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Predicted distribution of the Sunda stink-badger *Mydaus javanensis* (Mammalia: Carnivora: Mephitidae) on Borneo

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Wilting et al. (2016: Table 2) list all co-authors' affiliations.

Abstract. The Sunda stink-badger *Mydaus javanensis* is a small carnivore inhabiting the South-east Asian islands of Java, Sumatra, Borneo and Natuna Islands. It occurs in a wide variety of vegetation types and is presently listed by The IUCN Red List of Threatened Species as Least Concern. We analysed 15 (Balanced Model) or 77 (Spatial Filtering Model) location records to predict habitat suitability across Borneo. The analysis suggests that most of the suitable habitat is located in Sabah, northeast Sarawak and North Kalimantan. In addition, this species is also recorded, mostly historically, patchily in west Sarawak, and West, Central, South and East Kalimantan. Although this species appears to be disturbance-tolerant and is frequently observed in village areas, some conservation action – such as limiting large-scale forest conversion to oil palm plantations – is warranted because most lowland habitat is unprotected. Further research in central and southern Borneo needs to focus on showing if there are any further sizable populations. Also, hunting of Sunda stink-badger has been reported in some parts of Borneo and might be a possible driver for the species's patchy distribution. More research is warranted to understand what determines the species's distribution and density, based on which proper conservation strategies, if needed, can be developed to preserve the species.

Key words. Borneo Carnivore Symposium, Brunei, conservation priorities, habitat suitability index, Indonesia, Malaysia, species distribution modelling, survey gaps

Abstrak (Bahasa Indonesia). Teledu Sigung *Mydaus javanensis* merupakan karnivora berukuran kecil yang mendiami pulau-pulau di wilayah Asia Tenggara seperti Jawa, Sumatera dan Borneo. Tinggal dalam berbagai tipe vegetasi dan saat ini tercantum dalam daftar IUCN Red List of Threatened Species kategori Beresiko Rendah. Kami menganalisa 15 (Model Penyeimbang) atau 77 (Model SpasialTersaring) catatan keberadaan satwa tersebut guna memperkirakan kesesuaian habitat di wilayah Borneo. Hasil analisa kami memperkirakan bahwa jenis ini mempunyai kesesuaian habitat yang terluas di Sabah, timurlaut Sarawak dan Kalimantan Utara. Juga jenis ini tercatat, dari catatan sejarah, di bagian kecil Sarawak bagian barat serta Kalimantan Barat, Tengah, Selatan dan Timur. Walaupun jenis ini tampaknya tahan terhadap gangguan dan sering terpantau di wilayah pedesaan, beberapa langkah konservasi, seperti pembatasan perubahan hutan skala besar menjadi kebun kelapa sawit, dibutuhkan, mengingat kebanyakan habitat di dataran rendah tidak masuk kawasan perlindungan. Penelitian lebih lanjut di Borneo bagian tengah dan selatan diperlukan untuk melihat akan populasi yang memadai. Juga perburuan Teledu Sigung ada dilaporkan di beberapa tempat di Borneo dan kemungkinan menjadi penyebab mengapa jenis ini terpencar. Penelitian lebih lanjut diperlukan untuk lebih memahami penyebab dari persebaran jenis ini dan kepadatannya, berdasarkan strategi konservasi yang tepat, bila diperlukan, dapat dikembangkan untuk mengamankan jenis ini.

Abstrak (Bahasa Malaysia). Teledu *Mydaus javanensis* adalah karnivora kecil yang mendiami pulau-pulau di Asia Tenggara iaitu Java, Sumatra dan Borneo. Ia boleh dijumpai di pelbagai jenis habitat dan ketika ini ia disenaraikan sebagai Kurang Membimbangkan di dalam Senarai Merah Spesis Terancam IUCN. Kami menganalisis sejumlah 15 (Model Seimbang) dan 77 rekod lokasi (Model yang ditapis secara spasial) untuk meramal kesesuaian habitat di Borneo. Analisis yang kami jalankan mencadangkan bahawa Sabah, timur laut Sarawak dan Kalimantan Utara merupakan habitat yang paling sesuai bagi spesis ini. Selain itu, spesis ini juga telah direkodkan, kebanyakkannya rekod lampau, di sesetengah kawasan di bahagian barat Sarawak dan Kalimantan Barat, Tengah, Selatan dan Timur. Walaupun spesies ini nampak seperti mampu hidup di kawasan terganggu dan seringkali dilihat di kawasan kampung, beberapa tindakan pemuliharaan seperti menghadkan penukaran hutan pada skala besar kepada ladang kelapa sawit adalah perlu dilaksanakan kerana sebahagian besar habitatnya di kawasan tanah pamah tidak dilindungi. Selain itu, penyelidikan lanjut di bahagian tengah dan selatan Borneo diperlukan untuk melihat jika terdapat populasi Teledu di kawasan tersebut. Juga pemburuan Teledu telah dilaporkan di sesetengah bahagian Borneo dan ini mungkin menjadi penyumbang kepada taburan yang terpisah spesis ini. Penyelidikan lanjut diperlukan untuk memahami apa yang menentukan taburan dan kepadatan spesis ini. Berdasarkan daripada penyelidikan ini, jika perlu, strategi pemuliharaan yang sebaiknya dapat dilaksanakan untuk memastikan spesis ini terus kekal.

INTRODUCTION

The Sunda stink-badger *Mydaus javanensis* (Leschenault, in Desmarest), is a small carnivore (body weight 1.5–2 kg) with an elongated snout, pointed face, and short tail (Davis, 1962; Nowak, 1999). The body is black with a white dorsal stripe of varying length and width. When this species (Fig. 1) is detected, it is often by its strong, pervasive odour, which is secreted by an anal gland (Payne et al., 1985). For a long time the genus *Mydaus* was placed as a member of the family Mustelidae Fischer, to which all 'real' badgers belong, but DNA and morphological studies strongly support its inclusion within Mephitidae Bonaparte (Dragoo & Honeycutt, 1997; Wang et al., 2005; Abramov & Rozhnov, 2007). There are only two species of Mephitidae, *Mydaus javanensis* and Palawan stink-badger *M. marchei* Huet.

Sunda stink-badger is an omnivore, consuming birds' eggs, carrion, insects (e.g., cicada larvae), worms and plant material (Long & Killingley, 1983; Payne et al., 1985; Neal & Cheeseman, 1996). It is mostly nocturnal (Ross et al., in press). In Deramakot Forest Reserve all 70 photographs of the species taken by camera-traps set mainly along active or abandoned logging roads were taken between 1912 hours and 0538 hours (AM & AW, unpubl. data). Similarly, 96.8% of the 277 photographs of the species taken by camera-traps set inside the forest of the same area (Deramakot and Tangkulap Forest Reserves) were taken between 1800 hours and 0600 hours (HS, unpubl. data). During the day, it shelters in underground burrows dug either by itself or by porcupines *Hystrix* Linnaeus, or in the hollows of fallen trees (Long & Killingley, 1983; HS, unpubl. data). All the images taken in Deramakot and Tangkulap were of single individuals (HS, unpubl. data), and the species appears to be solitary, but Yasuma & Alikodra (1992) reported observations of a group of two or three in southern East Kalimantan. Although no studies have been conducted of its burrowing behaviour, some degree of social grouping might occur in burrows. Its home range and reproductive cycle also remain unstudied.

This species occurs in Java, Sumatra, Borneo and on Bunguran in the North Natuna Islands (Payne et al., 1985; Hwang & Larivière, 2003). The status of Sunda stink-badger on The IUCN Red List of Threatened Species is Least Concern Long et al., 2008). This species is neither protected in Sarawak (Wildlife Protection Ordinance 1998) nor Brunei (Wild Life Protection Act of Brunei 1981), but is protected in Sabah (Wildlife Conservation Enactment 1997) and Indonesia (Peraturan Pemerintah 7/1999).

Fig. 1. Sunda stink-badger *Mydaus javanensis* camera-trapped in Deramakot Forest Reserve, Sabah, Malaysia on 25 May 2008. (Photograph by: Hiromitsu Samejima).

RESULTS AND DISCUSSION

Species occurrence records. Of 170 records acquired, 32 were excluded from modelling because their spatial precision was too low (over 5 km; Categories 4 and 5), whereas 89 records had high precision (within 2 km, Category 1) and were collected between 2001 and 2011 (Table 1; Fig. 2). Most of the recent records were collected from Sabah and the north-eastern part of Sarawak and North Kalimantan. Records and reports were also obtained from West, Central, South and East Kalimantan, but these were mostly older records or reports from local people: recent confirmed records in these areas were scarce. Because of survey or search effort bias, only 15 (Balanced Model M_1) or 77 (Spatial Filtering Model M_2) records were used for modelling (see Kramer-Schadt et al. (2016) for methods). Because all recent records were from north-eastern Borneo, only the M_2 model is shown in Fig. 3.

Habitat associations. The eight respondents to the questionnaire were generally consistent in their assessments of suitable land-cover for the Sunda stink-badger (Table 2). All agreed that lowland forests and forest mosaics in lowlands are important for the Sunda stink-badger. Most also considered upland forest, old plantation and burnt forest area as suitable habitats, although some considered these to be very poor. However, there was limited agreement among respondents about the suitability of other land-cover classes, including mixed crops, bare area, montane forest, swamp forest, and mangrove. Although Sunda stink-badger is a disturbance-tolerant species, the lack of consensus over mixed crops and bare area reflects that degraded habitat types have not been well surveyed. The lack of consensus over the degree of suitability of montane forest might reflect a difference across the species's geographic range in its altitudinal use. In Java, Sunda stink-badger is abundant in higher elevations, and often inhabits areas above 2000 m a.s.l. (Horsfield, 1824). It has also been recorded in the Kelabit Highlands above 1000 m a.s.l., north-eastern Sarawak (Giman & Jukie, 2012) and in the Crocker Range at 1000–1500 m a.s.l., Sabah (SY, unpubl. data). Indeed, some authors believed the species only occurred at high elevation in Borneo (Bock, 1882; Jentink, 1895; Hwang & Larivière, 2003). However, it was not

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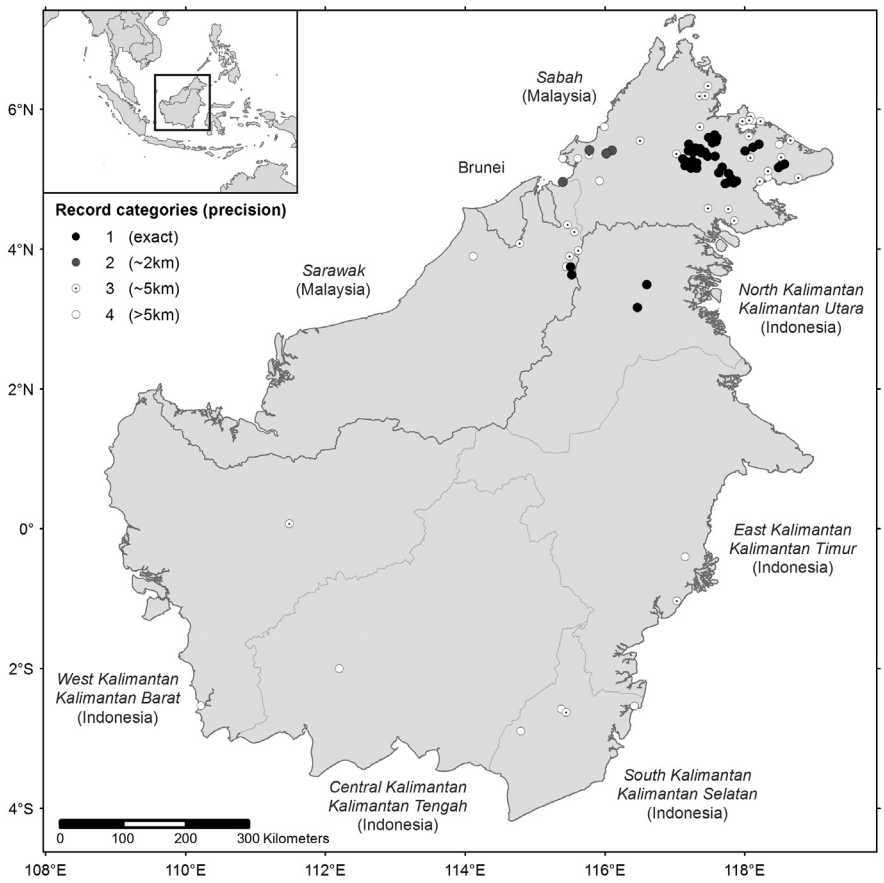

Fig. 2. Location of Sunda stink-badger *Mydaus javanensis* occurrence records in Borneo, with categories of spatial precision as well as countries and state boundaries.

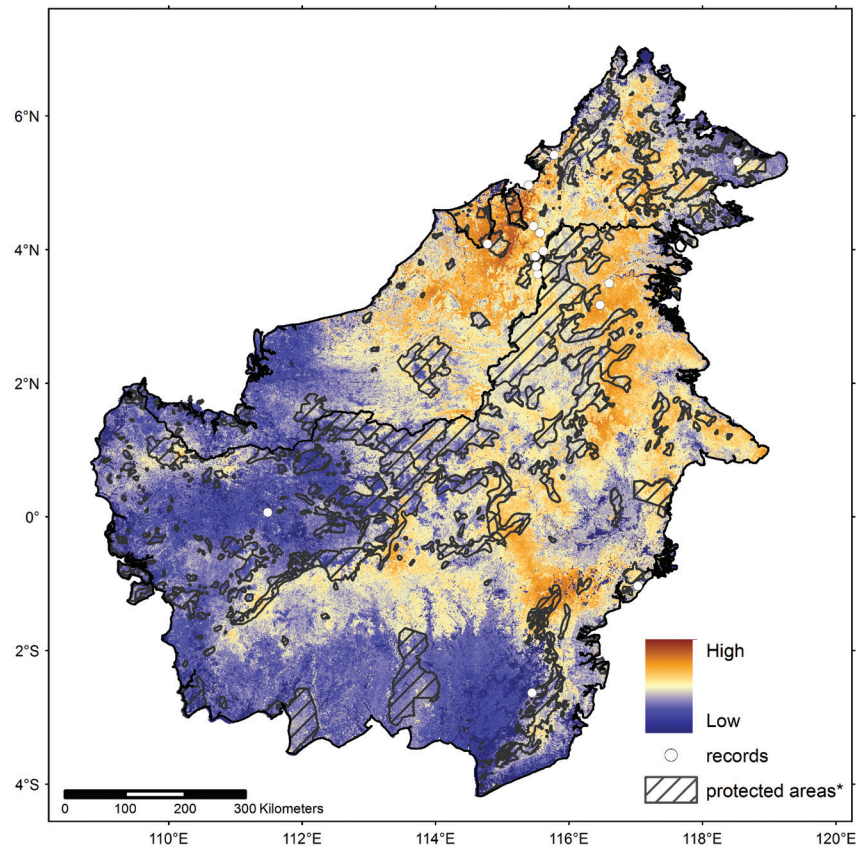

Fig. 3. Predictive Habitat Suitability Index (HSI) model for Sunda stink-badger *Mydaus javanensis*, including location records used in model. Only the Spatial Filtering Model for Sabah, Malaysia (M_2), is shown, because of the paucity of records from outside Sabah. Sources for protected area information: see Kramer-Schadt et al. (2016).

Table 1. Summary of the occurrence records for Sunda Stink-badger *Mydaus javanensis* on Borneo.

Spatial Precision	Total No. of Records	No. of Records in M_1	No. of Records in M_2	No. of Recent Records 2001–2011
Category 1 below 500 m	92	4	44	89
Category 2 500 m – 2 km	6	2	4	5
Category 3 2–5 km	40	9	29	7
Category 4 above 5 km	21	-	-	4
Category 5 (no coordinates*)	11	-	-	2
Total	**170**	**15**	**77**	**105**

M_1 = Balanced Model; M_2 = Spatial Filtering Model (5 km); *only coarse location description was available

Table 2. Land-cover reclassification for Sunda Stink-badger *Mydaus javanensis* based on the questionnaire results of eight respondents working on carnivores on Borneo.

Land-cover Class	Mean of Reclassification	Range of Reclassifications
Lowland forest	3.29	3–4
Upland forest	2.00	1–3
Lower montane forest	1.40	0–3
Upper montane forest	1.00	0–2
Forest mosaics/lowland forest	2.49	*
Forest mosaics/upland forest	1.79	#
Swamp forest	1.40	0–3
Mangrove	0.80	0–1
Old plantations	1.60	1–3
Young plantations and crops	1.20	1–3
Burnt forest area	0.80	1–2
Mixed crops	2.00	0–4
Bare area	0.33	0–1
Water and fishponds	0.17	0–1
Water	0.00	0–0

*/#Calculated based on the mean of the reclassification of old plantation and *lowland forest or #upland forest, respectively.
Habitat suitability rank ranges from 0 (unsuitable) to 4 (most suitable); further detail, and on land-cover classes, in Kramer-Schadt et al. (2016).

recorded by an intensive camera-trap study in and around Gunung [=Mount] Kinabalu across 690–3080 m a.s.l. (H. Nagano et al., unpubl. data). Sunda stink-badger has also been found to be common in lowland areas even near sea level in Sabah and South Kalimantan (Bock, 1882; van der Aa, 1884; Payne et al., 1985). It has also been recorded in lowland north-eastern Sarawak (Giman & Jukie, 2012). This species might be excluded from peatlands, freshwater swamps, mangroves and areas with thin soils on exposed rock (e.g., limestone areas) because of its burrowing behaviour.

Habitat suitability index (HSI) model. The habitat assessments (see Kramer-Schadt et al. (2016) for methods) predicted lowland areas to be the core habitat for Sunda stink-badger. This would suggest that large parts of suitable Sunda stink-badger habitat are located outside larger national parks, especially those outside the 'Heart of Borneo', a government-led and NGO-supported agreement signed between Brunei, Malaysia and Indonesia to manage sustainably the remaining relatively little-encroached band of forests in the centre of the island, particularly along the Sarawak–Kalimantan border. Although these national parks are less disturbed by human activities, they are dominated by upland and montane forests. Based on frequent sightings in disturbed areas including oil palm plantations (Bogor Agriculture Institute, 2010; Yue et al., 2015; M. Ancrenaz, pers. comm.), Sunda stink-badger can thrive in disturbed areas, at least locally. Camera-trapping in Tabin Wildlife

Reserve, which also included small forest patches within oil palm plantation, revealed that although photo-capture rates of the Sunda stink-badger were generally low, the species was apparently only photo-captured in the plantation habitat (Bernard et al., 2014). This finding supports the notion that the Sunda stink-badger is to some extent adapted to living in disturbed or converted habitats. However, whether it can survive in entirely disturbed landscapes remains unclear. This lack of clarity, exacerbated by the likelihood that habitat-use differs across the species's geographic range, hinders evaluation of the importance of the existing protected area network to the species's presence on Borneo.

The mapped predictions of the habitat suitability index model (Fig. 3) need to be interpreted with caution (see Kramer-Schadt et al. (2016) for more details). Of note, some areas, particularly in South and West Kalimantan had little information, reflecting the lower survey efforts in these areas. Although search-effort bias has been minimised during the modelling, these areas might still be underrepresented in the distribution map, especially if they are climatically distinct from the rest of Borneo. This is particularly likely for South Kalimantan which has a more pronounced dry season (see Kramer-Schadt et al., 2016: Fig. 3A). Thus, unless there are records sufficiently spatially precise to have been used in the model, the prediction cannot accurately reflect the potential for occurrence in that region. In general, only further surveys could determine if the lower predictions are because of the minimal survey efforts or reflect a genuine lower suitability of these areas for the species, perhaps because of different climatic conditions or because large areas have been transformed to unsuitable land-cover (see Kramer-Schadt et al., 2016: Fig. 3B).

Spatial analysis based largely on recent camera-trap records and study of historical literature both suggest a discontinuous distribution for Sunda stink-badger on Borneo. Records are well distributed in a near-continuous area including Sabah, north-eastern Sarawak and North Kalimantan. They also come from scattered areas in West, Central, South and East Kalimantan, as well as, recently, from western Sarawak (Borneo Post, 2012a, b; Meijaard & Wilting, 2012).

Where it does occur, Sunda stink-badger is often common. In a camera-trap study in the selectively logged natural forest of Deramakot and Tangkulap forest reserves, Sabah, conducted from 2007 to 2010, it was the third most frequently photographed carnivore, after Malay civet *Viverra tangalunga* (Gray), and banded civet *Hemigalus derbyanus* (Gray) (Samejima et al., 2012; unpubl. data). According to some historical literature, Sunda stink-badger was also a very common animal in South Kalimantan (Bock, 1882; van der Aa, 1884; Yasuma, 1995).

However, the species was not recorded even with intensive survey-efforts in many locations of central and southern Borneo. For example, none was recorded in 6000 camera-trap-nights in peat swamp forests in Sabangau, Central Kalimantan (Cheyne et al., 2010) or 17,974 camera-trap-nights in lowland mixed dipterocarp forests in the Schwaner mountains, Central Kalimantan (Samejima & Semiadi, 2012). Similarly, camera-trapping and other survey methods in central, southern and western Sarawak also failed to record the species (Azlan & Lading, 2006; Giman et al., 2007; Giman & Jukie, 2012; J. Hon & HS, unpublished data). Also, the species remains unrecorded in the Gunung Palung National Park in West Kalimantan, despite 30 years of mammal surveys (Blundell, 1996; A. J. Marshall, pers. comm.). Even in Sabah, the species was not recorded in Maliau Basin Conservation Area, 60–70 km from Deramakot and Tangkulap, after 2915 trap-nights (Brodie & Giordano, 2011). Survey effort in central and southern Borneo is still lower than in northern Borneo and is mostly conducted in natural forest, while the species perhaps occurs more in open vegetation types than in closed forest, as indicated, for example, by high encounter rates in some oil palm plantations in Sabah (Bernard et al., 2014; M. Ancrenaz, pers. comm.). Camera-trapping and other survey in the open vegetation types in central and southern Borneo are warranted to clarify its distribution range.

At least five non-exclusive reasons might contribute to the patchy distribution of Sunda stink-badger on Borneo, none of which can be substantiated without further study.

(1) In most of Borneo, the species might be restricted to certain fertile soils and open vegetation. Only environments that support high enough densities of certain animal species such as earthworms could support stink-badger populations. According to Hose (in Shelford, 1916), in Borneo, Sunda stink-badger is found where the land has been cultivated, but seldom in the dense forest. It burrows in the earth and feeds, to a great extent, on worms. Horsfield (1824) also wrote that earthworms abound in the fertile moulds in mountain area where Sunda stink-badger is common in Java.

(2) The species might have undergone significant local population declines through an ecological reason such as disease. Shelford (1916) speculated that the population of Sunda stink-badger in Borneo might perhaps be kept down by parasitic worms, or the species may be peculiarly susceptible to certain bacterial diseases.

(3) The population of this species might have declined over large areas and, particularly in isolates, have even been wiped out by over-hunting. There are several reports of hunting of this species in north-eastern Sarawak and North Kalimantan (Bock, 1882; Banks, 1931; Puri, 1997; Giman & Jukie, 2012; Rustam & Giordano, 2014). Banks (1931) reported that Kelabit people in north-eastern Sarawak hunted Sunda stink-badger with dogs and valued its skin for sale to down-country people, who mixed the shavings with water and drank them as a cure for fever or rheumatism. Horsfield (1824) also reported from Java that this species moves slowly and so is easily captured by local people, and that the meat is considered delicious. Long & Killingley (1983) reported that the anal gland secretion is diluted and made into perfume in Java. Hunting is considered to be a major factor in the patchy distribution of Greater Hog Badger *Arctonyx collaris* F.G. Cuvier, in Vietnam, Lao PDR and Cambodia, which has close behavioural parallels with Sunda Stink-badger

(R. J. Timmins et al., pers. comm., 2015). The impact that hunting has or has had on stink-badger occurrence pattern and local species densities remains unclear: there are still large continuous natural forests with a high canopy and a low human population density in central parts of Borneo. However, if Bornean populations of Sunda stink-badger are associated with human-dominated landscapes, the species might be more vulnerable to hunting than are other carnivores in Borneo.

(4) During the last glacial maximum, in Borneo the species might have been largely restricted to the north, and it has yet to recolonise some areas of now suitable land-cover. During this period, the climate of central and southern Borneo and lowland Java was drier than it is currently (Morley, 2000) and Sunda Stink-badger possibly could not have survived in these areas. Whilst this is also likely to have happened with other carnivores tied to evergreen forest, the Stink-badger might take particularly long to recover if the soil-dwelling invertebrates on which Sunda stink-badger depends have slow dispersal abilities. Other small carnivores whose principal prey has greater dispersal abilities or is not so habitat-constrained, such as flying insects, rodents or plant matter, might be less affected. Both this hypothesis and the first postulate the current distribution of earthworms as the key determinant of stink-badger distribution: hypothesis 1 focuses on current habitat suitability for earthworms, but hypothesis 4 relates to their colonisation speed.

(5) The species might occur naturally in Borneo only in northern parts, for any of the ecological and geological reasons above, but might artificially have been introduced sporadically into central and southern Borneo by traders for medical or other purposes, with populations persisting there only transitorily. This has happened with Malay civet in the Moluccas and Sulawesi and possibly other islands (Veron et al., 2014).

In addition, road-killed Sunda stink-badgers are frequently found in Gunung Halimun–Salak, Java (JE, pers. obs.) and in Sabah (SY, pers. obs.). However, road-kill is unlikely to be a major factor to the population decline in most parts of Borneo because the active road network densities are mostly very low (Gaveau et al., 2014), and the species remains common in lowland Sabah, with a very high road density in Bornean terms.

These hypotheses would best be tested by detailed studies of the habitat requirements, population dynamics and genetics of Sunda stink-badger as well as hunting activities of local people. The habitat study should focus on soil types and depths, soil invertebrates, soil fertility, vegetation, stink-badger burrowing sites, number of animals per burrowing location, and ranging behaviour in the field coupled with specimen studies, especially of the stomach contents. Studies on population dynamics using camera-trapping and dietary investigations as well as population genetic studies should be conducted according to vegetation and soil types to contrast northern with central and southern Borneo, and on Java and Sumatra, supported by community interviews with locals. Studies on hunting activity are required to collect more information on where and how intensively the species actually is and was hunted. Based on the current predicted distribution the following important localities and conservation actions could be suggested (see Fig. 3):

Brunei Darussalam. A large portion of Brunei Darussalam remains covered by natural lowland forest and Sunda stink-badger was recorded in the neighbouring Limbang division of Sarawak (Giman & Jukie, 2012). As a result, many parts of Brunei are predicted to be highly suitable for Sunda stink-badger. However, there is no reliable evidence that this species occurs in Brunei. Yasuma & Abdullah (1997) reported Sunda stink-badger in Brunei based on secondary information, not on direct evidence.

Sarawak, Malaysia. The model predicts the north-eastern and central lowland parts of Sarawak to be suitable for Sunda stink-badger. However, all previous records of this species in Sarawak are located only in the north-eastern part, i.e. Limbang and northern Miri divisions. The records range from Kuala Lawas in the far north at sea level to Pa' Umur and Pa' Main in the Kelabit Highlands at 1000–1100 m a.s.l. (Davis, 1958; Giman & Jukie, 2012). In this north-eastern area, montane regions are partly conserved in the Pulong Tau and Mulu National Parks, but lowland areas are poorly protected and are rapidly being converted into industrial tree plantations (Faeh, 2011). Although this species seems tolerant of habitat degradation to some degree, further study would be necessary to specify the degree of tolerance.

The central lowland area of Sarawak is also predicted to be suitable habitat, but Sunda stink-badger was not camera-trapped in either the natural forests of Lambir Hills National Park, Miri Division (Azlan & Lading, 2006) and Anap–Muput Forest Reserve, Bintulu Division (HS, unpubl. data), or in an acacia plantation with remaining secondary forests in Bintulu Division (McShea et al., 2009). HS visited 34 villages in Bintulu Division from 2011 to 2012 and interviewed the locals about Sunda stink-badger with an image of the animal. However, none of them knew about this species. Some unknown factors perhaps prevent the occurrence of Sunda stink-badger in this region.

In western Sarawak, Sunda stink-badger had until recently not been recorded and was unknown among locals (Giman & Jukie, 2012). However, in 2012, two individuals were killed in a pepper garden and an oil palm plantation, respectively, in Serian district, south-west Sarawak (Borneo Post, 2012a, b; Meijaard & Wilting, 2012). According to the newspaper article, the local people were unfamiliar with the species. This might indicate a patchy distribution, a low density and low awareness of people, or that some Sunda stink-badgers can range significantly beyond their area of origin. Recent long-distance transport into the area by people, theoretically possible, seems unlikely, given that all vehicles and other equipment used would stink of the animal potentially for a year or more (see Giman & Jukie, 2012). Wide-scale camera-trapping and interviews with locals about this species in western Sarawak and northern West Kalimantan

are warranted to determine its distribution in this region and set, if necessary, appropriate conservation goals.

Sabah, Malaysia. Most lowlands in Sabah are predicted to be highly suitable habitat for Sunda stink-badger. Many records are located in this state, especially in its eastern part, with some on the west coast (Thomas, 1902; Yasuma & Andau, 2000; Yasuma et al., 2003). SY (own data) camera-trapped this species frequently from 1000 to 1500 m a.s.l. in the Crocker Range. The species is relatively common and well known among locals in many places in Sabah. It is known to use not only natural forest but also secondary forest, rubber plantations, oil palm plantations (Bernard et al., 2014; Ross et al., in press; Yue et al., 2015), and open ground such as gardens adjacent to forest (Payne et al., 1985). Compared with the several carnivore species in Sabah evidently strongly tied to natural forests, the Sunda stink-badger is not currently an urgent conservation priority in the state.

North Kalimantan, Indonesia. Suitable habitat for Sunda stink-badger is predicted in the lowland parts of North Kalimantan (which became an independent province in 2012). In this region, Sunda stink-badger was recorded at two lowland areas (below 200 m a.s.l.) in Malinau Regency (O'Brien & Fimbel, 2001; Rustam & Giordano, 2014). Although the area is not predicted to be suitable, Sunda stink-badger also inhabits the mountainous parts of North Kalimantan in, Kayan Mentarang National Park, Malinau Regency (Wulffraat & Samsu, 2000), consistent with its occurrence in highland Sarawak at comparable latitudes (Giman & Jukie, 2012). In the national park, this species was mentioned frequently by local hunters who usually try to avoid the animal to prevent being sprayed by its pungent secretions (Wulffraat & Samsu, 2000). Puri (1997) listed this species as reported by local Punan hunters in Long Pujungan area in the southern part of this national park. We predicted that the habitat was less suitable than were lowland areas, because only a few records from higher altitudes (over 750 m a.s.l.) were included in the modelling. Most conservation areas in North Kalimantan are located in upland and montane regions, with oil palm plantation expanding rapidly in lowland areas. A proposal for a new lowland protected area (Momberg et al., 1998) lost out to proposals for new plantations. More conservation efforts are warranted in these lowland areas, not just potentially for Sunda stink-badger, but also for a range of other threatened lowland species. Because Sunda stink-badger seems relatively disturbance-tolerant, secondary forest and local communities' rubber plantations might also contribute to its conservation, if it is hunted sustainably.

East Kalimantan, Indonesia. Suitable habitat for Sunda stink-badger is predicted in northern East Kalimantan; the other parts of the province are predicted to be only marginally suitable. However, the species was not detected in many camera-trap studies in this region, e.g., Wehea Protected Forest, Kutai Timur Regency (B. Loken, pers. comm.), and Sungai Wain Protected Forest near Balikpapan (G. Fredriksson, pers. comm.). This species was also not known among people around Sandawar, Kutai Barat Regency (HS, pers. obs.), and around the Lumut mountains along the border with South Kalimantan (B. Wielstra pers. comm.). Yasuma (1994) interviewed local communities about mammals in many parts of this province, but received information about this species only from Bukit Soeharto Forest Park, south of Samarinda, where he himself observed it during 1986–1989 (Yasuma & Alikodra, 1992). Historically, the species was reported only from the area north of Samarinda (Nederlandsch-Indische Vereeniging tot Natuurbescherming, 1939). However, vast areas of the lowland forests in East Kalimantan, including Bukit Soeharto, were burnt during 1982–1983 and 1997–1998 (Siegert & Hoffmann, 2000) and the forest fires and habitat isolation might strongly have affected several species, i.e. three-striped ground squirrel *Lariscus insignis* (F. Cuvier), long-tailed porcupine *Trichys fasciculata* (Shaw), and small-toothed palm civet *Arctogalidia trivirgata* (Gray), in the area (Rustam et al., 2012). The perhaps only scattered populations of Sunda stink-badger in this region might have been particularly reduced by the fires. To determine this species's current status in East Kalimantan, more studies are necessary.

South Kalimantan, Indonesia. South Kalimantan was generally predicted to be mostly unsuitable. This is likely to reflect the low recent coverage (so absence of modelled records) and different climate (see above). Several historical documents recorded this species in the province. Bock (1882) and van der Aa (1884) recorded it in Amoentai (= current Amuntai, Ulu Sungai Selatan Regency), Barabai (Ulu Sungai Tengah Regency) and Birajian area in this province, to be known as 'sāăt' in the local language, and to be restricted to below 30 m a.s.l.; Bock (1882: 247) described Sunda stink-badgers to be "as common as rats". Feuilletau-de Bruyn (1933) stated that the species was relatively common in the cultivated areas of Hoeloe Soengei (present Tabalong, Balangan, Hulu Sungai Utara, Hulu Sungai Tengah, Ulu Sungai Selatan, and Tapin Regencies in the province) whilst it seemed to be absent from the eastern slopes of the Meratus mountains (Nederlandsch-Indische Vereeniging tot Natuurbescherming, 1939); another local name is 'sadoe' (Nederlandsch-Indische Vereeniging tot Natuurbescherming, 1939). Lyon (1911) noted that it was well known among locals on the east coast, Pamukan or Tjengal Bay, although absent from the island of Pulau Laut. The species was recorded by U.S. Naval Medical Research Unit, Jakarta, at Hantakan in Hulu Sungai Tengah Regency (Medway, 1977). Yasuma (1995) noted that he heard that Sunda Stink-badger was common around Banjarmasin and Tanjung (Tabalong Regency), western South Kalimantan, and villagers from those areas knew this species very well by the local name 'sado'. Only further surveys could determine whether the species is still present in the province and if so, where. Even if environmental conditions, such as soil, of lowland South Kalimantan had been suitable for Sunda stink-badger in the past, the province is the most populated area in Borneo and most forest has already been lost.

Central Kalimantan, Indonesia. While lowland areas south of the Schwaner and Müller mountains are predicted to be marginally suitable, most of Central Kalimantan is predicted to be unsuitable. Nederlandsch-Indische Vereeniging tot

Natuurbescherming (1939) recorded this species in 'Zuid-Borneo' (now, South and Central Kalimantan provinces) only at nine widely dispersed locations. The source did not name the areas, but the ethnic groups for which the local names of the species were given, Malay Kotawaringin in western Central Kalimantan (the local name was 'moentoer'), Ngadjoe – current Ngaju – in central Central Kalimantan ('sero') and Maanjan – current Ma'anyan – in eastern Central Kalimantan ('asero') imply the species inhabited the territories of those ethnic groups. There is one record in the upper Sungai [=River] Barito (Sheldon, 1991). A survey by the Indonesian Institute of Sciences (LIPI) reported that local people along the Murung tributary of the upper Barito in Murung Raya Regency were familiar with the species but did not camera-trap the species at Gunung Lumut (Partomiharjo, 2005). Bogor Agriculture Institute (2010) recorded this species at three locations in an oil palm plantation in Kotawaringin Timur Regency. However, the species was recorded neither by intensive camera-trapping in hill forest in a logging concession in the Schwaner mountains, northern Katingan Regency, near the border with West Kalimantan (Samejima & Semiadi, 2012) nor in swamp forest, very degraded in parts, in Pulang Pisau Regency (Cheyne et al., 2010). Perhaps natural hill and swamp forests are less suitable for Sunda stink-badger than are relatively degraded lowland habitats (Feuilletau-de Bruyn, 1933; Payne et al., 1985). The latter are rapidly being converted to oil palm plantations and more study is warranted.

West Kalimantan, Indonesia. Most of West Kalimantan is predicted to be unsuitable. The species remains unrecorded in the Gunung Palung National Park in Kayong Utara Regency, despite 30 years of mammal surveys (Blundell, 1996; A. J. Marshall, pers. comm.). However, there are at least two regions where Sunda stink-badger might occur in this province: the Sungai Melawi area (Melawi and Sintang Regencies) and southern Ketapang Regency.

In the Sungai Melawi area, the American Museum of Natural History collected a specimen from the Sintang area in the lower catchment (Medway, 1977), while Smit & Budiman (2010) noted local interviews indicating the species's occurrence in a non-forested area issued for oil palm plantation. In the Schwaner mountains, Central Kalimantan, HS visited from 2010 to 2012 a logging concession staffed by workers from the middle Sungai Melawi region, West Kalimantan. These workers called the species 'kensoduk' in the local Limbai language and reported it to be common in their rubber gardens in the middle Melawi region (Samejima & Semiadi, 2012).

In southern Ketapang Regency, Abbott (in Lyon, 1911) noted this species as well known among the locals along the Sungai Kendawangan, although the area is only about 100 km south of Gunung Palung where it has not been recorded by high recent effort (see above). HS visited another logging concession in the Ketapang Regency near the boundary with Central Kalimantan in 2012 and interviewed the workers about this species. Many of them come from surrounding villages and knew Sunda stink-badger as 'tlenseduk' in the local Kayong language.

In sum, this species seems to have a patchy distributional pattern in unprotected lowland areas in the province. Specification of Sunda Stink-badger distribution, especially in these two regions, would improve the ability to conserve the local population.

Research priorities. The Sunda stink-badger is somewhat of an enigma, with very limited understanding of what determines its patchy distribution (Meijaard & Wilting, 2012). Five hypotheses might explain its apparently patchy distribution with high densities in some locations but large intervening areas with very low densities or no populations at all. Testing these and other potential hypotheses requires research in different locations stratified according to levels of climate, habitat disturbance, soil characteristics and hunting pressure. Because this species is easily distinguished by locals based on its unique morphology and strong odour, wide-scale interview surveys can assist in such research. Studies should preferably include other parts of the species's range, such as Java and Sumatra, to help elucidate its distributional ecology.

General conservation priorities and potential starting points. Without understanding what determines the species's distribution and densities, it is difficult to recommend specific conservation actions. The main short-term priority is to determine how the species is affected by forest degradation, deforestation, plantation development and hunting, accepting that its response might vary locally. Once that is better understood, more specific recommendations can be given regarding the need – if any – for forest protection, landscape-level design of land use patterns that consider species ranging needs, and – if appropriate – the need for comprehensive listing of the species as protected and the enforcement of hunting bans and/or quotas.

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