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Modelling Distribution of *Onthophagus* Species (Coleoptera: Scarabaeidae) in Sarawak

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ABSTRACT

Dung beetles (Genus: *Onthophagus*) are members of the family Scarabaeidae and the subfamily Scarabaeinae. Despite their small size and unattractive appearance, dung beetles play an important role in the ecosystem, and they are widely recognised as one of the most effective bioindicators of ecosystem health. Although there has been an increase in dung beetle studies in Peninsular Malaysia, there are very few ecological studies of dung beetles conducted in Sarawak, despite being the largest state of Malaysia. Therefore, this study aims to provide recent information on the distributions of dung beetles from the genus *Onthophagus* in Sarawak. A total of 32 occurrences data for eight selected *Onthophagus* species representing 11 localities were successfully recorded. All analyses were performed using the Maximum Entropy Modelling Version 3.4.4 (MaxEnt) and Quantum Geographic Information Systems 3.28.2 (QGIS) software. It is revealed that most dung beetles' distributions are strongly influenced by temperature and precipitation which suggests its capabilities as a bioindicator to identify high biodiversity areas. In conclusion, this study could be beneficial to identify the potential hotspot areas for biodiversity conservation and effective management practices in Sarawak.

Keywords: Coleoptera, distribution, dung beetles, modelling, Sarawak

INTRODUCTION

Sarawak is known for its mega biodiversity with distinct ecosystems, of which its forests vary from typical hill mixed dipterocarp forest, peat swamp forest, and mangrove forest to heath forest, montane forest, and limestone forest (Hazebroek & Abang Kashim, 2000; Forest Department Sarawak, 2020). This emphasises the diversity and abundance of species-rich organisms, particularly insects. Beetles under the class Insecta, are well-adapted to both terrestrial and freshwater environments. They can survive in a variety of environments due to their diverse range of feeding behaviours (Krinsky, 2002). Even so, some beetles are highly sensitive to disturbance such as the dung beetles (Kakkar & Gupta, 2010).

Dung beetles from the genus *Onthophagus*, classified under the subfamily of Scarabaeinae (Bosuang *et al.*, 2017) are also known as dung chafers and tumblebugs (Gaur *et al.*, 2020). These scarab beetles can be distinguished through their distinctive antennae that end in three flattened plates that form a club, which are mostly dull black and some are metallic green (Triplehorn & Johnson, 2005; Gaur *et al.*, 2021). According to Howden and Cartwright (1963), over 1400 *Onthophagus* species have been described globally, with approximately 332 species recorded from Asia.

Despite their small size and unattractive appearance, dung beetles play important roles in the ecosystem as the most effective bioindicators of environmental and landscape changes (Davis *et al*., 2001; Saleh *et al.*, 2014; Goh & Hashim, 2019; Djamel *et al.*, 2021). Their occurrences are assumed to be associated with the presence of other vertebrates through droppings, of which the scarab beetles functioning as decomposers (Kakkar & Gupta, 2010; Goh & Hashim, 2019). In addition, they also play significant roles in other ecological functions from soil aeration and seed dispersal to plant growth and pollination services (Nichols *et al.,* 2008).

However, dung beetles are not legally protected in Malaysia and are not as charismatic as other insects such as lepidopterans. Furthermore, Goh and Hashim (2019) stated that the proper classification of dung beetles under the IUCN Red List is restricted by the lack of population-based studies and the unknown geographical ranges of most species. For instance, some beetles are typically endemic to a specific area, such as *Thorectes valencianus* which is endemic to south-east Spain and listed as 'Vulnerable' in the IUCN Red List of Threatened Species (Verdú & Ruiz, 2014).

Although there has been an increase in dung beetle studies conducted in Peninsular Malaysia (Aruchunnan *et al.*, 2016), there is little to no database on the distributions of dung beetles reported from Sarawak. Therefore, this study aims to provide recent information on the distribution of dung beetles from the genus *Onthophagus* in Sarawak.

MATERIALS AND METHODS

Input Data

A compilation record of occurrences of eight selected *Onthophagus* species from the UNIMAS Insect Reference Collection (UIRC), Faculty of Resource Science and Technology, Universiti Malaysia Sarawak and published articles were included in this study (Table 1). Those species were selected based on their presence in at least more than one locality to provide a better and more accurate distribution mapping of the species. A total of 11 localities within Sarawak, with at least more than one record per species, were obtained. The localities were initially geocoded using Google Earth to obtain respective geographical coordinates prior to the analysis. As for the environmental input, 19 bioclimatic variables (average for the years 1970-2000) with the highest spatial resolution of 30 seconds were retrieved from the WorldClim database (Table 2).

Table 1. The record of occurrences of eight *Onthophagus* species in Sarawak

Species	Localities	Division	Year	Latitude	Longitude	References
O. semiaureus	Mount Mulu	Miri	2008	4.0458°	114.93°	Krikken & Huijbregts (2008)
	Fairy Cave	Kuching	2021	1.3817°	110.1171°	UIRC
	Gunung Gading	Kuching	2021	1.7356°	109.8335°	UIRC
	Real Living Lab, UNIMAS	Samarahan	2021	1.4660°	110.4486°	UIRC
	Kampung Serpan Laut, Asajaya	Samarahan	2021	1.5478°	110.6012°	UIRC
	Sabal Agroforestry Centre	Samarahan	2021	1.0692°	110.9098°	UIRC
	Samunsam Wildlife Sanctuary	Kuching	2021	1.7222°	109.7848°	UIRC
	Sebangkoi, Sarikei	Sarikei	2021	1.9591°	111.4323°	UIRC
	Niah National Park	Miri	2022	3.8006°	113.7842°	UIRC
O. sarawacus	Mount Mulu	Miri	2008	4.0458°	114.93°	Krikken & Huijbregts (2008)
	Baram River	Miri	2013	4.5636°	114.0717°	Kishimoto-Yamada *et al*. (2013)
	Kampung Serpan Laut, Asajaya	Samarahan	2021	1.5478°	110.6012°	UIRC
	Sabal Agroforestry Centre	Samarahan	2021	1.0692°	110.9098°	UIRC
	Sebangkoi, Sarikei	Sarikei	2021	1.9591°	111.4323°	UIRC
O. aurifex	Lambir Hills National Park	Miri	1999	4.3133°	114.0125°	Sakai & Inoue (1999)
	Mount Mulu	Miri	2008	4.0458°	114.93°	Krikken & Huijbregts (2008)
	Baram River	Miri	2013	4.5636°	114.0717°	Kishimoto-Yamada *et al*. (2013)
	Real Living Lab, UNIMAS	Samarahan	2021	1.4660°	110.4486°	UIRC
O. vulpes	Mount Mulu	Miri	1983	4.0458°	114.93°	Hanski (1983)
	Lambir Hills National Park	Miri	1999	4.3133°	114.0125°	Sakai & Inoue (1999)
	Baram River	Miri	2013	4.5636°	114.0717°	Kishimoto-Yamada *et al*. (2013)
	Sebangkoi, Sarikei	Sarikei	2021	1.9591°	111.4323°	UIRC
O. rudis	Baram River	Miri	2013	4.5636°	114.0717°	Kishimoto-Yamada *et al*. (2013)
	Kampung Serpan Laut, Asajaya	Samarahan	2021	1.5478°	110.6012°	UIRC
	Sabal Agroforestry Centre	Samarahan	2021	1.0692°	110.9098°	UIRC
O. semicupreus	Baram River	Miri	2013	4.5636°	114.0717°	Kishimoto-Yamada *et al*. (2013)
	Kampung Serpan Laut, Asajaya	Samarahan	2021	1.5478°	110.6012°	UIRC
	Sabal Agroforestry Centre	Samarahan	2021	1.0692°	110.9098°	UIRC
O. deliensis	Gunung Gading	Kuching	2021	1.7356°	109.8335°	UIRC
	Lambir Hills National Park	Miri	2021	4.3133°	114.0125°	UIRC
O. waterstradti	Lambir Hills National Park	Miri	1999	4.3133°	114.0125°	Sakai & Inoue (1999)
	Baram River	Miri	2013	4.5636°	114.0717°	Kishimoto-Yamada *et al*. (2013)

Table 2. The 19 bioclimatic variables retrieved from the WorldClim Database

Code	Bioclimatic variables
BIO 1	Annual mean temperature
BIO 2	Mean diurnal range (mean of monthly (max temp – min temp)
BIO 3	Isothermality (BIO1/BIO2) (*100)
BIO 4	Temperature seasonality (standard deviation*100)
BIO 5	Max temperature of warmest month
BIO 6	Min temperature of the coldest Month
BIO 7	Temperature annual range (BIO5 – BIO6)
BIO 8	Mean temperature of wettest quarter
BIO 9	Mean temperature of driest quarter
BIO 10	Mean temperature of warmest quarter
BIO 11	Mean temperature of coldest quarter
BIO 12	Annual precipitation
BIO 13	Precipitation of wettest month
BIO 14	Precipitation of the driest month
BIO 15	Precipitation seasonality (Coefficient of Variation)
BIO 16	Precipitation of the wettest quarter
BIO 17	Precipitation of the driest quarter
BIO 18	Precipitation of the warmest quarter
BIO 19	Precipitation of the coldest quarter

Species Distribution Modelling

The distribution of *Onthophagus* species was predicted using Maximum Entropy Modelling Version 3.4.4 (MaxEnt) using presence-only data (Phillips *et al.*, 2006). The 'auto features' option was chosen as this will automate the task of selecting feature types using an empirical algorithm based on the number of presence records for the species (Phillips *et al.*, 2006), whereas all other parameters were set at default. According to Elith *et al*. (2010), when comparing species occurrences in different environments, a prevalence of 0.5 is assumed, indicating the equivalence of species presence and absence. The locations where species were found were then compared to the various environments within the study area. The outputs were imported into the Quantum Geographic Information Systems 3.28.2 (QGIS) to map out the distribution of each of the *Onthophagus* species.

Model Evaluation

Interpretation of the distribution map is based on a probability score ranging from 0 indicated by the blue hue (low probability of presence) to 1 indicated by the red hue (high probability of presence). To assess the model performance, the receiver operating characteristic (ROC) curve was generated. The main advantage of ROC analysis is that the area under the ROC curve (AUC) provides a single measure of model performance, independent of any choice of threshold (Phillips *et al*., 2006). The AUC values may vary from 0 to 1, where a score of 1 indicates perfect discrimination (Elith *et al.*, 2006). In general, an AUC value greater than 0.7 is considered potentially significant, while a value lower than 0.5 indicates that the model performance is worse than a random prediction.

RESULTS AND DISCUSSION

A total of 32 occurrences for eight *Onthophagus* species representing 11 localities were successfully recorded. The species with the most occurrences was *Onthophagus semiaureus* (nine sites), followed by *O. sarawacus* (five sites), *O. aurifex* and *O. vulpes* (four sites), *O. rudis* and *O. semicupreus* (three sites), whereas *O. deliensis* and *O. waterstradti* with two sites, respectively. In this study, only eight out of 29 *Onthophagus* species in Sarawak (Hanski, 1983; Sakai & Inoue, 1999; Krikken & Huijbregts, 2008; Kishimoto-Yamada *et al.,* 2013; UNIMAS Insect Reference Collection, 2022) were evaluated for the model prediction due to data deficiency. In order to have reliable prediction modelling, it is recommended that a minimum of five occurrences are required for each species (Nur Azizuhamizah *et al.*, 2020). However, Kadmon *et al.* (2003) stated that few records may suffice to characterise distributions of species with narrow environmental tolerance as compared to those with broader tolerance.

The distribution map of *O. semiaureus* (Figure 1a) showed that it is the most widely distributed species among others in this study. The predicted distribution for the species appears to be high in the coastline areas of Kuching and Mukah. However, the species showed a lower probability of presence in areas of Kapit and Miri which is indicated by the light blue hues. The maximum entropy model (MaxEnt) showed that the environmental parameters with the most significant impact towards the presence of *O. semiaureus* are BIO 17 (60.6%), BIO 15 (38.2%), and BIO 13 (0.7%). The environmental variables that are significant towards the distribution of *O. semiarureus* correlated with precipitation indicating they have a higher tolerance towards temperature changes. The distribution model is supported by an AUC value of 0.86.

As for *O. sarawacus* (Figure 1b) showed a high probability of presence especially in the southern (Kuching) and northern (Limbang) regions of Sarawak (Figure 1d). The species is also predicted to be present in areas of Serian, Mukah and Miri divisions indicated by the light red hues. Additionally, there is a 0.5 probability of the presence of the species in the central region (Sri Aman, Sarikei, Sibu and Miri) of Sarawak. Based on the maximum entropy model (MaxEnt), the environmental variable with the highest gain when used in isolation and the variable that decreases the gain the most when it is omitted for *O. sarawacus* is BIO 14 (100%), which therefore appears to have provided the most useful information towards the environmental preference of the species. The AUC value for the distribution model showed a performance value of 0.85.

The predicted distribution map for *O. aurifex* (Figure 1c) showed that it is one of the widely distributed species in Sarawak. The areas which are particularly habitable for the species are the coastline areas of Kuching, Mukah, Miri and Limbang which are indicated by the red hues. However, large areas of Serian, Samarahan, Sri Aman, Betong, Sarikei, Sibu and Bintulu only have a 0.5 probability of presence for the species. From the analysis of variable contributions in MaxEnt, BIO 17 (55.2%), Bio 2 (24.4%) and BIO 14 (20.4%) are the variables which have the most significant impact towards their distribution. The environmental variable with the highest gain, when used in isolation, is BIO 17, which therefore has the most useful information by itself. On the other hand, the environmental variable that has the most information that is not present in the other variables is BIO 14 as it decreases the gain the most when it is omitted. The AUC value for the distribution model showed a value of 0.91.

The potential distribution of *O. vulpes* is shown in Figure 1d. It is predicted that the species have a high probability of presence at Limbang and a 0.5 probability of presence in areas such as Serian, Sri Aman, Sarikei and Miri which are indicated by the green hues. There are only two environmental variables contributing to the maximum entropy model (MaxEnt), which are BIO 12 (74.1%) and BIO 17 (25.9%). The environmental variable with the highest gain when used in isolation and the variable that decreases the gain the most when it is omitted for *O. vulpes* is BIO 12, which therefore appears to have provided the most useful information towards the environmental preference of the species. The AUC value for the model is 0.95.

Both *O. rudis* (Figure 1e) and *O. semicupreus* (Figure 1f) showed a high probability of presence in the southern (Kuching and Samarahan) and the northern region (Miri). However, areas such as Sarikei, Sibu and Kapit showed a low probability of presence for the species. The areas nearer or along the coastline with mainly peat swamp forests type such as Betong, Sibu and Mukah showed a probability of the presence of 0.5 for the species. Since both *O. rudis* and *O. semicupreus* were recorded in the same three localities, the maximum entropy model suggests that the environmental parameters with the most significant impact towards their presence are similar which are BIO 14 (65%), BIO 9 (25.4%), and BIO 5 (7.9%). The environmental variable with the highest gain, when used in isolation, is BIO 5, which therefore appears to have the most useful information by itself. Whereas the environmental variable that decreases the gain the most when it is omitted is BIO 14, which therefore appears to have the most information that is not present in the other variables. The AUC value for the distribution model showed a value of 0.95.

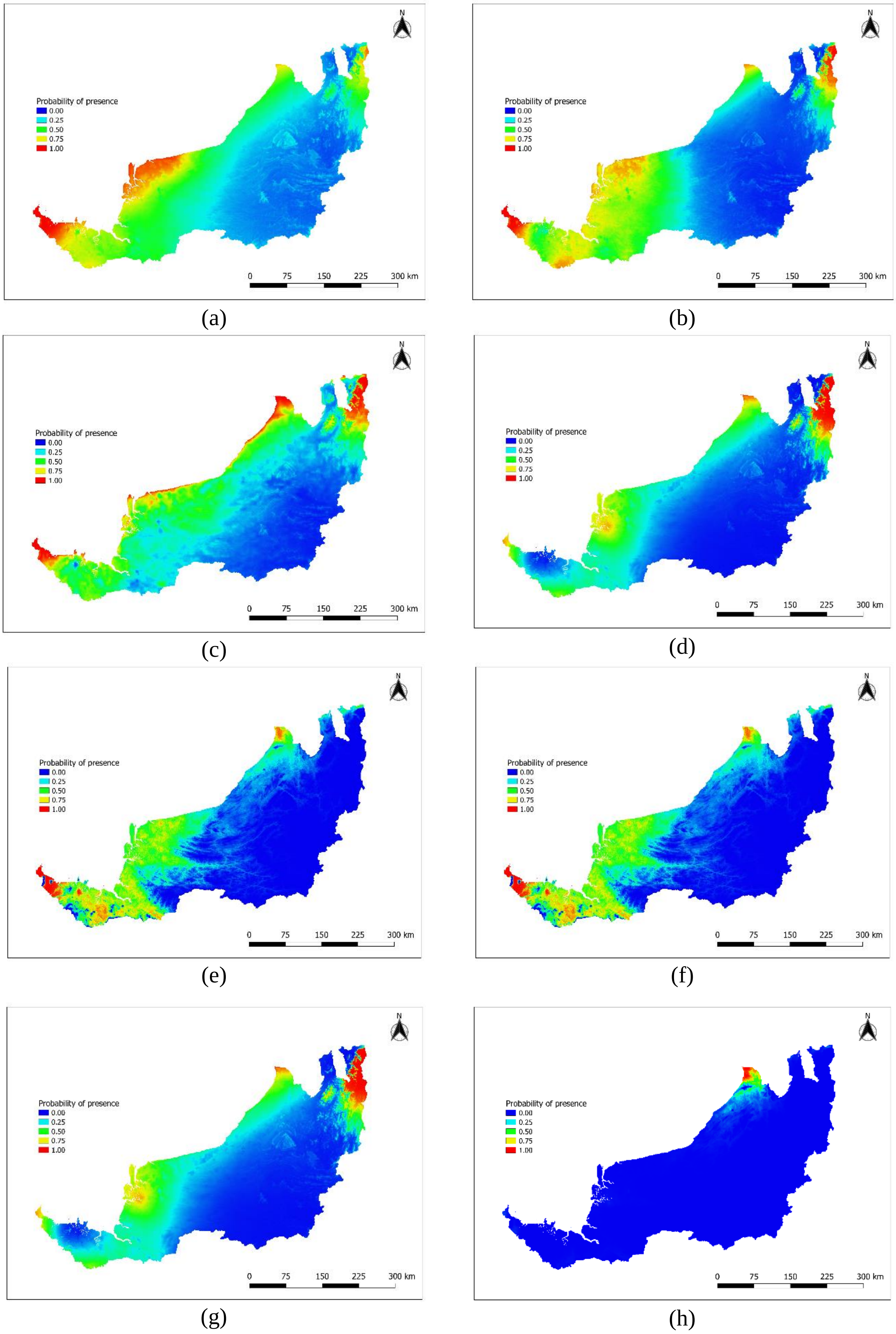

Figure 1. Distribution map of *Onthophagus* species in Sarawak. (a) *Onthophagus semiaureus*, (b) *Onthophagus sarawacus*, (c) *Onthophagus aurifex*, (d) *Onthophagus vulpes*, (e) *Onthophagus rudis*, (f) *Onthophagus semicupreus*, (g*) Onthophagus deliensis*, and (h) *Onthophagus waterstradti*

The distribution of *O. deliensis* (Figure 1g) appears to be concentrated along the coastline areas, especially in Kuching, Bintulu and Miri. The environmental variables that contribute to the distribution model (MaxEnt) the most are BIO 3 (82.7%), BIO 2 (13.9%) and BIO 17 (3.3%). Due to the high contribution of BIO 3 towards the model, it is the environmental variable with the most useful information and has the most information that is not present in the other variables. The model showed an AUC value of 0.98.

Uniquely, the distribution of *O. waterstradti* (Figure 1h) appeared to be very specific only to a small area in the northern region (Miri) and not in any other parts of Sarawak. There are a total of 12 environmental variables which contribute to the *O. waterstradti* model. The environmental parameters with the most significant impact towards the presence of the species according to the MaxEnt model are BIO 10 (29.4%), BIO 12 (20.6%), and BIO 2 (19.7%). However, the variable with the highest gain when used in isolation is Bio 10, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is BIO 13, which therefore appears to have the most information that is not present in the other variables. The distribution model is supported by an AUC value of 0.99.

Onthophagus species can be seen occupying different habitats or forest types based on the distribution model obtained. Every species has its habitat requirement and present in a specific place (Hernandez *et al.*, 2006). This study revealed that one species, *O. waterstradti* has a narrower environmental tolerance compared to the other *Onthophagus* species. However, among the eight species in this study, only *O. rudis* was considered a rare species (Goh & Hashim, 2019). This may be related to the different feeding behaviour of Scarabaeinae as they do not feed entirely on dung (Goh & Hashim, 2019).

The response of beetles towards other abiotic conditions such as light intensity and canopy cover may have contributed to the distribution outcomes (Widhiono *et al*. 2017; Goh *et al*. 2019). To support this, a study conducted by Estupiñan-Mojica *et al.* (2022) reported that vegetative cover, fragmentation, physical structure, and elevation of the local environment have a strong influence towards dung beetle distribution. However, all the environmental variables that are significant towards the distribution of *Onthophagus* species correlated with temperature and precipitation. Therefore, they have a preference towards drier and warmer surroundings in general.

CONCLUSION

This study has successfully provided the baseline data on the distribution of eight *Onthophagus* species in Sarawak. It is revealed that most of the dung beetle distributions are strongly influenced by temperature and precipitation. This study could be beneficial in identifying the potential hotspot areas for biodiversity conservation and effective management practices in Sarawak. Further studies should consider other localities from remote areas including Kapit and Belaga to fully represent other areas within this large state.

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