Predicted distribution of the marbled cat *Pardofelis marmorata* (Mammalia: Carnivora: Felidae) on Borneo

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

Abstract. Little is known about the ecology of the rare marbled cat *Pardofelis marmorata* on Borneo. In addition, the little information that is available on the species often comes from incidental sightings. Here we use the MaxEnt algorithm to produce a habitat suitability map for this species based on a compilation of existing data. We collected 105 marbled cat occurrence records for Borneo, of which 27 (Balanced Model) or 69 (Spatial Filtering Model) were used to estimate potential habitat suitability. The resulting relative habitat suitability map showed key conservation areas in Borneo. According to these results it appears that the most suitable habitats for marbled cat are lowland forests, but these forests are most threatened by deforestation and other anthropogenic activities. It is imperative to develop appropriate conservation strategies for the marbled cat on Borneo, including long-term research and monitoring, reduction of human disturbances in lowland forests, increased data-sharing and research networking, and stakeholder involvement for conservation planning and activities.

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

Abstrak (Bahasa Indonesia). Sangat sedikit informasi tentang ekologi Kucing Batu *Pardofelis marmorata* di Borneo. Informasi Kucing Batu sering diperoleh dari pengamatan yang tidak disengaja. Pada paper ini kami menggunakan pemodelan MaxEnt untuk membuat peta sebaran Kucing Batu berdasarkan data yang telah terkumpul. Kami mengumpulkan 105 catatan keberadaan Kucing Batu di Borneo, dimana 27 (Model Penyeimbang) atau 69 (Model Spasial Tersaring) catatan tersebut digunakan untuk membuat peta kesesuaian habitat. Hasil dari peta prediksi kesesuaian habitat diperoleh beberapa kawasan konservasi kunci di Borneo. Berdasarkan hasil ini tampak bahwa habitat terbaik untuk Kucing Batu adalah hutan dataran rendah, tetapi kawasan hutan ini adalah kawasan yang paling terancam oleh kegiatan deforestasi dan gangguan aktivitas manusia. Sangat penting untuk mengembangkan strategi yang tepat untuk pelestarian Kucing Batu di Borneo termasuk di antaranya penelitian dan pemantauan jangka panjang, pengendalian gangguan manusia terhadap hutan dataran rendah, peningkatan kegiatan berbagi data dan jaringan kerjasama penelitian, serta keterlibatan pemangku kepentingan untuk perencanaan kegiatan konservasi.

Abstrak (Bahasa Malaysia). Sangat sedikit yang diketahui berkenaan ekologi Kucing Dahan *Pardofelis marmorata* di Borneo. Selain itu, maklumat yang sedikit yang terdapat berkenaan spesis ini selalu diperolehi melalui pemerhatian yang secara kebetulan. Dalam kajian ini, kami menggunakan MaxEnt untuk menghasilkan peta kesesuaian habitat untuk spesis ini berdasarkan kompilasi rekod yang sedia ada. Kami mengumpul sejumlah 105 rekod Kucing Dahan di Borneo, yang mana 27 rekod (Model Seimbang) dan 69 rekod (Model yang ditapis secara spasial) telah diguna untuk meramal kesesuaian habitat. Hasil daripada peta ramalan kesesuaian habitat menunjukkan beberapa kawasan pemuliharaan yang penting di Borneo. Berdasarkan ramalan ini , didapati bahawa habitat yang paling sesuai untuk Kucing Dahan adalah kawasan hutan tanah pamah, tetapi kawasan hutan ini juga adalah yang paling terancam dengan kegiatan penebangan hutan dan aktiviti-aktiviti antropogenik yang lain. Oleh itu, adalah penting untuk menghasilkan strategi pemuliharaan yang sesuai untuk Kucing Dahan di Borneo, termasuk penyelidikan dan pemantauan jangka panjang, mengurangkan gangguan manusia di hutan tanah pamah, meningkatkan perkongsian data dan rangkaian penyelidikan, dan penglibatan pihak-pihak yang berkepentingan dalam perancangan dan aktiviti pemuliharaan.

INTRODUCTION

The marbled cat *Pardofelis marmorata* (Martin), has a coat pattern similar to that of the clouded leopard *Neofelis* (Curvier), with cloud-like markings and a very long tail (Fig. 1A). They also have similar coloration. However the marbled cat has less distinct black-edged blotches on the sides of its body, and numerous black spots on the legs. Because of the morphological similarity, the marbled cat and clouded leopards were previously grouped under the genus *Pardofelis* Severtzov, by many authors (e.g., Groves, 1982; Corbet & Hill, 1992). However, recent genetic analyses showed the marbled cat to be distinct from the clouded leopards, so the genus *Neofelis* Gray, was reinstated for the latter (Johnson et al., 2006; O'Brien & Johnson, 2007). Three subspecies have been described: *P. m. marmorata* (Martin), from Sumatra, Borneo and possibly the Thai–Malay peninsula; *P. m. longicaudata* (Blainville), from South-east Asia, possibly only north of the Isthmus of Kra, and *P. m. charltonii* (Gray), from Nepal to Myanmar. Often *P. m. longicaudata* is included within *P. m. marmorata* so only two subspecies are recognised (Ellerman & Morrison-Scott, 1951). Recent molecular data indicate a split between marbled cats north and south of the Isthmus of Kra, but more data would be needed for a taxonomic revision (Luo et al., 2014). The species ranges in weight from 2 to 8 kg, with a head-and-body length of 450–550 mm, a tail length of 350–500 mm, and a hind foot length of 118–122 mm (Lekagul & McNeely, 1977; Payne et al., 1985; Yasuma, 1994). A single radio-collared individual, studied for one month in Thailand, exhibited a home range of roughly 5.3 km² (Grassman et al., 2005). The species's diet is thought to include arboreal animals such as squirrels, fruit bats and birds, in addition to terrestrial prey such as mice, rats, fish, reptiles, frogs and insects (Banks, 1949; Payne et al., 1985).

The IUCN Red List of Threatened Species has categorised the marbled cat as Vulnerable since 2002 (Grassman et al., 2008), and it is listed on Appendix I of CITES. Many countries also list the marbled cat as a nationally protected species. In Indonesian and Malaysian Borneo (states of Sabah and Sarawak), the marbled cat is fully protected by the Government of the Republic of Indonesia Regulation No. 7 (1999), the Sabah Wildlife Conservation Enactment (1997) and the Sarawak Wild Life Protection Ordinance (1998). However, there is no legal protection outside protected areas in Brunei Darussalam (Brunei Wild Life Protection, 1978). Even though the marbled cat is protected almost throughout its Bornean range, it is occasionally hunted for its meat and pelt (Fig. 1B).

Historical and recent records indicate that marbled cat is a rare species, and therefore little is known about population
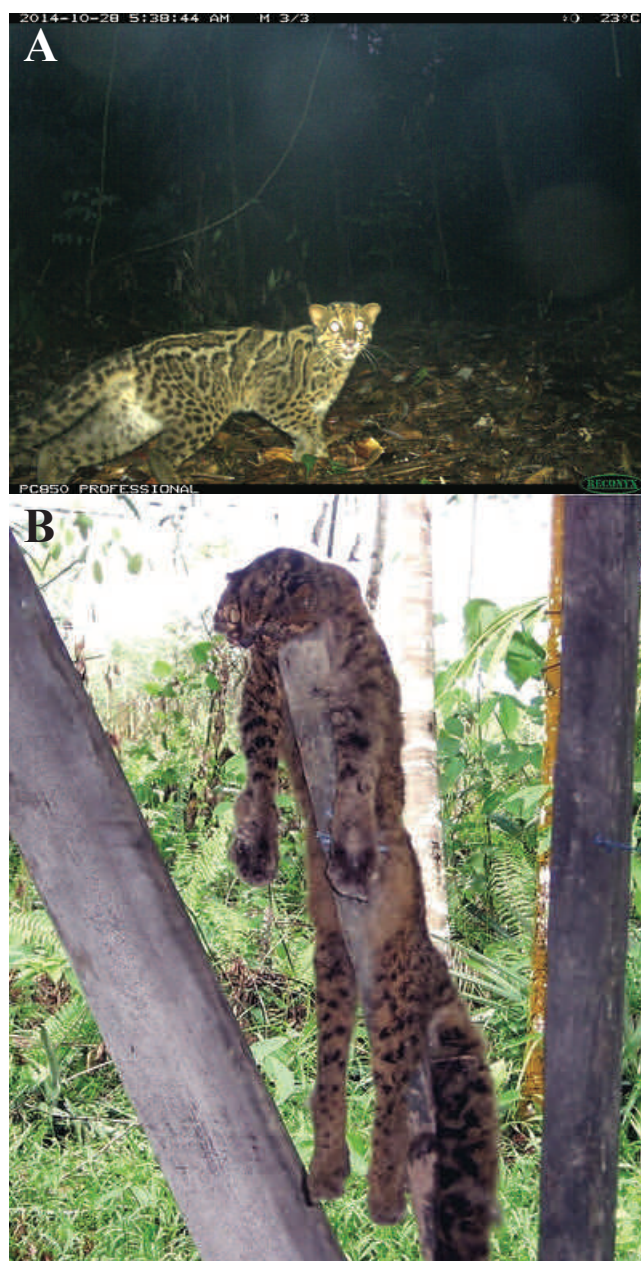

Fig. 1. A, marbled cat *Pardofelis marmorata* camera-trapped in Deramakot Forest Reserve, Sabah Malaysia on 28 October 2014; B, marbled cat hunted in eastern Sarawak for its meat and pelt. (Photograph by: A. Mohamed/IZW, SFD [A]; Kelvin Egay [B]).

densities, home range size or dispersal patterns (Nowell & Jackson, 1996; Duckworth et al., 1999; Holden, 2001; Sunquist & Sunquist, 2002; Grassman et al., 2005; Azlan & Sharma, 2006; Lynam et al., 2006; Mishra et al., 2006; Yasuda et al., 2007; Mohamed et al., 2009; Bernard et al., 2013). There are rather few locality records of this species (Nowell & Jackson, 1996; Sunquist & Sunquist, 2002; Povey et al., 2009; Ross et al., 2010; Bernard et al., 2012, 2013; Breitenmoser et al., 2014), particularly on Borneo. Most of the information on natural history and distribution of the species comes from opportunistic records including specimen collections (Brongersma, 1935; Medway, 1977), information from individuals kept in captivity (Sunquist & Sunquist, 2002), camera-trapping (Augeri, 2005; Yasuda et al., 2007; Ross et al., 2010; Brodie & Giordano, 2011;

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Cheyne & Macdonald, 2011; Bernard et al., 2012, 2013; Samejima & Semiadi, 2012; Samejima et al., 2012), and sightings (Mohamed et al., 2009). In this paper we use the MaxEnt niche distribution modelling algorithm to make predictions regarding the possible distribution of this species on Borneo. This information is valuable for the future planning and implementation of conservation strategies for the species on Borneo.

RESULTS AND DISCUSSION

Species occurrence records. The 105 historical and recent records of the marbled cat from across Borneo that were gathered included 64 recent records collected between 2001 and 2011 (Table 1; Fig. 2), of which fifty had high precision (within 2 km, Category 1). These high-precision records were photographs or direct sightings with known geographic coordinates. Most of the high-precision records were collected from Sabah, Malaysia, but a few were also obtained from Brunei Darussalam, Sarawak (Malaysia), North Kalimantan, East Kalimantan, Central Kalimantan, and West Kalimantan (all Indonesia). Twenty-five records were excluded from the modelling because their spatial precision was too low (above 5 km; Categories 4 and 5). Because of survey-effort bias, only 27 (Balanced model = M_1) or 69 (Spatial Filtering Model = M_2) records were used for modelling.

Habitat associations. The 10 respondents of the land-cover questionnaire were highly consistent in their assessment of land-cover classes suitable for the marbled cat (Table 2). Perceived suitable habitat coverage for the species included lowland forest, upland forest, lower montane forest and swamp forest. Disturbed areas, including old and young plantations, burnt forest, mixed crops, fishponds and bare land, were considered unsuitable (Table 2). Although several records were above 1000–1300 m a.s.l. (Mathai et al., 2016; J Hon, unpublished data), overall status in upper montane forest remains poorly known. Similar, more research in forest mosaic/lowland forest, forest mosaic/upland forest, mangrove, and old plantation, would allow more informed assessment of the suitability of these land-cover classes for marbled cats.

Habitat suitability index (HSI) model. The species distribution model (see Kramer-Schadt et al. (2016) for methods) predicted that the marbled cat is widely distributed on Borneo. The interior of the island, relatively less accessible to people and therefore largely forested, is predicted to be highly suitable habitat for the marbled cat. In contrast, the suitable habitats predicted in the lowlands are much more fragmented, because of habitat destruction through logging, agriculture and plantation expansion, and other human activities. Fig. 3 shows the current predicted distribution and the following important localities and conservation actions have been suggested.

Although historical and recent records are more numerous from Sabah, the lower number of occurrence records from Kalimantan does not mean that no suitable habitat exists for the marbled cat in Indonesian Borneo. Rather, this is

a result of the paucity of studies in Kalimantan. The few available presence records from Kalimantan are from studies in Gunung [=Mount] Niyut, Gunung Palung, Betung Kerihun, Sungai Wain, Bukit Soeharto, Wehea and Kayan Mentarang, conservation areas that are protected by the Indonesian government (Fig. 3). In general, 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).

Brunei Darussalam. Temburong forest in Brunei Darussalam consists of a large portion of lowland tropical forest predicted to be very important for the marbled cat. The border of the Belait district with Sarawak was also predicted to be suitable.

Sarawak, Malaysia. Sarawak has one of the highest levels of deforestation on Borneo, with at least 1.2 million ha of forest cover lost in the past two decades (Tsuyuki et al., 2011). As a result, the suitable habitat predicted for the marbled cat in Sarawak is highly fragmented with scattered suitable areas from southern Temburong forest in Brunei Darussalam to the centre of Sarawak. The highly suitable areas were in north-eastern Sarawak near the Brunei Darussalam border including Paya–Maga Forest Reserve, the Pulong Tau National Park complex (including Batu Lawi, Tama Abu range and around the Kelabit highlands), around Gunung Mulu National Park, and part of Apad Lunan Forest Reserve. In addition, in the centre of Sarawak, the Hose–Laga complex, Bakun catchment area, Anap–Muput Forest Management Unit, and Lanjak Entimau Wildlife Sanctuary were predicted to be suitable habitat. This area is a transboundary conservation area with Betung Kerihun National Park in West Kalimantan. Recent camera-trap surveys photographed this cat near Pelagus National Park in Central Sarawak (Mohd-Azlan, pers. comm.), Mulu National Park, Pulong Tau National Park, the Ulu Baram region (Mathai et al., 2010; JF Brodie, unpublished data), and Paya Maga at 1300 m a.s.l. (J Hon, unpublished data).

Sabah, Malaysia. Within Sabah, predicted marbled cat habitat and priority conservation areas extend from the northern portions of the Sungai [=River] Kinabatangan to Maliau Basin, Deramakot Forest Reserve to Danum Valley forest, and two groups of forested area, Tabin–Kulamba–

Table 1. Summary of the occurrence records for marbled cat *Pardofelis marmorata* 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	50	14	46	50
Category 2 500 m – 2 km	4	1	3	3
Category 3 2–5 km	26	12	20	7
Category 4 above 5 km	11	-	-	2
Category 5 (no coordinates*)	14	-	-	2
Total	**105**	**27**	**69**	**64**

M_1 = Balanced Model; M_2 = Spatial Filtering Model (2 km); *only coarse location description was available

Table 2. Land-cover reclassification for marbled cat *Pardofelis marmorata* based on the questionnaire results of 12 respondents working on carnivores on Borneo.

Land-cover Class	Mean of Reclassification	Range of Reclassifications
Lowland forest	3.50	3–4
Upland forest	3.22	2–4
Lower montane forest	2.44	1–4
Upper montane forest	1.56	0–4
Forest mosaics/lowland forest	1.98	*
Forest mosaics/upland forest	1.90	#
Swamp forest	2.00	0–4
Mangrove	1.33	0–3
Old plantations	1.13	0–3
Young plantations and crops	0.22	0–2
Burnt forest area	0.56	0–3
Mixed crops	0.44	0–2
Bare area	0.00	0–0
Water and fishponds	0.10	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).

Kretam and Ulu Kelumpang – Tawau hills in eastern Sabah. Several recent studies detected marbled cat in Deramakot Forest Reserve (Mohamed et al., 2009; Samejima et al., 2012), Tabin Wildlife Reserve (Yasuda et al., 2007; Bernard et al., 2012; Gardner et al., 2014), Imbak Canyon Conservation Area (Bernard et al., 2013), Danum Valley (Ross et al., 2010) and Maliau Basin (Brodie & Giordano, 2011). An eight-month camera-trapping survey in Tabin Wildlife Reserve, which also included small forest patches (5–27 ha) located up to 1.7 km inside oil palm plantations, did not detect the marbled cat in the oil palm landscape (Bernard et al., 2014). Similar results were obtained in oil palm plantations near Ulu Segama forest reserve, Madai–Baturong, and Ulu Kalumpang forest reserves in central Sabah (Yue et al., 2015). These findings suggest that oil palm plantations might not comprise suitable habitat for the marbled cat.

East Kalimantan and North Kalimantan, Indonesia. A high proportion of suitable habitat predicted in Borneo is located in East and North Kalimantan provinces extending from the lowland forests in the centre of East Kalimantan including Muara Kaman Sedulang Forest Reserve to Wehea Protection Forest, Berau district forest including Kelay and Segah forest to the southern sections of the Sungai Kayan. Further, the Kayan Mentarang National Park to the north of the Malinau basin in North Kalimantan was predicted to be suitable for the marbled cat. This large National Park forms a transboundary forest block with areas in Sabah
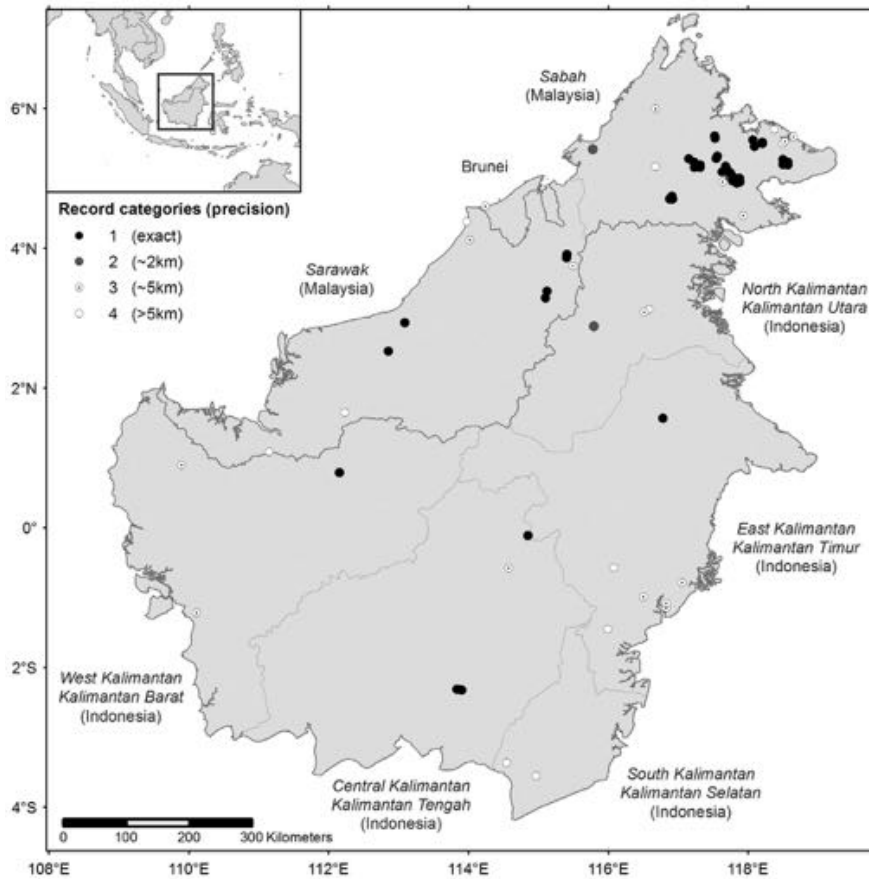
Fig. 2. Location of marbled cat *Pardofelis marmorata* occurrence records on Borneo with categories of spatial precision as well as countries and state boundaries.
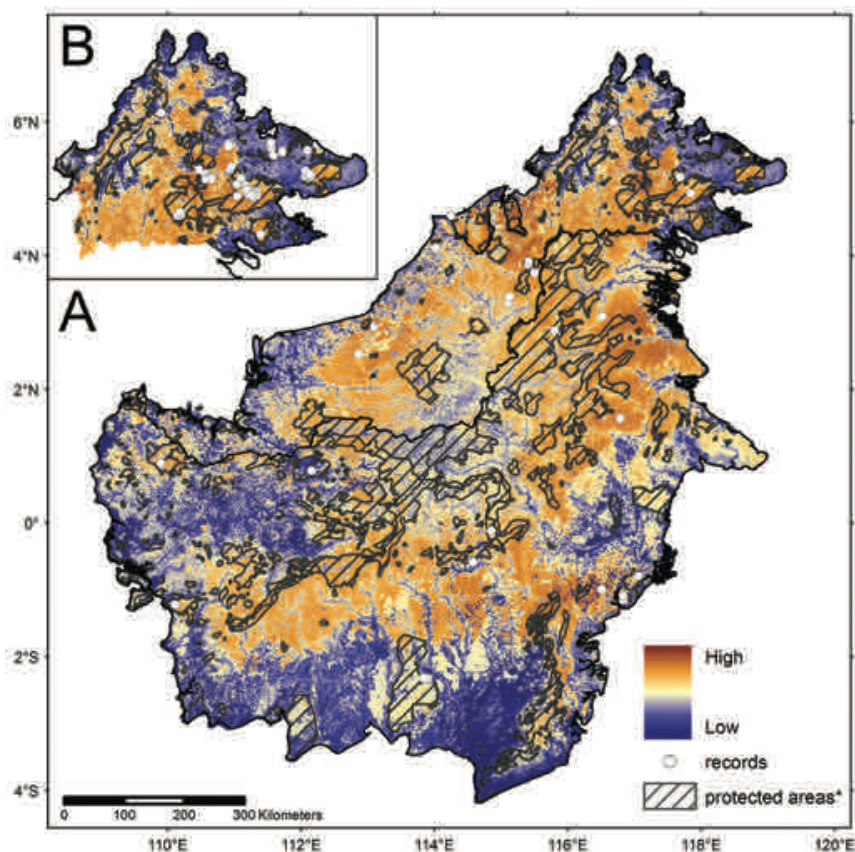

Fig. 3. Predictive Habitat Suitability Index (HSI) models for marbled cat *Pardofelis marmorata* including location records used in models. A, Balanced Model for the island of Borneo; B, Spatial Filtering Model for Sabah, Malaysia. Sources for protected area information: see Kramer-Schadt et al. (2016).

and Sarawak. However, this area is not protected at all and is under strong pressure for development from oil palm plantations, timber concessions, and other economic interests. Additional areas predicted to contain suitable habitat for the marbled cat include Tanjung Mangkalihat and Kutai National Park. Recent camera-trap photographs come from Sungai Wain Protection Forest (GM Fredriksson, pers. comm.), Wehea Protection Forest (B. Loken & Kasyanto, pers. comm.) and Long Hubung, Kutai Barat district (H Samejima, unpublished data).

South Kalimantan, Indonesia. Much of South Kalimantan was predicted to be unsuitable for marbled cat, although this perhaps reflects more the difficulty of modelling in data-poor areas than a real unsuitability (see above). The only suitable habitat predicted was around the Meratus mountains. Wildlife surveys in this province are very rare and intensive surveys are would allow a better understanding of local marbled cat distribution.

Central Kalimantan, Indonesia. In Central Kalimantan the areas of habitat predicted to be highly suitable for the marbled cat were in the northern part of the province. Recent marbled cat records come from Sabangau National Park and the surrounding forest (Cheyne & Macdonald, 2011) and the Schwaner mountains (Samejima & Semiadi, 2012). This area is thought to be a high conservation priority for the marbled cat in Central Kalimantan, as well as the Seruyan–Katingan, which lies south of the Schwaner mountains. Tanjung Puting National Park was also predicted as important habitat for the species in Central Kalimantan.

West Kalimantan, Indonesia. The lowland forests of West Kalimantan have been increasingly degraded since the 1970s. Heavy logging continued until recently. A new decentralisation regulation in 2001 allowed local districts to issue small logging parcels and permits for oil palm plantations. At least 56% (29,000 km^2) of lowland forest was lost in protected forests in West Kalimantan between 1985 and 2001 (Curran et al., 2004). The marbled cat was recorded in Gunung Niyut, Gunung Palung and Bukit Perai – Bukit Rongga, but the spatial analysis predicted a large amount of this province to comprise unsuitable habitat. The extent of forest degradation in this region limits the area of predicted suitable habitat, although studies in the region are also limited, which increases uncertainty in model predictions.

RESEARCH AND CONSERVATION PRIORITIES

A better understanding of marbled cat ecology and distribution in Borneo requires long-term research and monitoring. The map of the predicted habitat suitability (Fig. 3) can be used to guide for further research, particularly in-depth ecological studies using methods such as camera-trapping, radio telemetry and GPS tagging.

Current records suggest that the marbled cat is strongly dependent on forest, and almost all areas that are predicted to be highly suitable have extensive forest cover (Fig. 3).

Consistent with this, Grassman et al. (2005) in Thailand that concluded that the marbled cat is dependent on forest cover.

Because a large proportion of the habitat predicted to be suitable is in protected areas, appropriate management of these areas is vital for preserving the marbled cat. In addition the habitat suitability maps also predicted production forest and other forested areas to be suitable. Therefore, incentives for concessionaires to manage their forests sustainably will increase the habitat available for this species. The intensive pressure on wildlife habitat from plantations, mining and settlements needs to be minimised. In Borneo, changes of land-cover, excessive hunting, loss of microhabitats, reduction of critical resources such as food, shelter, mating and nesting sites, are major causes of decreases in wildlife populations (Meijaard et al., 2006; Fuller et al., 2010). Management and legislation are needed also to establish protected habitat corridors that link the existing protected areas in Borneo together, so that wildlife such as the marbled cat can disperse between them and thereby retain high population viability.

Management to reduce human disturbance in forest areas is essential, including preventing forest fires, poaching, illegal logging and illegal settlement at a regional scale, especially in conservation priority habitat. Research networking and commitment of stakeholders and local governmental authorities are needed to prepare and implement policies to conserve important habitats of the species. In addition, local awareness programmes for government staff and local people are needed to highlight the conservation problems of the marbled cat and other threatened wildlife species.

Relevant management measures should be supported by a comprehensive policy direction that incorporates inputs from all key stakeholders. The four key policy directions are (i) restoration of degraded ecological forest corridors/habitat, (ii) strengthening of the protection mechanism to prevent illegal conversion and encroachment, (iii) securement of land important for long-term dispersal of this species, and (iv) sustainable financing and management of the High Conservation Value Forest (HCVF) in and around the potential habitat of this species. These policies should become the guidelines for a detailed management plan to be implemented jointly by the governments of Malaysia, Brunei Darussalam, and Indonesia with support from key stakeholders (plantations, tourism industries, local communities and local NGOs).

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