of pangolins from similar habitats is potentially due to hunting pressure rather than an intrinsic unsuitability to the habitat.

Providing absolute densities based on burrows is likely to be very difficult, but coarse-scale monitoring of burrow density to track status may have application. Counts of active burrows could be a cost-effective way to establish pangolin presence within an area and broadly to track status over time, and, occasionally, space. If combined with estimates of home range size and burrow usage/occupancy rates (including any seasonality patterns in use), burrow densities could be used to produce basic population density estimates. However, this will be limited to species that use easily identifiable and detectable burrows i.e. the ground-dwelling species that live in relatively open habitat types (Indian pangolin, Temminck's ground pangolin and, in some areas, Chinese pangolin). Given the challenges in identifying a pangolin burrow as active and occupied by a pangolin (e.g., Ichu et al., 2017), efforts should be made to confirm a burrow's occupant through camera-trapping or by using a borescope (e.g. Trageser et al., 2017). Combinations of methods are likely to be needed in some instances given the sometimes complex, multi-chambered structures of pangolin burrows (E. Connelly pers. comm. 2018). Camera-traps set outside burrows have the potential to provide additional data (e.g., on breeding ecology; see Lim and Ng, 2008), but consideration should be given to burrows potentially having multiple entrances/exits (e.g., Bruce et al., 2018).

4.2. Nocturnal surveys

Most pangolin species are predominantly nocturnal (though not strictly, see Schoppe and Alvarado, 2015c; Pietersen, 2013; Lim, 2007; Lim and Ng, 2008) and the black-bellied pangolin is reportedly diurnal (Kingdon and Hoffmann, 2013; R. Cassidy pers. obs). Nocturnal (or spotlighting) surveys rely on detecting an animal's eyeshine or shape by eye using torchlight and by ear using sounds of the animal's movement and/or vocalisations and then sometimes using a stronger spotlight to identify the species (e.g. Duckworth, 1998a; Mathai et al., 2013). However, most pangolin species do not have a strong eyeshine (Newton et al., 2008; DW, pers. obs.). Pangolin-focused nocturnal surveys had zero detections (Willcox et al., 2017; ZSL, 2017) or very few (CPCP, 2014; Dorji, 2015; Trageser et al., 2017) relative to the survey effort required. Schoppe and Alvarado (2015b) reported that searching for indirect signs during the day, with locations selected based on community interviews, and then searching these transects for animals at night and using local hunting dogs are reliable methods. However, no information was included on how dependent direct observations during nocturnal surveys were on the use of hunting dogs.

A spotlighting survey effort of 254 h targeting nocturnal mammals (mostly lorises) within Sunda pangolin distribution had zero detections (Rode-Margono et al., 2014). Similarly, approximately 200 survey hours in central Vietnam, focused on nocturnal species of reptile and amphibian, produced only a single Sunda pangolin detection (S. Trageser pers. comm.). Nearly 100 h spotlighting in sites in Lao PDR, where pangolins were known to persist at the time of the surveys, failed to record pangolins (Duckworth et al., 1994).

Pangolins are relatively noisy when active and feeding, especially if the forest floor is dry. Cycling quietly along human-made trails at night whilst listening for these sounds proved an effective detection method in Lim and Ng (2008). At least one of the Sunda pangolins detected in Willcox et al. (2017) was first heard feeding on a weaver ant nest, before it was seen. Oates (2001), reports hearing and then observing a giant pangolin as it walked through the forest. Walking slowly along human-made trails that had been swept of leaves in a dense tropical forest, whilst scanning using torchlight detected a white-bellied pangolin in approximately 10 h of survey effort (DW and D. Pietersen pers. obs.). Thirty-eight white-bellied pangolins were detected in Akpona et al. (2008), though no details were provided on the survey effort required. Pietersen et al. (2014), followed the fresh tracks of Temminck's ground pangolins to capture animals for a telemetry study; although the authors did not survey using this method, it may have application in arid and open habitats (e.g., The Kalahari, Botswana: Keeping et al., 2014).

Due to weak eyeshine in pangolins, detection using this method will depend on being able to hear an active pangolin or see its body shape. This will limit the application of this method to habitats that are relatively open, or where there is a network of trails that allows for relatively soundless walking. Working at night has other challenges too; large and potentially dangerous mammals such as elephants are a hazard.

There was probably a time when surveying at night by scanning along pathways and surrounding habitat would have produced fairly regular pangolin detections in some habitats for some species; local hunters in Africa and Asia report on the ease at which pangolins can be hunted and caught, including by hand, when present (Carpaneto et al., 2007; Ichu et al., 2017). The ease at which pangolins have been and are hunted, and the growing transnational illegal trade, has caused many populations to decline to densities too low to make nocturnal surveys a cost-effective method. This is particularly true for most of South-east Asia, where only very well-protected populations (e.g. Singapore), or populations not yet reached by industrial-level hunting (U Minh, Vietnam: Willcox et al., 2017), could still be surveyed this way. The situation is less bleak in Africa, where relatively low survey efforts produce detections in areas where pangolin densities are relatively healthy (DW, pers. obs.), and/or where the habitat is open enough and animals can be tracked (e.g., Pietersen et al., 2014). However, given the increasing illegal trade in pangolins from Africa to Asia (Ingram et al., 2018), this situation will probably change rapidly.

This method will only ever be able to help confirm species' presence in an area (e.g., Duckworth, 1998a,b), and perhaps aid in a broad assessment of status, but given the previously listed restrictions, it will only be feasible in only a few regions or countries, and where the target species's ecology makes it suitable. This method would need to be targeted at pangolins; general mammal or wildlife surveys that used a mixture of diurnal and nocturnal surveys in areas that have relatively healthy mammal populations, and have been undertaken in open habitat have failed to record pangolins (e.g., Gaidet et al., 2005). Duckworth et al. (1999) compiled and reviewed wildlife records from multi-week surveys at 32 sites in Lao PDR; all had received some level of spotlighting effort. Only one field record of Chinese pangolin was produced (Duckworth, 1998b), and although Sunda pangolin was recorded more frequently (9/32 sites), the majority of these were of captured animals observed in villages, and not animals seen during the multiple survey efforts for nocturnal mammals (Duckworth et al., 1999).

4.3. Diurnal surveys

Surveys based on detecting signs have been used to detect presence within an area, and in some cases to estimate pangolin densities. Encounter rates (e.g. number of signs per km) have been used to assess pangolin status within surveyed areas. Detected pangolin signs have also been used to guide targeted camera-trapping, to confirm species (Ichu et al., 2017), or as part of pangolin-focused surveys (ZSL, 2017). Signs used to establish pangolin presence include feeding signs (e.g. broken termite mounds), claw marks, tail drag marks, foot prints and burrows. Faeces, particularly outside potential pangolin burrows, have also been used. No traced reports used DNA analysis to confirm species identity. Species other than pangolins that predate on ants and termites (e.g. Aardvark, Sun bear *Helarctos malayanus*), make species confirmation based only on faecal contents vulnerable to error.

There were reported difficulties in identifying pangolin signs to species level when there are multiple species in an area (Ichu et al., 2017), where there are ecologically similar species that leave comparable field signs (e.g. Aardvark feeding signs: Ichu et al., 2017), or where the most frequently detected sign is one that could easily be misinterpreted (e.g., claw marks on trees: ZSL, 2017). Additionally, there are several pangolin species that will not leave easily detectable signs; Sunda pangolin, Philippine pangolin and white-bellied pangolin are semi-arboreal, and black-bellied pangolin is arboreal. The forested habitats in which these species persist makes surveying for and detecting signs difficult; most surveys will be restricted to human-made pathways and the dense shrub layer that exists in some tropical forests will prevent a proportion of signs being visually detected. Pangolins are not known to make latrines or to use human-made trails or roads in a manner similar to that known for some other mammals (e.g., various carnivores), making predictions of where best to look for possible signs challenging. There are several observations of pangolins in the wild and in captivity exhibiting behaviours that probably help avoid detection by predators. These include defecating in water, burying faeces (CPCP, unpubl. data) and defecating in small tree hollows and cavities (R. Cassidy, pers. obs.). Sand traps (clearing ground of leaves and other debris, and then laying sand near areas where pangolins are thought to frequent) have been trialled for Sunda pangolins in Thailand (ZSL, 2017) but were unsuccessful; this method is unlikely to be suitable for forest-dwelling pangolin species.

Surveys that rely solely on the visual detection of field signs, without any sort of species confirmation (e.g., by using camera-traps or DNA analysis of faeces), will be an unreliable method for most pangolin species. The exception to this are areas where the substrate allows for easy detection of pangolin signs; this will probably generate useful information on pangolin status (though not always to species level). Track counts and densities, combined with existing ecological information (e.g. home range size), could be used to monitor status of some pangolin species over time and occasionally, space, but this may be only possible in certain habitats/seasons, and when enough ecological data exists.

4.4. Telemetry

Pangolins have a body shape and ecology that limits potential transmitter attachment options; both collars and harnesses are inappropriate. Attachment methods have comprised attaching transmitters directly onto a scale or scales (Pagès, 1975; Lim, 2007; Pietersen et al., 2014; Schoppe and Alvarado, 2015b) or attaching them via a flexible material that is then bolted onto a scale (CPCP, 2014). Epoxy glue is often used to strengthen the attachment and to help streamline the shape of the transmitter to reduce the chance of its snagging on vegetation and detaching. Large dorsal scales near the base of the tail, or at the top of a hind leg, have usually been chosen as points to attach the transmitter, again, to reduce the chance of the transmitter catching on vegetation and detaching.

The success of these methods seems to be determined by the size and thickness of the scales. Species that are primarily ground-dwelling, such as Chinese pangolin and Temminck's ground pangolin, have relatively large and thick scales that can support transmitters. In contrast, the semi-arboreal Sunda pangolin has relatively thin scales that tend to split when drilled into or that break during tracking (DW, pers. obs.). All telemetry studies on the Sunda pangolin have reported high transmitter drop-off rates. VHF transmitter implants have not been trialled, but given the potential mortality risks associated with implantation, and limited range, would seem inappropriate.

A form of telemetry not yet trialled on pangolins are PITs (Passive Integrated Transponder). PITs are small implants that activate when a scanner is near. However, PITs have an extremely small range (below 1 m). One potential application could be to place PIT scanners near or at the burrow entrances. As pangolins use multiple burrows such application would require considerable resources and careful piloting. Pangolins that are released in Singapore (H. Nash, pers. comm.), Vietnam (Nguyen Van Thai, pers. comm.) and Zimbabwe (E. Connelly, pers. comm.) are implanted with PIT transmitters prior to release, to monitor if the animal is ever recaptured; this method confirmed that a Sunda pangolin confiscated from hunters in Pu Mat National Park, Vietnam, was not a released animal (Nguyen Van Thai, pers. comm). Capturing pangolins in order to attach transmitters also provides an opportunity to learn more about basic biological parameters and pathogens (Khatri-Chhetri et al., 2015). It is unknown whether wild pangolins are natural carriers of infectious diseases, but given the large number of animals that are confiscated from the wildlife trade and then released into protected areas, this warrants further research and a precautionary approach.

4.5. Camera-trapping

Camera-trapping is used widely across the tropics to survey and monitor medium to large-sized mammals. It has been used to monitor populations (e.g., tiger *Panthera tigris*; Karanth et al., 1998), and 'by-catch' of non-target species has been used to track the status of species at a coarse scale (e.g., Willcox. et al., 2014). Camera-traps have also been used effectively to detect the presence of elusive, often nocturnal, species of mammal, including pangolins (e.g., Bruce et al., 2018).

Pangolin status is difficult to monitor through camera-trap by-catch. Medium to large-scale survey efforts (over 3000 camera-trap-nights), that had set camera-traps for medium to large-sized mammals recorded either very few (Jenks et al., 2011; Jambari et al., 2015; Nakashima, 2015; Bruce et al., 2017; Gray et al., 2017; Suzuki et al., 2017) or no pangolins (Moo et al., 2017; Lahkar et al., 2018). Several of these survey efforts set camera-traps at heights that could detect ground-dwelling pangolins (around 30 cm), and were, based on the other species detected, at sites where other hunting-impacted mammal species were present, sometimes in relatively healthy numbers (e.g., tiger; Moo et al., 2017). Lynam et al. (2003) reported zero Sunda pangolin detections, whilst Jenks et al. (2011) had a detection rate of 0.12 per 100 trap-nights in Khao Yai National Park (Jenks et al., 2011). Suzuki et al. (2017) had an encounter rate of 0.42 in 1000 camera-trap-nights in 2012–2013, but no detections in 2013–2014. These patterns suggest ground-dwelling pangolins can often be missed during conventional camera-trapping, and that it is probable that the low number of records or apparent absences are often due to non-detections.

In most mammal surveys, camera-traps are set at micro-habitat features (e.g., trails, salt licks, glades) or where there are clear signs of mammal activity (e.g., latrines), to maximise the chance of producing clear, verifiable photographs that can be identified to species level. There is no evidence that pangolins frequently use trails or roads and the opposite is probably true, given low detection rates on human-made pathways or roads. There is some evidence to suggest that pangolins will avoid trails based on telemetry data of a monitored Sunda pangolin (see Panjang, 2012). In captivity, trade-confiscated pangolins have been observed forcing their way through dense vegetation (DW, pers. obs), the opposite behaviour of large carnivores, which can often be predicted to use more open areas such as roads, on the basis that these are spaces are easier to move through. There is no evidence that pangolins will make latrines; multiple species have been observed hiding their faeces, either by defecating in water, or defecating in small tree cavities [see Section 4.3]. Gray et al. (2017) suggested that randomly placed camera-traps have a better chance of detecting Sunda pangolins, compared with more conventional methods. This is plausible, but given the low densities of many populations, it will probably produce a high rate of non-detections unless using a substantial and costly survey effort involving many tens of thousands of camera-trap-nights.

Pangolin populations are known to have gone through significant trade-driven declines in some regions (e.g. South-east Asia), and the paucity of camera-trap records from general mammal surveys may reflect their low densities. Similar camera-trapping efforts in Africa have recorded pangolins with relatively low survey effort, i.e. fewer than 1000 camera-trap-nights (Gessner et al., 2014). However, this type of general mammal survey can at best only confirm presence, not status, based on the low number of records from populations that are assumed to be relatively healthy.

Camera-traps set specifically for pangolins have been only marginally more successful, at least at establishing presence, though feasibility varies between species, habitat and hunting pressure. In areas where ground-dwelling pangolins have gone through significant declines, camera-trapping is ineffective. This is particularly true of mainland South-east Asia, where industrial-scale hunting has caused declines in a number of wildlife species (Harrison et al., 2016), including pangolins (IUCN, 2019). Pangolin-focused surveys that have used camera-trapping in combination with other methods such as spotlighting, have failed to detect pangolins in this region (Willcox et al., 2015). Camera-traps set by possible signs of pangolin activity have been successful at establishing presence in mainland South-east Asia, but required significant survey effort: approximately 13,260 camera-trap-nights produced 23 Sunda Pangolin detections in Thailand (ZSL, 2017). Replication of this effort at the same, or other sites, to establish comparable detection rates would require significant resources.

Exceptions exist in areas where pangolins have not gone through significant declines. Relatively low survey effort of fewer than 900 camera-trap-nights, with a proportion or all of the units set for pangolins, produced multiple records in south Vietnam (Willcox et al., 2017), Sabah, Malaysia (Panjang, 2012), Palawan, Philippines (Marler, 2016), and Cameroon (Ichu et al., 2017; Bruce et al., 2018). Each survey deployed camera-traps at heights suitable for pangolins and/or at locations where pangolin detection was plausible based on the presence of field signs.

Camera-trapping can help to confirm pangolin presence, and allow some inferences on possible status, but it will be most cost-effective in areas where pangolins have not gone through significant population declines, and with species that are largely ground-dwelling. Arboreal camera-traps (see Whitworth et al., 2016) may have application for the semi- and arboreal pangolins but will need piloting. A fuller discussion on occupancy modelling and random encounter models (REMs) using camera-traps is in section 5.3.

4.6. Community interviews

Community interviews are one of the most cost-effective methods to assess pangolin distribution at local levels but only at a relatively broad resolution (e.g. a protected area, a province, nationally), though not always to species level. Pangolins are a very recognisable group; nearly all surveys that used this method reported that most respondents were able to recognise or describe a pangolin (e.g., Nash et al., 2016), and sometimes, reportedly, multiple species (Ichu et al., 2017; Newton et al., 2008). In areas where pangolin populations have declined significantly, this may be the only method that can rapidly generate information on possible status (e.g. Rao et al., 2010). An exception appears to be the black-bellied pangolin, which was reportedly poorly known relative to the giant pangolin and white-bellied pangolin, despite being present, as discussed in Ichu et al. (2017). Community perceptions of distribution and abundance can, provisionally, identify priority sites for the conservation of wild populations (e.g., Nash et al., 2016), and aid clarification of distribution (Newton et al., 2008).

Community interviews can also provide useful information on pangolin ecology. Newton et al. (2008) used information from hunter interviews to help identify survey and monitoring techniques that were likely to be feasible. However, careful cross-validation will be needed in most instances. Trageser et al. (2017) used this process to help confirm that many of the statements made by local hunters on pangolin ecology, were supported by direct observations and records.

Caution is needed when interpreting interview survey results to avoid incorrect information or interpretation (e.g., Sampaio et al., 2011), particularly in areas with more than one pangolin species: multiple different ‘types’ may be identified and which may not equate to different species (Newton et al., 2008). Caution is also needed when using and interpreting local names (Stevens et al., 2014) as single species may have several names (e.g., Nash et al., 2016). Where pangolin species are sympatric, community interviews are only likely to be able to provide a course understanding of status, and little species-level understanding. This will vary depending on the knowledge of community members, but additional methods will probably be needed to verify interview statements, especially if a species-level understanding forms part of the research or survey objective.

Interviews can also be used to help guide surveys and identify priority areas to focus survey efforts, for example through participatory mapping (Thapa et al., 2014). They can also be used to provide information on prices, hunting practices, composition of hunting groups, and trade routes (Katuwal et al., 2015) which could be used to develop site-level knowledge, and by extension knowledge on a national and international level.

4.7. Detection dogs

Although there were no traced reports on using trained detection dogs (or 'sniffer dogs') to survey pangolins, accounts of ongoing research using this method were sourced and it has therefore been included. Detection dog teams have been used to detect pangolins in Vietnam and Nepal (H. J. Kim, pers. comm.), and are being trialled in Singapore (S. Luz, pers. comm.). Hunters have used dogs to help detect pangolins in the Philippines (Schoppe and Alvarado, 2015b), pangolin burrows in Vietnam (Newton et al., 2008) and in Lao PDR in the 1990s (J. W. Duckworth pers. comm. in Challender et al., 2014). Dogs have also been trained to detect illegally trafficked pangolin scales (Parker, 2015).

In Vietnam, two detection dogs trained on Sunda and Chinese pangolin faeces were used at multiple survey locations in 2017. Sixteen surveys days in Pu Mat National Park, and 8 days in Na Hang Nature Reserve produced no confirmed pangolin detections, though potential burrows were detected in both survey efforts (H. J. Kim, pers. comm. 2017). In Cat Tien National Park, 10 days of surveying (totalling 80 km walked), resulted in the detection of a live Sunda pangolin and three possible faecal samples, all in areas where trade-confiscated Sunda pangolins had been previously released. In each of these sites, populations have gone through significant declines as a result of overexploitation and the survey results demonstrate the application of this method to surveying low density populations. In some cases, follow up will be needed to confirm presence, for example, using camera-traps at identified burrows where other field signs (e.g., faeces) are not present. Detection dogs were more successful in Nepal, where this method was used to confirm the presence of Chinese pangolin multiple times: detection dogs detected buried and unburied faeces (H. J. Kim, pers. comm. 2018).

The cost of using detection dogs, and other important considerations, should be considered when deciding whether to use this method. It is expensive to select, train and maintain dogs, including veterinary care. The use of detection dogs at a survey location should therefore be based on a strong rationale for their application. For example, where community interviews have provisionally identified a priority population, where other methods are largely unsuitable because the population is likely to be at a very low density, and/or where analysis of faecal DNA is required to produce a population baseline and other methods are unfeasible. Additionally, in hot and humid environments, dogs may be restricted to a few hours of surveying per day which requires consideration. Although dogs will be one of the most effective ways of detecting pangolins within most habitats, in dense tropical forests where the more arboreal pangolin species are known to exhibit behaviours to hide their faeces, such as defecting in water [see Section 4.3] this would probably result in non-detections, potentially at significant rates. The use of hunting dogs sourced from local communities should also be considered carefully to avoid injury to pangolins.

4.8. Molecular techniques

There have been few published attempts to detect or monitor populations using molecular techniques. Chinese pangolin populations, demographics and breeding ecology have been researched using DNA (Pei et al., 2015) and the genetic structure of Temminck's ground pangolin populations in southern Africa have been researched using mtDNA analysed from scale clippings (Du Toit, 2014). The Sunda pangolin was also detected using eDNA collected from a salt lick in Borneo (Ishige et al., 2017), and analysis of eDNA may have application if used with other methods such as camera-trapping at known or purported pangolin signs such as burrows (Bruce et al., 2018). However, if species detection relies solely on identification from eDNA, careful consideration should be given to how long DNA persists in specific environments and how recently pangolins were present (Thomsen and Willerslav, 2015).

Molecular techniques are probably essential if establishing pangolin presence based on faeces [see Section 4.3]. This will be applicable even where only one species is present (i.e. limited chance of misidentification) as the presence of other mammals that predate on ants and termites will probably mean species confirmation based on faeces is unreliable.

There is limited genetic material from pangolins of known geographic origin to assist with species identification or research into populations. Pangolins can also be misidentified, and reference samples deposited in DNA databases (e.g. GenBank) can be incorrectly assigned, as there is no species confirmation of samples when these are submitted (see Ruedas et al., 2000).

Blood or tissue samples taken during capture for telemetry studies, or potentially during mark-recapture based population sampling, have the potential to significantly bolster understanding of population level genetics for pangolin species (see Nash et al., 2018b). This would support the development of a more complete genetic reference library for pangolins, aiding species identification when analysing a DNA sample from an unknown pangolin species (Mwale et al., 2016).

5. Recommendations

Information is needed on pangolin activity patterns, habitat use (particularly outside of protected areas), den site choice, den densities and population densities across all pangolin species to further inform monitoring. Without it, it is challenging to design methods that can adequately and cost-effectively monitor population trends, especially for the semi-arboreal and arboreal species. However, there will be many sites where direct monitoring of a pangolin population is not financially viable nor the best uses of conservation resources; assuming threats are known, efforts should instead focus on monitoring these threats, monitoring other hunting-sensitive/impacted species that are easier to record, and collating whatever pangolin records exist (including interview records) to monitor changes over time, and the impacts of any conservation interventions. In these conditions, ongoing collation of incidental pangolin records (both from the field and from local trade), and a careful review of these records, will be the most cost-effective method for monitoring pangolin status, though this will be mostly unquantifiable.

The recommendations that follow are based on information collated and assessed during this review only. Although each method has been assessed individually, combinations of methods are likely to be most effective, and in some cases essential, but will increase costs considerably. Combined methods, and the application of novel methods that need piloting, are discussed further in Challender et al. (in prep.).

For many methods, the suitability or efficiency of confirming species presence or status will decrease if used in an area with sympatric species. This is particularly true of community-based interviews or sign-based surveys. There would need to be careful consideration of any additional methods needed following provisional identification of a pangolin population and associated costs. The rarity of most pangolin species and difficulties in detecting them, will in many cases make local hunters or other community members with specialist knowledge an essential part of survey teams. However, given the illegalities of pangolin trade and consumption, there must be careful consideration of the motivation of local communities for assisting with pangolin surveys.

As in any survey or monitoring programme, careful design of the research question is needed, and the relevant technique's, cost, effort and replicability. Any technique that relies on local ecological knowledge will be vulnerable to the latter; the availability of local people familiar enough with a species to detect burrows for example, will vary, unless employed on a permanent basis. Standardisation of methods is crucial to enable long-term monitoring at a site and to allow comparison between sites. Apart from community interviews there are no other standardised techniques for monitoring pangolins. To enable the development of standardised, replicable techniques, it is crucial that the details in pangolin-focused research/surveys (including negative results) are published, and that there is adequate discussion on the (often unquantifiable) influences of seasons, habitat and observer experience.

There is probably a large amount of information and data that could not be reviewed because it is unpublished. We encourage anyone who possesses pangolin field data to publish these records; the publication of incidental observations would significantly improve understanding of pangolin status and ecology, and therefore how best to identify, conserve and monitor priority populations. Species specific recommendations, including the piloting of novel techniques, are discussed in Challender et al. (in prep.).

5.1. Identification of probable pangolin status

The following section will give initial information on the likelihood that pangolins are present in an area and, if they are, perceptions of decline or conservation status. Additional methods will be needed to confirm species present, as well as threats.

Community-based interviews will be the most cost-effective method for obtaining basic information on pangolin presence and inferring status in most survey areas, particularly where there have been significant population declines. However, in areas with sympatric species, information on status is unlikely to be to species level. Community interviews and a comprehensive review of existing records (e.g., museum records and media reports; see Newton et al., 2008; Trageser et al., 2017), should be used as a first step, before more costly survey techniques are used to confirm species presence, to establish population baselines for monitoring, or for ecological research.

Best practice examples include Newton et al. (2008) and Nash et al. (2016). Surveys should be anonymized, conducted in local languages, use negative controls, and caution should be used when interpreting different ‘types’ of pangolin as distinct taxa, especially in areas where there are multiple pangolin species. Negative controls, using questions about or photographs of species that were historically present but are highly unlikely to still occur and of species that are superficially similar but are not distributed in the survey area/country should be used to test the respondents' knowledge (e.g. Nash et al., 2016).

Most pangolin trade is illegal, which will result in some respondents being unwilling to talk openly, as has been observed in Java, Indonesia (J. Rode-Margono pers. comm. 2018); in situations like this there will need to be careful selection of interviewers or survey assistants, and in many instances significant time invested in establishing trust. Pangolins are well-known and have significant trade value; there is a risk that local people simply lie about pangolin status or distribution in order to prevent any outsider interference or conservation activities being implemented. Another risk is that local community members report any identified pangolin burrows to traders/hunters. Caution should always be exercised when implementing any community-dependent research.

5.2. Confirming species presence

Community interviews will not always be able to provide verifiable information on which species are present, unless hunting trophies (e.g., skins) are kept by hunters, or there is an opportunity to engage directly with hunters when sourcing pangolins. Interviews will not provide information on species status in the wild, only its presence, perceived abundance or rate of decline. In areas where there are multiple pangolin species present, or respondents are describing multiple 'types' of pangolin, field surveys will be needed to confirm the species present. Community interviews can be used to assess threats to pangolins directly, such as presence of snares or other proxies of hunting pressure. Given the cost-effectiveness of this method and the distinctiveness of pangolins, interviews can be used to assess perceived rate of declines, though perhaps not to species level.

Given the difficulties in finding pangolin signs, particularly in forested habitats, and the increasing rarity of most pangolin species, efforts should be made to use local ecological knowledge to help guide survey locations and to help identify potential pangolin signs. Exceptions are arid and open habitats where pangolin tracks and other signs are relatively easy to detect and identify (D. Pietersen pers. comm. 2017). In priority sites where pangolins are likely to be very rare, and/or the topography is too challenging for most methods (even for detection), resources should instead focus on mitigating known threats, and reviewing changes in pangolin status by monitoring these threats and collating incidental records whenever possible.

Where signs have been detected, camera-traps or similar methods such as borescopes should be used to confirm pangolin species and presence, and which presents an opportunity to gather ecological information (Trageser et al., 2017). For some species in regions that have not yet gone through severe populations decline, nocturnal spotlighting may still have some application, but it is extremely limited. The multi-method approach used by Trageser et al. (2017), which relied on the local knowledge of indigenous hunters, will be the most effective method for establishing status rapidly and clarifying species distribution in an area or country.

Encounter rates along line transects (direct observations and/or signs) can provide information on pangolin presence and be used as a coarse way of monitoring status, but detectability will vary across space and time. Encounter rates, if caveated with contextual information on the potential or known influences of season, habitat, routes used, observers etc., can provide some information on pangolin presence in an area, but this will be limited to ground-dwelling species that leave easily detectable signs or where population densities are suspected to be high enough to enable nocturnal surveys.

5.3. Monitoring pangolin populations

Monitoring pangolin populations is very challenging. Many populations have been overexploited for trade, trafficking and local consumption for many decades, making densities so low in places that an extremely high survey effort is needed to confirm presence, prior to any monitoring. Recommendations for monitoring include the use of mark-recapture for burrow-dwelling species, sign-based surveys in arid and open habitats, detection dogs, and targeted camera-trapping.

There will be many circumstances where direct monitoring of a population at a site, to a level that will generate precise data, is not financially viable. Under such circumstances the use of proxies e.g. presence/status of other hunting-sensitive species, in combination with enforcement or patrol data and/or community interviews, and the best available information on pangolin status (even if unquantifiable or limited to incidental records), are likely to be the most cost-effective method for monitoring pangolin status and assessing the impacts of conservation interventions. This, however, assumes that the threats are known and that a reduction in these threats will enable pangolin populations to recover.

For ground-dwelling species that use burrows or detectable dens, mark-recapture techniques can be used. They have been used to estimate population sizes and survival rates of birds (Jones et al., 2003; Sutherland and Dann, 2012), mammals and reptiles (Moore et al., 2010), with several long-term studies producing detailed data on population trends (e.g. Platypus *Ornithorhynchus anatinus*: Bino et al., 2015). Modified mesh traps could be set outside active burrows, with caught pangolins marked. Although there is no evidence of pangolins being harmed by mesh traps, for best practice these traps should include activity sensors or similar, to avoid pangolins being caught in traps for too long. Re-capture rates could be used to produce population estimates and survival rates. This method would also enable population demographics to be collected during capture (age, sex, weight), and for DNA analysis (e.g., from blood samples). For mark-recapture to produce reliable population estimates, there would need to be careful consideration of the factors that may influence burrow detectability, burrow occupancy rates, and the capture of individuals including substrate, season and trap shyness.

The process of detecting burrows/dens for mark-recapture will bring additional costs. Many populations occur at low densities, and/or in habitats where surveying for burrows is difficult because visibility is poor, such as where a dense shrub layer exists. In these scenarios, employing local hunters or community members to help find pangolin burrows (e.g., Thapa et al., 2014) could be used, as could detection dogs. The former method runs the potential risk that hunters will return to the site after capturing the animals for marking, to recapture them for trade. Detection dogs will add considerable costs, and for the semi- and arboreal species there is a risk that dens that are off the ground will go undetected. Caught animals could be marked using small implanted chips or have identifying tags bolted to scales. The latter would be cheaper and be beneficial in that tagged animals could potentially be identified using camera-traps. However, careful consideration of whether identifying tags would increase the risk of detection by poachers is needed. Another potential method could be to use scale counts and position on a pangolin's head. This has been used on reptiles (e.g., Treilibs et al., 2016) but has not been tested on pangolins.

Most of the assumptions that are required for density estimates based on line transects (see Buckland et al., 2001) are likely to be violated, as they are for other groups of elusive, difficult-to-detect mammals (e.g., small carnivores: Duckworth, 1998a; Mathai et al., 2013). A possible exception is the use of line transects and sign counts, but densities derived from these data will need to be informed by additional information on species ecology, and will be limited to habitats that are relatively open, i.e. where signs along a transect may be detected, and where random placement of transects is possible. There would need to be careful consideration of the effects of season and substrate on the density and therefore detectability (e.g., burrows or tracks). It is extremely unlikely that the conditions and data needed to make accurate density estimates for pangolins from line transects would ever exist. Occupancy sampling based on transect surveys and counts of pangolins burrows, or other verifiable signs may have application but grid cell size and survey times need to be informed by ecological knowledge (e.g. home range size, territoriality and seasonality), data that do not currently exist for most pangolin species (see Challender et al., in prep.). Occupancy based on direct observations will have no application because of the nocturnal nature of most pangolin species and would be restricted to human-made pathways in forested areas; the frequency of detection would be too low for this approach to be feasible.

Non-targeted camera-trapping is unlikely to be a cost-effective method for monitoring pangolin populations. Whilst there has been some success in Singapore (H. Nash pers. comm. 2018), this was in a very small and contained area, with relatively healthy pangolin populations. These conditions will not be met for most other pangolin populations, particularly in Asia, and even very high camera-trapping effort at these sites, is unlikely to produce sufficient data for monitoring. Targeted camera-trapping has greater application but will in most cases, be limited to confirming presence, species distribution, and gathering ecological information. If pangolins are marked before release, targeted camera-trapping at release sites could enable some assessment of survival rates. Marking could be based on the presence of a transmitter (CPCP, 2014) or high-visibility tags attached to scales on either side of the animal. It should not increase the chance of the pangolin being detected by hunters; it requires piloting.

Assuming camera-traps can be better set for pangolins than they have been in previous research, occupancy sampling may have application (Challender et al., in prep.; Khwaja et al., in prep.). Consideration should be given to detection rates (i.e. the high probability that a camera-trap will not detect a pangolin that is present) and difficulties in setting camera-traps for pangolins; it may only be suitable for monitoring the status of ground-dwelling pangolin species (all except black-bellied pangolin) in sites that have not yet experienced significant declines. However, given the difficulties in detecting pangolins, even in sites where populations are assumed to be relatively healthy, combined methods are likely to be the most effective (e.g. Abrams et al., 2018). Combined methods will increase costs considerably, and may still not produce enough pangolin detections (see Abrams et al., 2018: Figure 3) to be a useful monitoring method. There will be a number of sites and regions where camera-traps are only useful for detection, not monitoring. Careful consideration must be made of the costs and whether these resources would be better spent on conservation interventions and cruder, but still informative, monitoring that relies on proxy variables.

Pangolins have no easily useable individual markings; this prevents using camera-trapping combined with mark-recapture to estimate and monitor populations. Although techniques exist which do not rely on individual identification (e.g., Random Encounter Model (REM): Rowcliffe et al., 2008, 2013), the data needed on pangolin movement (and how it varies over time and space) does not yet exist to a level that can be applied to this type of population estimate. Even if data on pangolin ecology exists, and a cautious detection distance is used, the resources required to produce population estimates using REM will be significant and random placement of camera-traps is unlikely to be possible, and even if it is, given the rarity of most pangolin species, it may result in significant underestimates, or worse, pseudo-absences. Additionally, even slight changes in camera-trap placement can influence detection probabilities (e.g., Kolowski and Forrester, 2017), and the influences of microhabitat on pangolin detection are currently unknown. Given these barriers, REM is not currently recommended for monitoring pangolins.

Consideration needs to be given to observer experience and its influence on detectability of pangolins and/or their signs (e.g., Barata et al., 2017). Numerous surveys report on using local ecological knowledge or the direct help of local hunters to track and find pangolin signs. If effective surveying of verifiable pangolin signs is dependent on the direct assistance of local people it must be included in any survey design and cost, and will have implications on repeatability, a requirement for occupancy analysis. Detection dog teams could be used to survey for faeces, burrows and live animals within occupancy survey cells, which would probably produce the highest number of detections for the ground-dwelling pangolins, particularly in areas where they occur at very low densities. Faeces would then need to be identified to species level using DNA analysis (as it is unknown which, if any, other species can leave similar looking faeces) which could potentially yield information on population size. The costs of using a detection dog unit however, and the subsequent laboratory work to analyse DNA will make this prohibitively expensive in many cases.

Acknowledgements

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2019.e00539.

Annex 1

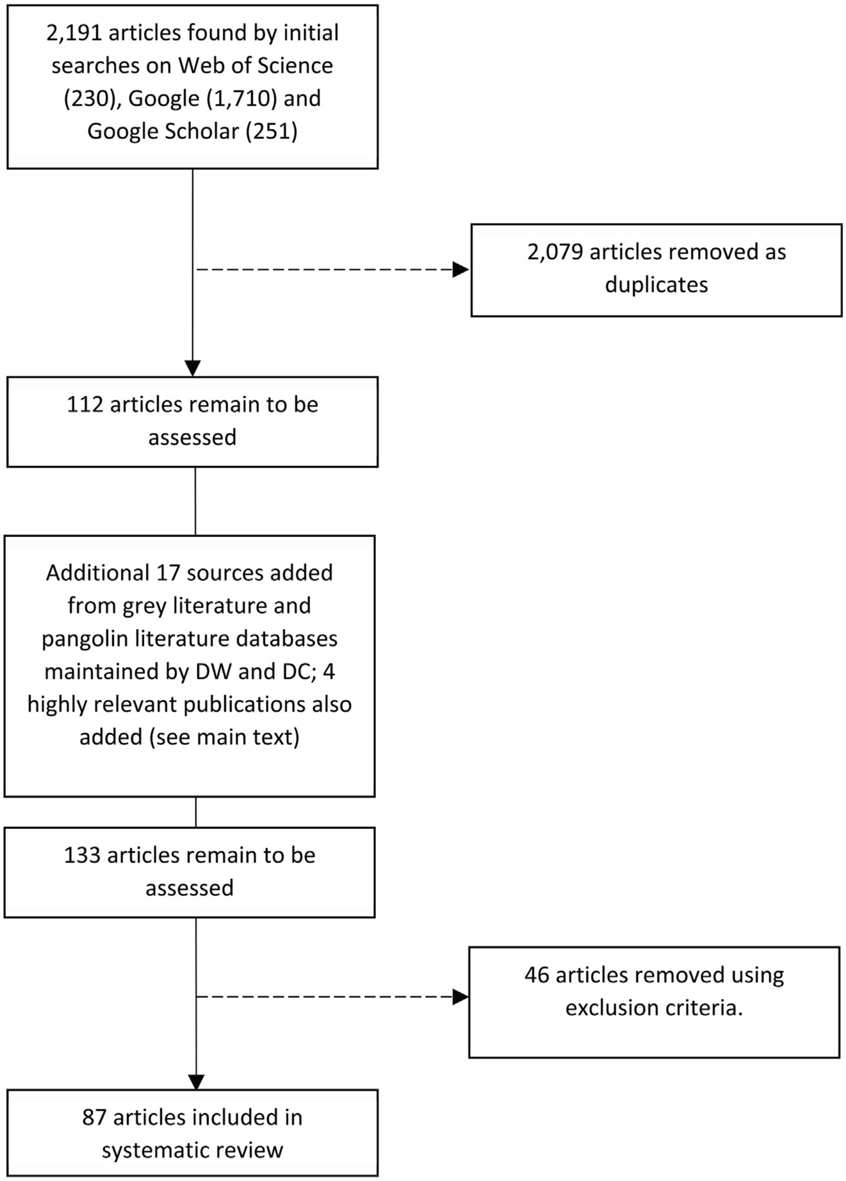

Fig. 1. Flowchart showing article selection process.

Annex 2

Table 1
Search terms used in Google (google.com/ncr). No country region (ncr), all years (unless specified), all languages. "… " identifies and searches for particular phrases, e.g. "pangolin monitoring". filetype: will search only for a specified filetype.

Search term
"pangolin monitoring" filetype:ppt
"pangolin monitoring" filetype:pptx
"pangolin monitoring" -laser -mine -mining filetype:doc
"pangolin monitoring" -laser -mine -mining filetype:docx
"pangolin survey" filetype:pdf (1990–2004)
"pangolin survey" -mine -mining filetype:pdf (2005–2017)
"pangolin survey" filetype:ppt
"pangolin survey" filetype:pptx
"pangolin survey" filetype:doc
"pangolin survey" filetype:docx
"pangolin distribution" filetype:doc
"pangolin distribution" filetype:docx
"pangolin distribution" filetype:pdf
"pangolin distribution" filetype:ppt
"pangolin distribution" filetype:pptx
"pangolin status" filetype:pptx
"pangolin status" filetype:ppt
"pangolin status" filetype:doc
"pangolin status" filetype:docx
"pangolin status" filetype:pdf

Annex 3

Table 2
Sources provisionally included for the review, but then rejected, including rationale for exclusion.

Source	Rationale
AFCD [Agriculture Fisheries and Conservation Department]., 2004. Findings of the Ecological Surveys. Hong Kong. ACE Paper 33/2004. Available from: https://www.epd.gov.hk/epd/sites/default/files/epd/english/boards/advisory_council/files/ace_paper33_2004_e.pdf	Summary of a government-led wildlife survey in Hong Kong. Survey used camera-traps and detected Chinese Pangolin. Survey effort was probably significant: "over 400 sites" were surveyed. Report does not have any details on camera-trap-nights, number of camera-trap stations, how camera-traps were set, or how many pangolin detections there were.
Carnivore and Pangolin Conservation Program. (2013). Developing release protocols for fully-rehabilitated trade-confiscated Sunda Pangolin (*Manis javanica*) in Vietnam. Unpublished progress report to donor.	Progress report for a donor. Report was written prior to the monitored release being implemented. Does not include many details. More up-to-date details on methods used in CPCP (2014).
Chiang, P.-J., 2007. Ecology and conservation of Formosan clouded leopard, its prey, and other sympatric carnivores in southern Taiwan. PhD thesis. University of Virginia, USA. Parts published in: Chiang, P.-J et al., 2015. Is the clouded leopard Neofelis nebulosa extinct in Taiwan, and could it be reintroduced? An assessment of prey and habitat. Oryx 49, 261–269.	Set camera-traps to assess availability of possible Clouded Leopard *Neofelis nebulosa* prey. Not applied to pangolins.
Chinlampianga, M., Singh, R.K., Shukla, A.C., 2013. Ethnozoological diversity of Northeast India: Empirical learning with traditional knowledge holders of Mizoram and Arunachal Pradesh. Indian Journal of Traditional Knowledge 12, 18–30.	Pangolins listed with some details on local uses. No details on survey effort.
Nguyen Xuan Dang, Pham Truong Anh, Nguyen Minh Tam, Le Hong Tuyen. 2004b. Mammals. *In* Biodiversity Survey U Minh Thuong National Park. Sage N., Kutcher S., Nguyen X. V., Wilson P. and Dunlop J. (Eds). Agriculture Publishing House, Ho Chi Minh City, Vietnam, 85–103, 133-138	Limited information on how pangolins were recorded. Has a photograph in the report of a Sunda Pangolin *Manis javanica* and has "observed in the wild", but too little information on these records to review how these pangolins were detected.
Durojaye, A.S., Olufemi, A.S. 2015. Utilization of pangolins in Africa: Fuelling factors, diversity of uses and sustainability. International Journal of Biodiversity and Conservation 7, 1–10.	Literature review of local uses of pangolins and threats, no survey methods to assess.
Fauzi, Muhammed Faisel Bin. 2006. Ethnozoologiocal Survey in Selected Areas in Sarawak. BSc dissertation. University of Sarawak, Malaysia.	General wildlife use and trade survey, does not include enough information on pangolins to assess how Sunda Pangolins were detected.
Giman, B., Stuebing, R., Megum, N., Mcshea, W.J. and Stewart, C.M., 2007. A camera trapping inventory for mammals in a mixed use planted forest in Sarawak. Raffles Bulletin of Zoology. 55, 209–215.	Not enough information on camera-trap stations and on which camera-trap detected Sunda Pangolin (only a single record).
GIZ., 2005. Rapid assessment of mammals in the Tam Dao National Park. Available from: http://cerec.org.vn/userfiles/file/Protected%20area/Tam%20Dao%20NP/Rapid%20assessment%20of%20mammals_English.pdf	Authors report on detecting Chinese Pangolin based on the presence of active burrows but not enough detail to review detection method.

Table 2 (*continued*)

Source	Rationale
Smithsonian Institute., 2005. An assessment of the reptiles and amphibians of the Monte Mitra forest, Monte Alen National Park. DOI: 10.13140/2.1.4290.7843	Includes encounter rates for Giant Pangolin based on number of signs detected per km. No information on how signs were identified and no discussion on these records as amphibians and reptiles were the focus of the report.
Goswami, R., Ganesh, T., 2014. Carnivore and herbivore densities in the immediate aftermath of ethno-political conflict: the case of Manas National Park, India. *Tropical Conservation Science*, *7*, 475–487.	Observation records for Indian Pangolin and Chinese Pangolin but not enough detail on these records, or on how much survey effort was required to detect pangolins.
Kaspal, P., 2009. Saving the Pangolins: Ethno zoology [SIC] and Pangolin conservation awareness in Human dominated Landscapes. A Preliminary report to The Rufford Small Grants Foundation. Available from: https://www.rufford.org/rsg/projects/prativa_kaspal	Preliminary report to Rufford. Not enough information included on methods, which were mainly community interviews, to review the methods used.
Kaspal, P., 2010. *Saving the Pangolins:* Ethno zoology [SIC] and Pangolin conservation awareness in human dominated landscapes of Nepal. In SMCRF 2010. Poceedings [SIC] of the First One Day National Seminar on Small Mammals Issues. May 15, 2010, LDTA Building, Jawalakhel, Lalitpur, Nepal,	More information than in 2009 report, but not enough to include in review. Has some information on community survey results; how pangolins are tracked and hunted by local community, what they are traded for but not enough to review.
Katala Foundation., 2008. Technical progress report. May–August 2008.	No information on surveys; a report on the organisation's activities, not results.
Katuwal, H.B., Neupane, K.R., Adhikari, D., Thapa, S., 2013. Pangolins Trade, Ethnic Importance and its Conservation in Eastern Nepal. Report submitted to WWF Nepal. Available from: https://docplayer.net/46935725-Pangolins-trade-ethnic-importance-and-its-conservation-in-eastern-nepal-hem-bahadur-katuwal-kaustuv-raj-neupane-dipendra-adhikari-sanjan-thapa.html	Unpublished report - 2015 paper is the publication based on this survey. 2015 paper included.
Kuswanda, W., Setyawati, T., 2016. PREFERENSI HABITAT TRENGGILING (Manis Javanica Desmarest, 1822) DI SEKITAR SUAKA MARGASATWA SIRANGGAS, SUMATERA UTARA. Jurnal Penelitian Hutan dan Konservasi Alam 13, 43–56. [Habitat preference of Sunda Pangolin (*Manis javanica* Desmarest, 1822) around Siranggas Wildlife Reserve, North Sumatra]	In Indonesian (Bahasa). Abstract in English. Detail on habitat preferences, though not enough detail on methods to review how these were identified.
Mackinnon, J., 1973. Orang-utans in Sumatra. Oryx 12, 234–242. https://doi.org/10.1017/S0030605300011595	No detail on pangolin records and detection method. Not a pangolin focused survey.
Maddox, T., Priatna, D., Gemita, E., Salampessy, A., 2007. The conservation of tigers and other wildlife in oil palm plantations, Jambi Province, Sumatra, Indonesia. ZSL Conservation Report, ZSL London, UK.	Sunda Pangolin records in palm oil landscape. Includes camera-trap photograph of Sunda Pangolin. Eight track records, though no detail in which to verify or assess these. Has two sighting records. Does not have a table for each survey method and effort. Cannot review survey details or detection methods.
Mésochina, P., Langa, F., Chardonnet, P., 2008. Preliminary survey of large herbivores in Gilé National Reserve, Zambezia Province, Mozambique. Unpublished report, IGF Foundation, Paris.	Lists pangolin record as "feeding site", no other details. Not a pangolin focused survey.
Mishra, C., Datta, A., Madhusudan, M.D., 2004. The high altitude wildlife of Western Arunachal Pradesh: a survey report (No. 8). CERC technical report. Available from: http://www.aoc.nrao.edu/~sbhatnag/Nature/warunachal/Docs/cerc_tr8.pdf	Chinese Pangolin listed a present; only a skin (trade) record. No other reviewable details.
Nuwer, R., Bell, D., 2014. Identifying and quantifying the threats to biodiversity in the U Minh peat swamp forests of the Mekong Delta, Vietnam. Oryx 48, 88–94.	Not targeted at pangolins.
Onoguchi, G., Matsubayashi, H., 2008. Comparative study on mammalian fauna in different harvesting intensities with reduced-impact and conventional logging in Sabah, Malaysia. *Sustainability and Biodiversity Assessment on Forest Utilization Options*, 133–140. Retrieved from http://www.forest.sabah.gov.my/tangkulap/Pages/ComparativeStudyOnFaunaUnderDifferentHarvestingRegimes.pdf	Low survey effort (14 camera traps <800 camera-trap days); no pangolin records. But did record other threatened species e.g. Sunda Clouded Leopard. Cameras set at 50 cm - not suitable for small-medium sized mammals such as pangolins.
Perera, P.K.P., Karawita, K.V.D.H.R., Pabasara, M. G. T., 2017. Pangolins (*Manis crassicaudata*) in Sri Lanka: A Review of Current Knowledge, Threats and Research Priorities. Journal of Tropical Forestry and Environment 07, 1-14	Collation of existing information on Indian Pangolin in Sri Lanka; no survey techniques to review.
Plumptre, A.J., Ayebare, S., Mugabe, H., Kirunda, B., Sekisambu, R., Mulondo, P., Mudumba, T., 2015. Biodiversity surveys of Murchison Falls Protected Area. Wildlife Conservation Society, Kampala, Uganda. https://doi.org/10.13140/RG.2.1.4332.8728	Giant Pangolin recorded; but not enough detail on camera-trapping to determine effectiveness - no information on survey effort, number of stations that recorded the species.
Rovero, F., De Luca, D.W., 2007. Checklist of mammals of the Udzungwa Mountains of Tanzania. *Mammalia 71*, 47–55. https://doi.org/10.1515/MAMM.2007.015	Ground [Temminck's] Pangolin observed in Lowland Forest. Not enough detail on survey methods and how pangolin was detected.
Samejima, H., Ong, R., Lagan, P., and Kitayama, K. 2012. Camera-trapping rates of mammals and birds in a Bornean tropical rainforest under sustainable forest management. Forest Ecology and Management 270, 248–256. https://doi.org/10.1016/j.foreco.2012.01.013	Small number of Sunda Pangolin records for camera-trap survey effort (authors state 15,400). Difficult to work out methods efficiency; no table for number of detections in each survey plot/area, only the mean. Camera-traps set at 50 cm off the ground; too high for pangolins.
Sanderson, J.G., Trolle, M., 2005. Monitoring elusive mammals. American Scientist 93, 148–155. https://doi.org/10.1511/2005.2.148	Has a small note on a Sunda Pangolin record; nothing to review.

(*continued on next page*)

Table 2 (*continued*)

Source	Rationale
Sathyakumar, S., Bashir, T., Bhattacharya, T., Poudyal, K. (undated). Mammals of the Khangchendzonga Biosphere Reserve, Sikkim, India. < http://www.sikkimforest.gov.in/Reports%20and%20Publications/Biodiveristy-of-Sikkim/18%20Mammals_327-350%20web.pdf>	No pangolin records. Most camera-trapping above the known range of Chinese Pangolin.
Shek, C., Chan, C.S.M., Wan, Y., 2007. Camera trap survey of Hong Kong terrestrial mammals in 2002–06. Biodiversity 15, 1–11.	2010 paper by Pei et al. on same data set, which has already been included.
Shrestha, B., Basnet, K., 2005. Indirect methods of identifying mammals: a case study from Shivapuri National Park, Nepal. Ecoprint: An International Journal of Ecology 12, 43–57.	Not enough detail on how Chinese Pangolin signs were determined, and what references were used.
Taipei Zoo., 2004. Formosan Pangolin PHVA. Available from: https://www.cpsg.org/sites/cbsg.org/files/documents/Pangolin%20PHVA%20Final%20Report%20.pdf	No information on surveys/monitoring methods
Teo, R.C.H., Rajathurai, S., 1997. Mammals, Reptiles and Amphibians in the Nature Reserves of Singapore - Diversity, Abundance and Distribution. The Gardens' Bulletin, Singapore 49, 353–425.	No information on survey effort per method; and no information on record type for Sunda pangolin.
Thapa, P., 2013. An Overview of Chinese Pangolin (*Manis pentadactyla*): Its General Biology, Status, Distribution and Conservation Threats in Nepal. *The Initiation*, *5*164–170.	Compilation of existing information; no methods to review.
Timmins, R. J. and Evans, T. D. 1996. A wildlife and habitat survey of Nakai-Nam Theun National Biodiversity Conservation Area, Khammouan and Bolikhamsai Provinces, Lao PDR. Vientiane: CPAWM/WCS	No pangolin records.
Treves, A., Mwima, P., Plumptre, A.J., Isoke, S., 2010. Camera-trapping forest–woodland wildlife of western Uganda reveals how gregariousness biases estimates of relative abundance and distribution. *Biological Conservation*, *143,* 521–528.	8841 camera-trap days produced a single photograph of White-bellied Pangolin. No details on how camera traps were set.
Tsai, Y.-L., Yuan, H.-W., Chen, P.-C., Ci-Wen Yang., 2004. Preliminary Study on the Habitat of the Taiwan Pangolin (*Manis Pentadactyla Pentadactyla*) at Muchia Area. Journal of the Experimental Forest of National Taiwan University 18, 29–34.	Abstract in English, rest of the paper in Chinese. Searches for Chinese Pangolin in Taiwan (grounds of Taipei Zoo?). Not enough information in abstract.
Wilting A, Mohamed A bin. 2010. Wildlife surveys in Segaliud Lokan Forest Reserve KTS Plantations – Final Report. Available at: http://www.forest.sabah.gov.my/tangkulap/Pages/KTS_Final_report_ConCaSa.pdf.	Sunda Pangolin recorded, but no detail on detections per survey effort.
Wu, S., 2002. The population and density of pangolin in Dawuling Natural Reserve and in Guangdong Province. Acta Theriologica Sinica 22, 270–276. [In Chinese]	In Chinese, only abstract in English. (2003) paper includes most of details.
Wu, S., Liu, N., Ma, G., Xu, Z., Chen, H., 2003. Studies on habitat selection by Chinese pangolin (*Manis pentadactyla*) in winter in Dawuling Natural Reserve. *Acta Ecologica Sinica*, *23* (6), 1079–1086. Retrieved from http://europepmc.org/abstract/CBA/534537 [In Chinese]	In Chinese. Full English version traced and included in review.
Wu, S., Liu, N., Zhang, Y., Ma, G., 2004. Assessment of threatened status of Chinese Pangolin. Chin. J. Appl. Environ. Biol. 10, 456–461. [In Chinese]	In Chinese; not enough detail in English abstract.
Wu, S., Ma, G.-Z., Tang, M., Chen, M., Liu, N.-F., 2002. The status and conservation strategy of pangolin resource in China. Journal of Natural Resources 17, 174–180. [In Chinese]	In Chinese; not enough detail in English abstract.
Zhang, S., Zheng, F., Li, J., Bao, Q., Lai, J., Cheng, H., 2017. Monitoring diversity of ground-dwelling birds and mammals in Wuyanling National Nature Reserve using infrared camera traps. Biodiversity Science 25, 427–429. [In Chinese]	In Chinese.
Zhang L, Li Q, Sun G, Luo S. (2010) Population and conservation status of pangolins. Bulletin of Biology 45: 1–5. [In Chinese]	In Chinese.
ZSL., Undated. Securing pangolin strongholds: A Cameroon case study. Presentation.	Includes White-bellied Pangolin and Giant Pangolin detections per 100 camera-trap days but enough information to review. Presentation only.

Appendix 4

Tables 3–9 Traced methods for pangolin species.

Traced methods comprise any attempts to monitor, detect or research pangolin populations. This does not include general wildlife surveys, including camera-trapping, where pangolins were not explicitly the focus of the survey. Burrow Counts: any attempt that specifically targets pangolin burrows. Nocturnal Surveys: spotlighting surveys to obtain direct observations. Diurnal Surveys: general sign-based surveys, usually for a combination of signs (e.g., burrows, faeces, dens, claw-marks), as well any attempts to directly observe diurnal/diurnally active pangolins. Telemetry: any attempt to monitor or research pangolins using transmitters (VHF, GPS or satellite). Targeted camera-trapping: camera-trapping set for pangolins (and not part of a general wildlife/mammal survey). Community interviews: social research on pangolins, including distribution, status and threats. Trade/specimen reviews: reviews of specimens held in museums, local collections, government departments and/or reviews of verifiable trade records where provenance has been investigated. Live capture: any attempts to monitor or research pangolins using live capture but not if an activity that forms part of telemetry-based research.

Table 3
Traced methods for Chinese pangolin *Manis pentadactyla*.

Site	Method description	Source
Burrow counts		
Dawuling Nature Reserve, China	Randomly placed 4 km line transects.	Wu et al. (2003)
Shivapuri Nagarjun National Park, Nepal	Randomly placed strip transects of 700 m × 60 m.	Bhandari and Chalise (2014)
Samtse district, Bhutan	Randomly placed 2 km belt transects with 100 m^2 plots perpendicular to the transect line. Used community interviews and participatory mapping to guide identification of survey locations for burrow counts. Dimensions of belt transect not reported.	Dorji (2015)
Dhankuta and Ilam districts, Nepal	100 m^2 plots set every 200 m perpendicular to human-made pathways. Areas selected based on high reported sightings of pangolins from villages (Village Development Committees). No distinction made between feeding and sleeping burrows. No information on how information on reported sightings was collected and reviewed.	Katuwal et al. (2017)
Nepal	Randomly placed 600 m^2 plots and used multiple 25 m width belt transects to search within these plots for pangolin burrows. Plot sizes based on a home range size of 0.35 km^2 for Chinese pangolins in Taiwan (Sun et al., 2015 in SMCRF, 2017). Areas for plot searches based on habitat and elevation characteristics, not community interview data.	SMCRF (2017)
Nangkholyang Village Development Committee, Taplejung, Nepal	Used community interviews and participatory mapping to guide identification of survey locations for burrow counts which were done from footpaths. Also used random searches in these areas. Unclear how random searches were done, or how far searches were done from pathways. No distinction made between feeding and sleeping burrows.	Thapa et al. (2014)
Nocturnal surveys		
Lawachara National Park, Bangladesh	41 nocturnal transects averaging 4 h in duration along human-made pathways produced a single record.	Trageser et al. (2017)
Samtse District, Bhutan	2 km line transects were surveyed at night for 6 h per week for three months (i.e. approximately 72 h survey effort) produced five records. Areas for the surveys were selected following community interviews and participatory mapping to inform possible Chinese pangolin distribution. Habitat was then stratified and transects randomly placed within each major habitat type (Dorji, 2015).	(D. Dorji, pers. comm. 2017)
Nakay [Nakai]-Nam Theun NBCA and Nam Theun Extension NBCA, Lao PDR	Approximately 108 h nocturnal searching in four locations. One record in 39 h in the Nam Thuen Extension (NTX). Not pangolin specific – general mammal survey.	Duckworth (1998b)
Diurnal surveys		
Lawachara National Park, Bangladesh	Hunters from the Mro ethnic minority (hired as "parabiologists") led on intensive sign-based surveys for pangolins in. Two days of diurnal surveys (09:00 to 18:00) by a three-person team resulted in the sighting and capture of one large male Chinese pangolin.	Trageser et al. (2017)
Telemetry		
Taiwan	Attached to a large dorsal scale near the base of the tail, with a webbing material used to allow the attachment some flexibility and reduce the risks of its snagging on vegetation and breaking off. Pangolins in Taiwan tracked for an average of 147 days (range 52–250).	NOW (2010)
Taiwan	As above – same research group as (NOW, 2010). Produced estimates of home range size (including differences between males and females), population density, number of burrows used per pangolin, seasonal differences in activity, and habitat associations. Mapped home ranges have been combined with genetic analysis of faeces to investigate breeding biology.	Pei et al. (2015)
Targeted camera-trapping – none traced		
Community interviews		
Multiple locations in Vietnam	Semi-structured interviews. 'Snowball' sampling used to identify hunters. Interviews anonymous as pangolin hunting is illegal. Interviews focused on the hunter's knowledge of pangolin ecology, historic and contemporary pangolin hunting practices, and the dynamics of the trade in pangolins. Used in combination with reviews of records from biodiversity surveys and museum records to assess the species status and distribution.	Newton et al. (2008)
Multiple locations in Hainan, China	Randomly selected 10 villages per reserve/survey area. Used 'snowball' sampling to identify villagers likely to be knowledgeable. Combination of structured and open questions in a questionnaire. Used negative controls. Interviewees were anonymized. Questions asked on perceptions of rarity/abundance and decline.	Nash et al. (2016)
Nangkholyang Village Development Committee, Taplejung, Nepal	'Snowball' sampling method. Respondents asked about hunting practices, population trends and trade dynamics. Little information on interview method.	Thapa et al. (2014)
Samtse District, Bhutan	Interviewed 50% of households in survey site, using a semi-formal interview questionnaire [semi-structured]. Questions asked on pangolin ecology, threats, and trade. Responses used to guide locations for transect searches. Little information on interview method.	Dorji (2015)
Sangu Wildlife Sanctuary, Bangladesh	Semi-structured interviews, targeting known/identified hunters. Conducted at night to ensure people had returned from daily activities. Photographs of pangolins were shown to the interviewees, and questions asked on pangolin status, ecology and trade.	Trageser et al. (2017)
Trade/specimen records		
Vietnam	Interview data was coupled with a review of museum specimens and field records, to help map the proposed distribution of Vietnam's two pangolin species: Sunda and Chinese pangolin.	Newton et al. (2008)
Bangladesh	Used to media searches to collate and review verifiable pangolin records. Used to better understand status and distribution of pangolin in Bangladesh.	Trageser et al. (2017)
Live capture – none traced		

Table 4
Traced methods for Indian pangolin *Manis crassicaudata*.

Site	Method description	Source
Burrow counts		
Pir Lasura National Park, Pakistan	Sampling transects of 1 km length and varying width. Counts of active burrows used to calculate population density. Number of pangolins in a burrow was assessed by footprints outside burrow's entrance. No information on how transect lines were established, or coverage of the site. Camera-traps not used to confirm whether a burrow was occupied or not.	Akrim et al. (2017)
Potohar Plateau, Pakistan	Sampling sites based on results of diurnal searches along transect lines. Transects of variable length and width were established in each, though areas of 2–4 km^2 are given in the text. Burrows were assessed as to whether feeding digs/dens, and if dens, whether these were inactive or active. Population estimates were based on number of active burrows/km^2. No information on number of transects per sampling site or other details. Camera-traps not used to confirm whether a burrow was occupied or not.	Irshad (2015)
Margalla Hills National Park, Pakistan	Sampling sites of 1 km^2 were selected based on discussions with local communities and searches on foot to establish whether pangolins were present or not. Number of active burrows per km2 used to calculate density. No information on how sampling sites were surveyed. Camera-traps or similar not used to confirm burrow occupancy.	Mahmood et al. (2015)
Potohar Plateau, Pakistan	Line transects and burrow counts used to estimate density. Number of burrows counted per km^2. No information on how sampling sites were surveyed or transect lines established. Camera-traps or similar not used to confirm burrow occupancy.	Mahmood et al. (2014)
Potohar Plateau, Pakistan	Sampling transects of 1 km length and variable width. Active burrows counted – number per km^2 used to calculate density. No information on how transect lines were established or surveyed. Camera-traps or similar not used to confirm burrow occupancy.	Nadeem et al. (2015)
Yagirala forest reserve, Sri Lanka	50 × 100 m belt transects in each habitat type. Burrows, burrowing/digging marks on termite and ant mounds, and claw marks used to record pangolin presence. Abstract only. No further information available.	Pabasara et al. (2015)
Nocturnal surveys		
Chiplun Taluka, India	105 h of nocturnal searches, in areas identified based on village interviews. No pangolin sightings.	Anon (2016)
Pir Lasura National Park, Pakistan	Reported as a method, but no details or results given.	Akrim et al. (2017)
Diurnal surveys		
Potohar Plateau, Pakistan	Used roads as transect lines. Searches were in 250 m plots on either side of the road, every 5–7 km along a road. Burrows, faecal samples, road-kills/dead animals and direct sightings used to confirm presence on a transect. No DNA testing of faeces. No indication of what constitutes a suitable pangolin habitat.	Irshad (2015)
Chiplun Taluka, India	Survey locations identified using community interviews. Only three transects. No information on transect width, length, or habitats targeted. No information on types of sign that were being surveyed for or what was detected, though report has photographs of three burrows.	Anon (2016)
Potohar Plateau, Pakistan	200 m plots on either side of roads surveyed for burrows, faeces, direct sightings and dead pangolins (e.g. road kills). Areas selected based on whether a habitat looked suitable or not. No other information on how plots were selected, or intervals between plots. No indication of what constitutes a suitable pangolin habitat. No DNA testing of faeces.	Nadeem et al. (2015)
Targeted camera-trapping		
Chiplun Taluka, India	Eight camera-trap stations, set by recorded pangolin signs. Total effort was approximately 116 camera-trap-days. Recorded pangolin once.	Anon (2016)
Telemetry – none traced		
Community interviews		
Potohar Plateau, Pakistan	Questionnaire based study on local villagers' knowledge on pangolin breeding ecology. No information on how respondents were selected.	Mahmood et al. (2016)
Chiplun Taluka, India	Interviewed at least 5–6 people per village. Interviewed knowledgeable people familiar with the species e.g. hunters. Used information to map village level occurrence and to inform field surveys. No information on how respondents were selected.	Anon (2016)
Potohar Plateau, Pakistan	Questionnaire surveys of local communities. Used to inform possible pangolin occurrence in area. Interviewees selected opportunistically. About 2 to 7 interviewees per transect area. Used to support diurnal searches (selection of areas).	Irshad (2015)
Potohar Plateau, Pakistan	No details on interview method. Used to inform possible pangolin distribution in survey area.	Mahmood et al. (2014)
Margalla Hills National Park, Pakistan	No details on interview method. Used to inform possible pangolin distribution in survey area.	Mahmood et al. (2015)
Pir Lasura National Park, Pakistan	Questionnaires and group discussions. Respondents sampled using consecutive sampling method and were anonymized. Used to understand threats and local perceptions and attitudes.	Akrim et al. (2017)
Trade/specimen reviews		
Odisha, India	Collation of rescue/confiscation records in Orrisa [Odisha] state, north India to map possible distribution.	Mishra and Panda (2011)
Live capture		
Potohar Plateau, Pakistan	Modified mesh traps set outside burrows. Burrows initially detected using local hunting dogs. Unclear how the mesh nets were modified	Mahmood et al. (2016)

Table 5
Traced methods for Temminck's pangolin *Smutsia temminckii*.

Burrow counts – none traced		
Nocturnal surveys – none traced		
Diurnal surveys – none traced		
Targeted camera-trapping – none traced		
Telemetry		
Site	Method description	Source
Mpumalanga, Limpopo, Gauteng and North-West Provinces (former Transvaal region)	VHF transmitter attached to a large dorsal scale. Fixed using steel wire and fibreglass resin. 18 days tracking.	Jacobsen et al. (1991)
Sengwa Wildlife Research Area, Zimbabwe	VHF transmitter attached to a large dorsal scale near the base of the tail. Attachment smoothed over using epoxy glue. Tracked for 87–291 days.	(Heath et al., 1997a)
Sengwa Wildlife Research Area, Zimbabwe	Same attachment method as in (Heath et al., 1997a). Transmitters stayed on for 2–8 months.	(Heath et al., 1997b)
Sengwa Wildlife Research Area, Zimbabwe	Same attachment method as in (Heath et al., 1997a). No information on how long transmitters stayed on for.	Richer et al. (1997)
Sabi Sand Wildtuin, South Africa	Transmitters attached to large dorsal scale. No information on how long transmitters stayed on for.	(Swart, 1996; Swart et al., 1999)
Kalahari Desert, South Africa	VHF transmitter weight of 100–120 g, including the epoxy glue used to strengthen the attachment. Four pangolins fitted with GPS data loggers. Which were 200 g and therefore only suitable for large, adult pangolins (over 6 kg). 9 to 1111 tracking days with the majority (62%: 8/13 pangolins) exceeding 200 days. Ant and termite samples collected during telemetry used to research diet (see Pietersen et al., 2015)	(Pietersen, 2013; Pietersen et al., 2014)
Community interviews – none traced		
Trade/specimen reviews – none traced		
Live capture – none traced animals for telemetry research were caught by hand, either through chance encounters by park staff (Heath and Coulson, 1997a; Richer et al., 1997), by identifying burrows using the presence of faeces (Richer et al., 1997), or by following fresh tracks during the day and then capturing any detected pangolin, or by waiting outside burrows until the animal emerged in late afternoon (D. Pietersen, pers. comm. 2018).		

Table 6
Traced methods for giant pangolin *Smutsia gigantea*.

Burrow counts – none traced		
Nocturnal surveys – none traced		
Diurnal surveys		
Site	Method description	Source
Dja Biosphere Reserve, Mbam and Djerem National Park, Camp Ma'an National Park, Cameroon	Feeding signs (e.g. broken termite mounds), attributed to this species, were the most commonly purported pangolin signs during pangolin-focused line transect surveys. Tail drag marks and footprints were used to attribute feeding signs to this species (Ichu et al., 2017: p. 24). The frequency of signs was used to produce basic encounter rates (number of signs per km), to help inform the species possible conservation status.	Ichu et al. (2017)
Targeted camera-trapping		
Dja Biosphere Reserve, Cameroon	Potentially active burrows were identified by local wildlife trackers, the Ba'Aka. Nine camera-traps were placed outside nine purported burrows and were set for a maximum of 29 days. A giant pangolin was recorded two days later at one of the camera-trap stations. The complexity of the burrow, which had multiple exits/entrances, prevented more details on burrow occupancy rates being collected. Giant Pangolin was recorded apparently scent marking.	Bruce et al. (2018)
Dja Biosphere Reserve, Mbam and Djerem National Park, Camp Ma'an National Park, Cameroon	Camera-traps set at areas of suspected recent/high pangolin activity (identified during line transects), successfully recorded the species: 597 camera-trap-nights produced three giant pangolin "events" (i.e. notionally independent photographs)	Ichu et al. (2017)
Telemetry – none traced		
Community interviews		
Dja Biosphere Reserve, Mbam and Djerem National Park, Camp Ma'an National Park, Cameroon	Respondents from local communities were widely able to recognise the species and were able to offer statements on their perceptions of its rarity, decline, and ecology. Community members stated that giant pangolin burrows were sometimes old Aardvark *Orycteropus afer* dens that had been abandoned, and one such burrow	Ichu et al. (2017)

(*continued on next page*)

Table 6 (*continued*)

Burrow counts – none traced		
Nocturnal surveys – none traced		
Diurnal surveys		
Site	Method description	Source
	was detected during line transects (Ichu et al., 2017: Fig. 25). Only targeted camera-trapping confirmed the species's presence in Ichu et al. (2017).	
Trade/specimen reviews		
Nigeria	Targeted pangolin bushmeat and trade surveys in Nigeria in the 1990s did not record this species, though a hunter claimed to have caught an individual animal in the late 1970s	Sodeinde and Adedipe (1994)
Central Africa	Trade records were traced in a review of local-scale bushmeat/wildlife trade data from Central Africa. Used to show patterns and scale of decline.	Ingram et al. (2018)
Live capture – none traced		

Table 7
Traced methods for Sunda pangolin *Manis javanica*

Burrow counts – none traced		
Nocturnal surveys		
Site	Method description	Source
Western Forest Complex and Khlong Nakha Wildlife Sanctuary, Thailand	Survey effort in Thailand was low (approximately 10 km). There were no pangolins detected and the method was not trialled further due to safety concerns; Asian Elephants *Elephas maximus* were active in the area.	ZSL (2017)
U Minh Wetlands, Vietnam	16 h of nocturnal surveys produced three records in U Minh Ha National Park; 43 h in the adjacent U Minh Ha Fisheries and Forestry Enterprises (FFEs) produced none.	Willcox et al. (2017)
Ke Go – Khe Net Lowlands, Vietnam	101 h in the Ke Go – Khe Net Lowlands, focused on small carnivores and pangolins, produced no records.	Willcox et al. (2015)
Cat Tien National Park, Vietnam	Approximately 30 h of spotlighting near release sites produced two records: one released pangolin and one wild pangolin (distinguished as wild because it did not have a receiver, was not part of the pangolin release, and there had not been any other known releases).	(CPCP unpublished data; CPCP, 2014)
Pu Mat National Park, Vietnam	Four weeks (approximately 200 h) of nocturnal surveys for reptiles and amphibians in 2013 produced a single observation.	(S. Trageser pers. comm. 2018)
Diurnal surveys		
Western Forest Complex and Khlong Nakha Wildlife Sanctuary, Thailand	Approximately 69 km of diurnal transects were completed. These focused on detecting possible pangolin signs such as den sites, broken ant nests or termite mounds, and claw marks. Claw marks were the most detected sign, but due to the difficulties in determining that they were made by pangolins, as opposed to other species that climb trees and leave claw marks (e.g. monitor lizards *Varanus* sp.), they were treated as unconfirmed records. The presence of signs and possible den sites was used to guide placement of camera-traps, which later generated the only verifiable and confirmed records by ZSL at sites in Thailand (see ZSL, 2017).	ZSL (2017)
Peninsular Malaysia	Sleeping dens/burrows were identified by searching for possible feeding signs and subsequently identifying nearby tree hollows or other similar structures; claw marks and faeces were used to determine whether it was a Sunda Pangolin den and whether it was active. This produced data on 122 purported Sunda Pangolin dens. No information was included on the survey effort needed e.g. number of hours, transects, or how survey areas were identified, or how claw marks were distinguished from other wildlife species. Faeces were not genetically tested.	Chong et al. (2016)
Telemetry		
Singapore	VHF transmitter attached directly onto a scale. 25 tracking days maximum. Transmitter drop off rates were 80% within the first two weeks. Transmitters weighed either 21 g or 12 g.	(Lim, 2007; Lim and Ng, 2008)
Singapore	20 g VHF transmitters snapped scales and dropped off within 1–2 weeks. Smaller 15 g VHF transmitters attached on adults, with two weeks monitoring data.	Nash et al. (2018a)
Sepilok, Sabah, Malaysia	VHF transmitter attached directly onto a scale near hind leg. Six tracking days.	Panjang (2012)
Cat Tien National Park, Vietnam	VHF transmitter attached via a strip of flexible nylon. Attached to either large dorsal scale near base of tail, or scale on hind leg. 7–44 tracking days. Transmitters weighed 26 g.	CPCP (2014)
Targeted camera-trapping		
Singapore	Camera-traps set outside a natal den of one female, collected data on breeding ecology, including maternal care.	Lim and Ng (2008)
Sepilok, Sabah, Malaysia	871 camera-trap-nights produced records at two camera-trap stations in Sabah, Malaysia	Panjang (2012)
Brunei	Approximately 200 camera-trap-nights at 10 stations. One record in a location where a pangolin had been released recently.	(L. Fletcher, undated)

Table 7 (*continued*)

Burrow counts – none traced		
Nocturnal surveys		
Site	Method description	Source
Cat Tien National Park, Vietnam	Camera-trapping at release locations recorded released Sunda pangolins, but this might be due to the released animals having a higher den site fidelity than wild animals (CPCP unpublished data). Around 350 camera-trap-nights were needed to record the presence of a released Sunda pangolin whose home range was largely known.	CPCP (2014)
U Minh Ha National Park, Vietnam	896 camera-trap-nights recorded Sunda pangolin at three stations during dry season surveys (November to May) in 2007 and 2008.	Willcox et al. (2017)
Western Forest Complex and Khlong Nakha Wildlife Sanctuary, Thailand	Approximately 13,260 camera-trap-nights at 120 stations produced 23 detections. Used a pangolin-focused survey design with camera-traps set near possible signs of pangolin activity (e.g. feeding signs, tree hollows, prints or scratch marks)	ZSL (2017)
Community interviews		
Peninsular Malaysia	Interviews were used to assess local knowledge of pangolin ecology (including den site characteristics), hunting techniques, and trade dynamics. Unclear how respondents were selected.	Chong et al. (2016)
Vietnam	Hunters living in communities close to three protected areas in Vietnam were interviewed on their knowledge of pangolin ecology, techniques used to capture pangolins, and trade dynamics. This used a respondent-driven sampling method (‘snowball’ sampling) to identify knowledgeable pangolin hunters within each community. Semi-structured interviews were used and because pangolin hunting was illegal, all interviews were informal and anonymized.	Newton et al. (2008)
Trade/specimen review		
Vietnam	Interview data was coupled with a review of museum specimens and field records, to help map the proposed distribution of Vietnam's two pangolin species: Sunda and Chinese pangolin.	Newton et al. (2008)
Live capture – none traced but in Lim (2007) pangolins were caught by hand at night whilst listening carefully for sounds of activity such as feeding or a pangolin disturbing leaf litter as it walked on the forest floor.		

Table 8
Traced methods for Philippine pangolins *Manis culionensis*.

Burrow counts – none traced		
Nocturnal surveys		
Site	Method	Source
Riza, Puerto Princesa, Taytay municipalities, Palawan, Philippines	From 23h00 until dawn, a four-person team surveyed for pangolins with a hunting dog if available; no further details were included. Across the sites at Taytay, Puerto Princesa and Rizal, nine, nine, and four pangolins were detected respectively. Reported estimated densities across the sites ranged from 2 to 4.5 pangolins/km^2. Locations for transects were based on information from community interviews.	Schoppe and Alvarado (2015b)
Bacungan and Langogan in Puerto Princesa, and Dumaran Island, Palawan, Philippines	Used the same method in Schoppe and Alvarado (2015b). No pangolins were found in Bacungan, potentially due to recent poaching, while 6 animals were found in Longogan producing an estimated density of 3 pangolins/km^2. A total of 10 pangolins were detected on Dumaran Island producing an estimated density of 5 pangolins/km^2.	Schoppe and Alvarado (2015c)
Diurnal surveys		
Riza, Puerto Princesa, Taytay municipalities, Palawan, Philippines	Following community interviews on status, a 20 km^2 site was then selected in each municipality and divided into 20 plots (0.10 km^2 in each plot). Over a period of 14–16 days at each site, burrows and potential resting sites (e.g. decomposing tree trunks), and ant and termite nests, were searched for in the plots during the day and trails cleared for nocturnal searching.	Schoppe and Alvarado (2015b)
Telemetry		
Dumaran Island, Palawan, Philippines	6 g VHF transmitter used to track a young male Philippine pangolin for 51 days between March and July 2014. In 2015, 6 animals were tagged on Dumaran Island using the same equipment and animals were caught with the aid of hunting dogs. Transmitters were glued to the left side of the base of the tail with epoxy putty. Each animal also had its study number painted on its back to aid identification. Data were collected on movement and home range. Attempts to repeat the painted number have not worked in Vietnam – paint was quickly rubbed off (SVW unpublished data). No information on transmitter drop off rates; all six were apparently tracked for two months.	Schoppe and Alvarado (2015a)
Targeted camera-trapping		
Santa Lucia and Cleopatra's Needle Forest Reserve, Palawan, Philippines	Conducted in the dry season (January to June) it comprised two different set-ups: camera-traps were placed randomly at one site and baited, or were set at fixed distances of 200 m along transect lines and baited. Baits comprised uncooked chicken	Marler (2016)

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Table 8 (*continued*)

Site	Method	Source
Burrow counts – none traced		
Nocturnal surveys		
	egg, canned sardines, fish oil, fresh pig blood or small intestines and were set 30 cm from the ground. Camera-traps that were set along transects were set near possible pangolin signs, including scratch marks or diggings. Although hard to decipher (no table on survey effort is included), approximate survey effort was less than 200 camera-trap-nights. Three camera-trap stations recorded the species; there was no evidence that the species was attracted to the baits.	
Community interviews		
Riza, Puerto Princesa, Taytay municipalities, Palawan, Philippines	Used local knowledge to initially assess Philippine pangolin populations in three municipalities, Taytay, Puerto Princesa and Rizal, in 2013 and 2014. Informal interviews (but using a questionnaire format) were conducted with professional and opportunistic hunters to learn how they caught pangolins. Information used to guide nocturnal searches.	Schoppe and Alvarado (2015b)
Trade records – none traced		
Live capture		
Brooke's Point, Palawan, Philippines	Used a novel but risky method for detecting pangolins; 20 snares were set along 1 km transects and checked "at least once a week" in 10 survey locations. Locations for trapping were selected based on reconnaissance surveys and guidance from local communities. Although there are no details on survey effort (i.e. number of trap days), eight pangolins were captured. The author did not report on capture myopathy, injuries or any deaths related to this method.	Acosta-Lagrada (2012)

Table 9
Traced methods for white-bellied pangolin *Phataginus tricuspis*.

Site	Method description	Source
Burrow counts – none traced		
Nocturnal surveys		
Lama Forest Reserve, Benin	3 km × 1 km belt transects. Surveys were done in the dry season (months not given). Fifteen transects covering approximately 45 km^2 produced 38 records and data on population densities, observed age classes, and habitat associations. It is unclear at what time of day transects were completed, or what the total survey effort was (in hours); these details were not reported. It is assumed that as this species is predominantly nocturnal (Kingdon and Hoffmann, 2013), that these surveys would have been done at night.	Akpona et al. (2008)
Diurnal surveys		
Dja Biosphere Reserve, Mbam and Djerem National Park, Camp Ma'an National Park, Cameroon	In three protected areas, there were a total of 123 km of diurnal sign surveys (approximately forty 1 km line transects at each site). Due to the difficulty in distinguishing white-bellied pangolin signs from those of black-bellied pangolins, these were grouped to produce encounter rates for "small pangolins".	Ichu et al. (2017)
Telemetry		
Gabon	VHF transmitter, attached to several scales using copper wires. Provided information on species's ecology, including den sites (see Kingdon and Hoffman, 2013: 393).	Pagès (1975)
Targeted camera-trapping		
Dja Biosphere Reserve, Mbam and Djerem National Park, Camp Ma'an National Park, Cameroon	Camera-traps were set at a height of 30 cm and set near signs that indicated recent or abundant pangolin activity (recorded during the line transects); total survey effort was 597 camera-trap-nights. There were five notionally independent photographs.	Ichu et al. (2017)
Community interviews		
Lama Forest Reserve, Benin	Focused on local uses and beliefs, hunting pressures and trade. No method given. Combined with observations to give an assessment of the species's conservation status at the site.	Akpona et al. (2008)
Dja Biosphere Reserve, Mbam and Djerem National Park, Camp Ma'an National Park, Cameroon	Semi-structured interviews. Questions focused on respondent knowledge or perceptions of pangolin status/declines, hunting practices and trade dynamics. 'Snowball' sampling design; focused on hunters, or people familiar with pangolins.	Ichu et al. (2017)
Ogun state, Nigeria	Interviewed local hunters on hunting practices used to capture the species and their perceptions of population status, ecology, and local trade dynamics.	Sodeinde and Adedipe (1994)
Trade/specimen reviews		
Ogun state, Nigeria	A total of 142 white-bellied pangolins were observed from 42 market visits during November 1988 to April 1989. Also reviewed "collection centres" near Omo Forest Reserve to establish harvesting patterns – 111 white-bellied pangolins observed.	Sodeinde and Adedipe (1994)
Ogun state, Nigeria	178 during market surveys in 2007. Also interviewed local hunters on hunting practices used to capture the species and their perceptions of population status, ecology, and local trade dynamics.	Soewu and Ayodele (2009)
Live capture – none traced		

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