Malaysian Applied Biology (2024) 53(6): 167-177
https://doi.org/10.55230/mabjournal.v53i6.11

Research

Understanding The Effects of Climate Change on *Elaeidobius kamerunicus* (Coleoptera: Curculionidea), An Important Oil Palm Pollinator in Malaysia: Predicting Future Distribution For The Year 2050 Under Different Climate Pathways

Kumara Thevan Krishnan[1]*, Marcela Pimid[2]

1. Faculty of Agro-Based Industry, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia
2. Institute for Tropical Biology and Conservation, University Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
*Corresponding author: thevan@umk.edu.my

ABSTRACT

Elaeidobius kamerunicus is an African oil palm weevil that plays a crucial role as the primary pollinator of oil palm trees and is linked to the production of fruit and palm oil. Malaysia's palm oil and related products export earnings reached RM94 billion in 2023, according to the Malaysia Palm Oil Board (MPOB). Climate change poses a potential threat to the *E. kamerunicus* population in Malaysia, necessitating research to comprehend the impacts of various climate change variables. This project seeks to document the presence of *E. kamerunicus*, collect current and future climate data, develop a predictive model using MaxEnt software, and assess the model using statistical techniques to forecast the geographical distribution of *E. kamerunicus* in Malaysia. The habitat distribution of *E. kamerunicus* was projected for the year 2050 using two typical concentration pathways (RCPs) from global climate models (GCMs), specifically 2.6 and 8.5. The Maxent models generated a satisfactory model forecast of the Area Under the Curve, which was 0.71. Moreover, True Skilled Statistics achieved a rating of 0.84 (acceptable limit >0.5). The model showed a much greater distribution of *E. kamerunicus* in Peninsular Malaysia than in East Malaysia. The future model under RCP 2.6 indicates a decrease *in E. kamerunicus* in high distribution areas in Perak, Selangor, Negeri Sembilan, Melaka, northern Johor, and Sabah, while RCP 8.5 reveals that all states in Malaysia exhibit very high and high distribution of *E. kamerunicus*. Given the expected increase in atmospheric CO^2 levels due to climate change, a more thorough evaluation of the long-term effects of elevated atmospheric CO^2 on the physiological characteristics of *E. kamerunicus* is necessary.

Key words: *Elaeidobius kamerunicus*, future, Maxent, oil palm, pollinator

Article History
Accepted: 3 December 2024
First version online: 25 December 2024

Cite This Article:
Krishnan, K.T. & Pimid, M. 2024. Understanding the effects of climate change on *Elaeidobius kamerunicus* (Coleoptera: Curculionidea), an important oil palm pollinator in Malaysia: Predicting future distribution for the year 2050 under different climate pathways. Malaysian Applied Biology, 53(6): 167-177. https://doi.org/10.55230/mabjournal.v53i6.11

INTRODUCTION

Elaeidobius kamerunicus is indigenous to West Africa and is extensively spread across many African nations such as Cameroon, Nigeria, and Ghana (Corley & Tinker, 2016). The weevil has been brought to Southeast Asia and now plays a crucial role as a pollinator of oil palm. *Elaeidobius kamerunicus* has a specialized symbiotic relationship with oil palm trees, and its population and range are directly connected to the oil palm plantations (Yousefi *et al*., 2020). The oil palm sector is highly dependent on the pollination services *E. kamerunicus* and the value of these pollination services are substantial, with studies indicating that effective pollination can lead to fruit set rates as high as 93.6% in optimal conditions (Saravanan *et al*., 2023). *Elaeidobius kamerunicus* undergoes five phases in its life cycle: egg, neonate, larval instars 1, 2, and 3, nymphal stage, and adult phase (Tuo *et al*., 2011; Yousefi *et al*., 2020). The pupal stage lasts approximately two weeks, after which the adult weevils emerge and typically live for around 27 days for males and 32 days for females, as reported by Tuo *et al*. (2011). Weevils are mostly drawn to male oil palm inflorescences and aid in pollination, which involves transferring pollen from male to female flowers. When *E. kamerunicus* is abundant, 30–60% of blooms produce fruit, and the fresh fruit bunch weight increases (Yousefi *et al*., 2020).

Studies show that climate change has impacted the worldwide spread and abundance of pollinators (Burkle *et al*., 2013; Othman *et al*., 2021). In Europe, various bee species have decreased in numbers because of climate changes, impacting their distribution and population levels (Conte & Navajas, 2008; Potts *et al*., 2016). A study in Nigeria revealed that climate change has impacted the distribution and abundance of *E. kamerunicus*, a key pollinator of oil palm. Temperature and rainfall patterns were shown to be important factors affecting the abundance and spread of *E. kamerunicus*. (Olatinwo *et al*., 2020). Studies revealed that the pollination efficiency of *E. kamerunicus* and the pollen viability of the crop were influenced by rainfall patterns (Gunawan *et al*., 2020; Saharul *et al*., 2023a). Tan *et al*. (2020) studied how temperature impacts the reproductive success of *E. kamerunicus* in oil palm fields in Sabah, Malaysia. The research revealed temperature strongly influenced the reproductive success of the weevil, as higher temperatures resulted in greater weevil population and fruit production in oil palm. The study revealed that temperatures can adversely affect the weevil's reproductive capabilities. This suggests that the influence of climate change, including fluctuating annual temperatures, min/max temperatures, and various precipitation factors, on the distribution of *E. kamerunicus* requires more research. These studies emphasize the necessity for continuous research on climate change's influence on *E. kamerunicus* and its potential consequences for Malaysia's palm oil industry. Studying *E. kamerunicus* spread in several climate scenarios (present and year 2050) can help create measures to minimize the climate change effects on the palm oil business. Moreover, detecting possible changes in the *E. kamerunicus* range can help in creating strategies to guarantee the sustainable utilization of *E. kamerunicus* as a pollinator in oil palm farms. This project aims to document the presence of *E. kamerunicus* and create a predicted distribution map to enhance our comprehension of its dispersal under current and year 2050 climate conditions.

MATERIALS AND METHODS

Elaeidobius kamerunicus location data

All occurrence records on *E. kamerunicus* are extracted from databases (Scopus, Springer, Web of Science) and GBIF - the Global Biodiversity Information Facility (https://www.gbif.org/), CABI (https://plantwiseplusknowledgebank.org), Swaray *et.* al., (2021); Yousefi *et.* al., (2020); Saharul *et.* al., (2023b); Haran *et.* al., (2020); Tambunan *et al*., (2020); Latip *et al*., (2019); Latip *et al*., (2018); Zahari *et al*., (2019); MPOB, (2016); Dzulhelmi *et.* al., (2022); Fahmi-Halil *et al*., (2021); Zulkefli *et al*., (2022); Saharul *et al*., 2021; Saharul *et al*., 2020; Luqman *et al*., (2018); Zalipah *et al*., (2023); Najib *et al*., (2009); Amanina *et al*., (2016). The longitude and latitude of these occurrences are geolocated using Google Maps (https://www.google.com/maps). These data are recorded into a Microsoft Excel file in comma-delimited format. The data was filtered to remove duplicate records and geographically rarefied occurrences within a 20-kilometer distance using ArcGIS 10.8 to avoid duplicated entries (Hosni *et al*., 2022). Twenty-seven data points were collected from the literature for model construction (Figure 1).

Climatic variables

The species distribution modeling requires 19 bioclimatic data points (Table 1). The bioclimatic raster layers were transformed into ASCII format. Climate variables are established using monthly rainfall and temperature data retrieved from meteorological stations between 1970 and 2000 (published in January 2020, www.worldclimate.org). These data were collected (2.5-min spatial resolution) from the WorldClim Ver. 2.0 database (www.worldclimate.org). To prevent correlation among the predictive variables, the Pearson correlation test was performed using ArcGIS 10.8. Any correlation variables ($r \geq 0.8$) are deleted, leaving only the remaining variables included in the model. Bioclimatic factors 3-6, 8-11, 14, and 16-19 were omitted from the analysis due to their high correlation with numerous other variables. The six remaining variables are annual mean temperature (Bio1), mean diurnal range (mean of monthly max temp-min temp) (Bio2), temperature annual range (Bio7), annual precipitation (Bio12), precipitation of wettest month (Bio13), and precipitation seasonality (coefficient of variation) (Bio15) as shown in Table 2. To forecast the future acceptable climatic region for *E. kamerunicus* in Malaysia, we applied climatic models (RCP 2.6 and RCP 8.5, respectively) for the years 2050 (average from the years 2041-2060), that were derived from global climate models (GCMs): MIROC6. The future climatic data were obtained from the WorldClim database (spatial resolution of 2.5 min equivalent to 4.5 km^2) (www.worldclim.org). These data were utilized to construct the present and projected distribution model. To clarify, RCP 2.6 represents a scenario that seeks to limit global warming to less than 2°C over pre-industrial temperatures, while RCP 8.5 represents a future with extremely high human-caused greenhouse gas (GHG) emissions. The Representative Concentration Pathways (RCPs), utilized for producing forecasts, were created by the Intergovernmental Panel on Climate Change (IPCC, 2014).

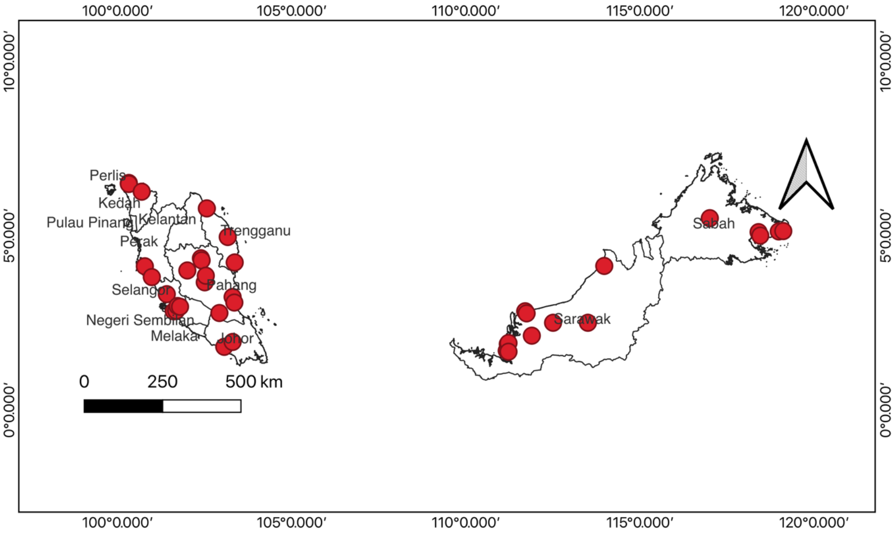


Fig. 1. Distribution of the occurrence records of *E. kamerunicus* extracted from the Swaray *et.* al., (2021); Yousefi *et.* al., (2020); Saharul *et.* al., (2023b); Haran *et.* al., (2020); Tambunan *et al*., (2020); Latip *et al*., (2019); Latip *et al*., (2018); Zahari *et al*., (2019); MPOB, (2016); Dzulhelmi *et.* al., (2022); Fahmi-Halil *et al*., (2021); Zulkefli *et al*., (2022); Saharul *et al*., 2021; Saharul *et al*., 2020; Luqman *et al*., (2018); Zalipah *et al*., (2023); Najib *et al*., (2009); Amanina *et al*., (2016).

Table 1. A total of 19 bioclimatic variables were utilized before conducting the Pearson correlation test

Variable	Description
Bio 1	Annual mean temperature (°C)
Bio 2	Mean Diurnal Range (Mean of monthly max temp – min temp) (°C)
Bio 3	Isothermality (bio2 / bio7 x 100) (%)
Bio 4	Temperature Seasonality (°C)
Bio 5	Max Temperature of Warmest Month (°C)
Bio 6	Min Temperature of Coldest Month (°C)
Bio 7	Temperature Annual Range (°C)
Bio 8	Mean Temperature of Wettest Quarter (°C)
Bio 9	Mean Temperature of Driest Quarter (°C)
Bio 10	Mean Temperature of Warmest Quarter (°C)
Bio 11	Mean Temperature of Coldest Quarter (°C)
Bio 12	Annual Precipitation (mm)
Bio 13	Precipitation of Wettest Month (mm)
Bio 14	Precipitation of Driest Month (mm)
Bio 15	Precipitation Seasonality (Coefficient of Variation) (%)
Bio 16	Precipitation of Wettest Quarter (mm)
Bio 17	Precipitation of Driest Quarter (mm)
Bio 18	Precipitation of Warmest Quarter (mm)
Bio 19	Precipitation of Coldest Quarter (mm)

Table 2. Bioclimatic variables were used in the model after excluding highly correlated variables

Type	Variable	Description
Thermal	Bio 1	Annual mean temperature (°C)
	Bio 2	Mean Diurnal Range (Mean of monthly max temp – min temp) (°C)
	Bio 7	Temperature Annual Range (°C)
Rainfall	Bio 12	Annual Precipitation (mm)
	Bio 13	Precipitation of Wettest Month (mm)
	Bio 15	Precipitation Seasonality (Coefficient of Variation) (%)

Modeling calibration

The MaxEnt (version 3.4.4) model was used to analyze the occurrence data of *E. kamerunicus* and selected climatic factors. Highly correlated variables were removed before using them as inputs. The model was then used to simulate present and future climate scenarios, as described by Phillips *et al*. (2006). The configuration input for the MaxEnt model is as follows: the random test percentage is set to "0" and cross-validation is being used. The regularisation multiplier is set to 1, the maximum number of background points is 10000, the maximum number of interactions is 500, and there are 10 repetitions. The convergence threshold is set to 10^{-5} and the threshold rule is the 10th percentile of training presence. Upon generating the present and future distribution map for *E. kamerunicus*, the distribution areas were classified into five categories according to the obtained models: very high (more than 0.8), high (0.6 to 0.8), moderate (0.4 to 0.6), low (0.2 to 0.4), and rare (0 to 0.2), using ArcGIS 10.8.

Model evaluation

The model's performance was assessed by calculating the area under the curve (AUC) of the receiver operating characteristic (ROC) (Zhu *et al*., 2018; Aidoo *et al*., 2022). The AUC values, ranging from 0 to 1, offer an estimation of the discriminatory power of the species distribution model (Jiménez-Valverde, 2012). AUC values below 0.5 indicate predictions that are weaker than random, while values between 0.5 and 0.7 indicate poor model predictions. AUC values within the range of 0.7 to 0.9 suggest satisfactory model predictions, whereas values over 0.9 indicate highly accurate model predictions (Aidoo *et al*., 2022). The AUC values were produced via niche modelling using MaxEnt software (version 3.4.4; Phillips *et al*., 2006). In addition, the True Skill Statistic (TSS) analysis allows for the assessment of the accuracy of the model using a threshold-dependent measure (Allouche *et al*., 2006). The TSS analysis values range from 1 to +1. Findings greater than 0.6 are considered "good", values between 0.2 and 0.6 are considered "intermediate", and a value of 0.2 is considered "poor" (Jones *et al*., 2010).

RESULTS

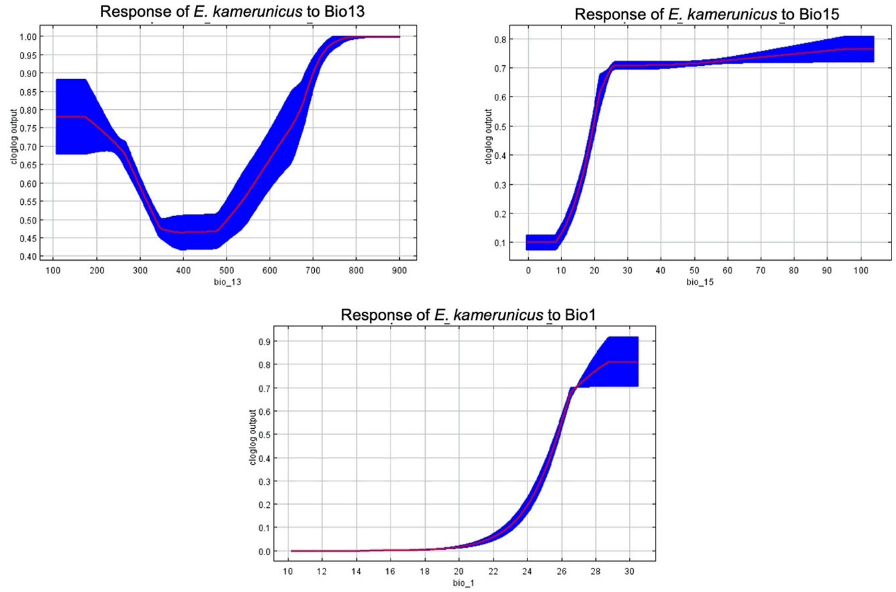
Bioclimatic variables represent seasonal trends relevant to the physiological limitations of various species. In the current study, six bioclimatic variables were utilized for modeling. Bio1, Bio2, and Bio7 denote thermal types, whereas Bio12, Bio13, and Bio15 signify rainfall types (Table 2). Bio 1 signifies the annual mean temperature, which approximates the total energy inputs for an ecosystem; Bio 2 serves as an index that offers insights into the significance of temperature fluctuations for various species. Bio 7 is valuable for assessing the impact of extreme temperature ranges on species distributions; Bio 12 indicates annual total precipitation, serving as a proxy for total water inputs and thus aiding in evaluating the significance of water availability for species distribution; Bio 13 denotes precipitation during the wettest month, which is pertinent for understanding how extreme precipitation events may affect a species' potential range; and Bio 15 offers a measure of precipitation variability, as species distributions can be significantly affected by fluctuations in precipitation. According to the response curves of key environmental parameters, the optimal precipitation for the *E. kamerunicus* species varied from 100 mm to 170 mm in the wettest month (Bio13, Figure 2), while the yearly average temperature ranged from 20°C to 28.5°C (Bio1, Figure 2). For Bio15 (Figure 2), the percentage of between 10-25% shows favorable to the *E. kamerunicus*, and larger the percentages represent greater variability of precipitation.

Modeling performance

The Maxent model for *E. kamerunicus* yielded a satisfactory Area Under Curve (AUC) value of 0.71, as shown in Figure 3. The red curve (AUC of 0.710) shows the “fit” of the model predicting *E. kamerunicus*. The blue region signifies variations in the model's prediction, serving as the true assessment of the model's predictive capability. The black line represents the expected outcome if the model performs randomly. A TSS value of 0.844 indicates that the model has a high level of map-producing quality, as determined by the functional assessment.

Role of bioclimatic factors

The jackknife test demonstrated the percentage contribution of bioclimatic variables to the predictive distribution model, as shown in Figure 4 and Table 3. Precipitation of the Wettest Month (mm) (Bio 13) made the largest contribution to *E. kamerunicus* distribution with 28.1%, followed by Precipitation Seasonality (Coefficient of Variation) (mm) (Bio 15), Annual mean temperature (°C) (Bio 1) with 27.8% and 23% respectively. The remaining variables, Mean Diurnal Range (Mean of monthly max temp – min temp) (°C) (Bio 2), Temperature Annual Range (°C) (Bio7) and Annual Precipitation (mm) (Bio 12), had only a minor effect with 11%, 5.4% and 4.1%, respectively (Table 3).

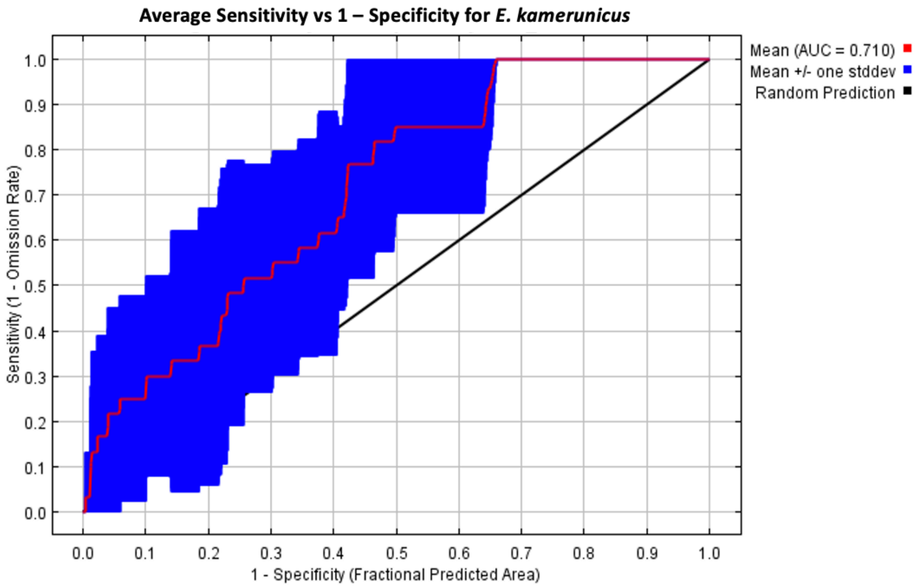


Response of *E. kamerunicus* to Bio13

Response of *E. kamerunicus* to Bio15

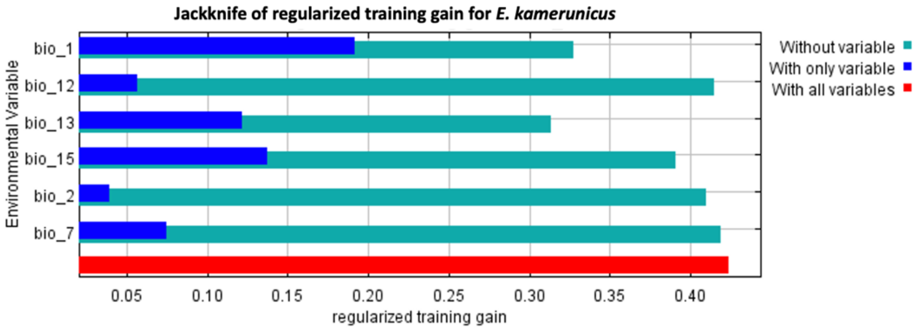
Response of *E. kamerunicus* to Bio1

Fig. 2. The response curve depicts the relationship between the distribution of *E. kamerunicus* and the key environmental conditions that have the greatest impact. (the shown values are the average of the ten replicates).



Average Sensitivity vs 1 – Specificity for *E. kamerunicus*

Fig. 3. The Receiver operating characteristics (ROC) curve of the training and test data.



Jackknife of regularized training gain for *E. kamerunicus*

Fig. 4. The jackknife test of the most important variables.

Table 3. The bioclimatic factors used in Maxent to model the existing and future distribution of *E. kamerunicus* in Malaysia are expressed as percentages

Bioclimatic Variables	Description	Contribution Percentages (%)
Bio 13	Precipitation of Wettest Month (mm)	28.7
Bio 15	Precipitation Seasonality (Coefficient of Variation) (%)	27.8
Bio 1	Annual mean temperature (°C)	23
Bio 2	Mean Diurnal Range (Mean of monthly max temp – min temp) (°C)	11
Bio 7	Temperature Annual Range (°C)	5.4
Bio 12	Annual Precipitation (mm)	4.1

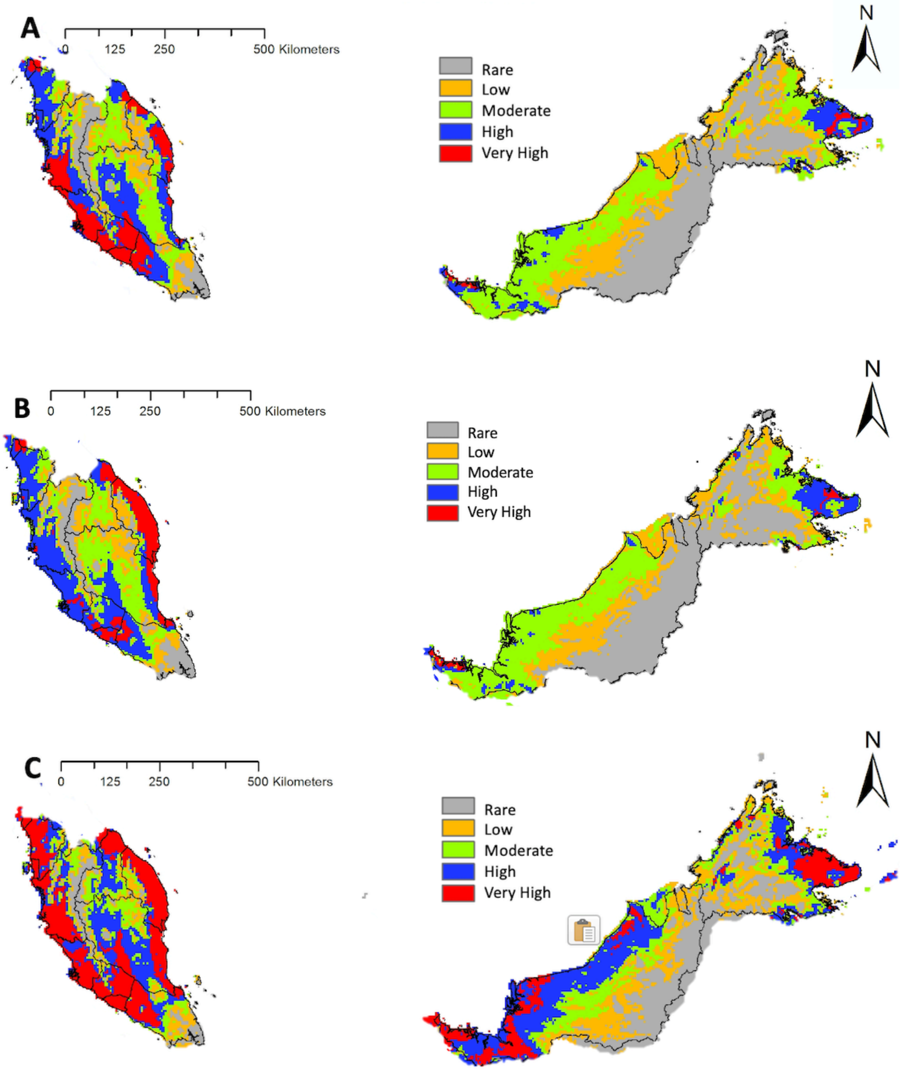


Fig. 5. (**A**) Known and current distribution for *E. kamerunicus*. (**B**) Future predicted distribution for *E. kamerunicus* for the year 2050 under RCP 2.6. (**C**) Future predicted distribution for *E. kamerunicus* for the year 2050 under RCP 8.5.

The distribution of *E. kamerunicus* at present

The projected model aligns with the documented instances of *E. kamerunicus* from Peninsular and East Malaysia as collected from literature sources (Figure 5A). The map also displays states with a significant existing distribution, such as Perlis, Perak, Selangor, Negeri Sembilan, Melaka, the northern part of Johor, and Terengganu. Most East Malaysian states have low to medium distribution of *E. kamerunicus*. *Elaeidobius kamerunicus* is highly concentrated in western Peninsular Malaysia (Perlis, Perak, Selangor, Negeri Sembilan, Melaka, and northern Johor), with its distribution decreasing towards the central region of the peninsula. On the East Coast of Peninsular Malaysia, about half of Terengganu state had a very high prevalence of *E. kamerunicus*. Kedah and Pahang have a combination of high and moderate distribution of *E. kamerunicus*. The kelantan state exhibits a low to moderate habitat suitability distribution for *E. kamerunicus*. *Elaeidobius kamerunicus* is predominantly distributed in East

Malaysia, specifically in the Kuching region of Sarawak, and sections of the Sandakan and Tawau districts in Sabah. Other regions in Sabah and Sarawak exhibit varying levels of prevalence of *E. kamerunicus*, ranging from rare to medium.

The projected future potential distribution of *E. kamerunicus* (the year 2050).

The future model in RCP 2.6 confirmed a reduction in high distribution areas in Perak, Selangor, Negeri Sembilan, Melaka, north of Johor and Sabah (Figure 5B). The high habitat distribution for *E. kamerunicus* shifted towards the east of Peninsular Malaysia along the coastline of Kelantan, Terengganu, and Pahang. District Kuching, Sarawak predicted an increase high habitat suitability for *E. kamerunicus*. Meanwhile, the rest of Sabah and Sarawak do not show many changes to compare with the current distribution. For the future model in RCP 8.5 (Figure 5C), the predictive model illustrated a dramatic change in *E. kamerunicus* distribution in Malaysia. All states in Malaysia showed very high and high distribution of *E. kamerunicus* across all states in Malaysia.

DISCUSSION

Research globally indicates that climate change has affected the range and population of pollinators worldwide (Conte & Navajas, 2008; Burkle *et al*., 2013; Potts *et al*., 2016; Othman *et al*., 2021; Olatinwo *et al*., 2020). *Elaeidobius kamerunicus* is a crucial oil palm pollinator that significantly contributed to Malaysia's savings of RM 10 billion by boosting palm oil production between 1982 and 2015 and eliminating the need for artificial pollination (Bakeri, 2016). Through pollination services, planters in Malaysia were able to enhance the fruit set of palm oil from 50% to 80% (Syed *et.* al., 1982; Latip *et al*., 2019). Since being introduced to oil palm fields globally, there have been documented instances of decreased natural pollinators in oil palms (Yousefi *et al*., 2020). Seasonal poor fruit set in Malaysia, ranging from 10 to 20%, is attributed to a decrease in *E. kamerunicus* population caused by parasitic nematodes, rainfall patterns, and a reduced number of oil palm male inflorescences (Rao *et al*., 1998). The population size of the pollinating *E. kamerunicus* is essential for achieving adequate pollination levels (Zulkefli *et al*., 2022). Studies demonstrate different population densities of *E. kamerunicus* in the wild. For instance, Donough *et al*. (1996) stated that 20,000 weevils per hectare are needed to achieve a fruit set of 55%. Saharul *et al*. (2021) recommended a population of 14,000 individuals per hectare to achieve a fruit set percentage of 65%.

In addition, researchers from Malaysia, Kalimantan, Indonesia, India, and Colombia have globally documented the impact of rainfall on the population of *E. kamerunicus* (Dhileepan, 1994; Mohd Rizuan *et al*., 2013; Latip *et al*., 2018; Montes Bazurto *et al*., 2018). The *E. kamerunicus* population is impacted differently by variations in rainfall volume and geographical factors. In Sabah, Malaysia, Mohd Rizuan *et al*. (2013) observed that the population of *E. kamerunicus* rose during the dry season when monthly rainfall was less than 120 mm. The variable "Precipitation of Wettest Month (mm) (rainfall) (Bio13)" had the highest contribution percentage in the prediction model as shown in Table 3. Furthermore, the response curve exhibited in Fig. 2 aligns with prior research findings about the association between *E. kamerunicus* and rainfall. In addition, TSS levels of 0.5 are considered acceptable according to Hosni *et al*. (2022), and the current models scored a TSS value of 0.844. The current model indicated that if rainfall surpasses 170 mm, the probability distribution of *Elaeidobius kamerunicus* drops, as shown in Figure 3 of Bio 13, which aligns with the results of Mohd Rizuan *et al*. (2013).

In the 1980s in Malaysia, the population of *E. kamerunicus* was first reported to vary from 40-200 individuals per spikelet but later decreased to 14-54 individuals per spikelet in Peninsular Malaysia (Syed *et al*., 1982; Daud & Idris, 2016). In Sabah, the density ranged from 8 to 45 per spikelet according to Mohd Rizuan *et al*. (2013), whereas in Sarawak, the average population size of *E. kamerunicus* was between 16 and 17 individuals per spikelet as reported by Sulaiman *et al*. (2018). These studies confirmed our findings that *E. kamerunicus* is more prevalent in the very high and high distribution areas of Peninsular Malaysia compared to the states in East Malaysia (Fig. 5A). Further attention is required for the occurrences and population distribution of low *E. kamerunicus* in these states. Proactive actions should be implemented to optimize palm oil yield in the future. The proposal to establish a breeding and release plan should include future bioclimatic conditions and appropriate geographical locations that are suited for *E. kamerunicus* habitat, along with implementing sound agronomic methods.

Climate change impacts are observable worldwide and therefore inevitable. Oil palm planters must have proper planning and mitigation strategies in place to address these changes. Global mean surface temperature is projected to rise between 0.3°C to 1.7°C under RCP 2.6 and 2.6°C to 4.8°C with RCP 8.5 by the end of the 21st century compared to 1986–2005 levels (IPCC, 2014). The Intergovernmental Panel on Climate Change concluded in 2014 that carbon dioxide emissions resulting from the combustion of fossil fuels and industrial activity were responsible for almost 78% of the total rise in greenhouse gas emissions from 1970 to 2010. These emissions are a significant factor in global warming. According to the distribution map, *E. kamerunicus* shows a significantly high presence in Malaysia, particularly in RCP 8.5 (Fig. 5C). This will happen at the peak project paths of greenhouse gas emissions (GHG). Moreover, the anticipated rise in greenhouse gas emissions will raise atmospheric CO^2 levels. Hence, it is necessary to further assess the impact of increased atmospheric CO^2 on the physiological aspects of oil palm plants and pollination services, particularly focusing on *Elaeidobius kamerunicus*, in the context of climate change. The study by Amanina *et al*. (2016) found that the effect of increased CO^2 levels on the growth of *E. kamerunicus* was low when CO^2 levels ranged from ambient to 800 ppm. The long-term impacts of increasing ambient CO^2 on *E. kamerunicus* biology and adaptability are not well recognized yet (Amanina *et al*., 2016; Saharul *et al*., 2022). Additionally, it has been noted that increased warmth can impact pollination, specifically on the physiology of the oil palm. Various factors such as plant density, oil palm clones, morphology, soil type, pesticides, predators, and genetic differences need to be further evaluated for the sustainability of the oil palm farming industry.

CONCLUSION

This study effectively simulated the present and future worldwide spread of *E. kamerunicus* in Malaysia. Commercial oil palm planters can use the study's findings to understand how climate change may affect the distribution of *E. kamerunicus*. This knowledge can help them make informed decisions about agronomic practices that can boost the population of *E. kamerunicus* in their plantations, leading to improved oil palm yield and quality in Malaysia.

ACKNOWLEDGEMENTS

We express our gratitude to Dr. Gbenga Festus Akomolafe from the Federal University of Lafia, Nigeria for providing technical assistance.

ETHICAL STATEMENT

Not applicable

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Aidoo, O.F., Souza, P.G., Silva, R., Santana Júnior, P., Picanço, M., Osei-owusu, J., Setamou, M., Ekesi, S. & Borgemeister, C. 2022. A machine learning algorithm-based approach (MaxEnt) for predicting invasive potential of *Trioza erytreae* on a global scale. Ecological Informatics, 71: 101792. https://doi.org/10.1016/j.ecoinf.2022.101792

Amanina S.N., Yunos, Md., Harun, M., Noor, R., Abdul Razak, A. & Moslim, R. 2016. Effects of high carbon dioxide level on the emergence of oil palm pollinating weevil, *Elaeidobius kamerunicus*. Journal of Oil Palm Research, 28. https://doi.org/10.21894/jopr.2016.2802.04

Bakeri, N. 2016. Serangga ini telah membantu Malaysia jimat sehingga lebih RM40 bilion. URL https://www.astroawani.com/berita-malaysia/serangga-ini-telah-membantu-malaysia-jimat-sehingga-lebih-rm40-bilion-95644. (accessed 02.24.24)

Burkle, L.A., Marlin, J.C. & Knight, T.M. 2013. Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. Science, 339(6127): 1611–1615. https://doi.org/10.1126/science.1232728

Corley, R.H.V. & Tinker, P.B.H. 2003. The Oil Palm (World Agriculture Series). 4th Edition. Blackwell Science, Oxford, United Kingdom. 562 pp.

Conte, Y. & Navajas, M. 2008. Climate change: Impact on honey bee populations and diseases. Revue scientifique et technique (International Office of Epizootics), 27: 485-97.

Daud, S.N.S.M. & Idris, A.G. 2016. Population density of oil palm pollinator weevil *Elaeidobius kamerunicus* based on seasonal effect and age of oil palm. AIP Conference Proceedings, 1784: 060051. https://doi.org/10.1063/1.4966889

Dzulhelmi, M.N., Razi, A.N., Kalog, N.S.F., Murdi, A.F., Su, S. & Hazmi, I.R. 2022. Assessment on pollen carrying capacity and pollen viability of *Elaeidobius kamerunicus* (Coleoptera: Curculionidae). Philippine Agricultural Scientist, 105(3): 309–314.

Dhileepan, K. 1994. Variation in populations of the introduced pollinating weevil (*Elaeidobius kamerunicus*)

(Coleoptera: Curculionidae) and its impact on fruitset of oil palm (*Elaeis guineensis*) in India. Bulletin of Entomological Research, 84: 477-485. https://doi.org/10.1017/S0007485300032703

Donough, C.R., Chew, K.W. & Law, I.H. 1996. Effect of fruit set on OER and KER: Results from studies at Pamol Estates (Sabah) Sdn. Bhd. Planter, 72: 203-219.

Fahmi-Halil, M., Haris-Hussain, M., Mirad, R., Idris, A.B. & Jalinas, J. 2021. Responses of oil palm pollinator, *Elaeidobius kamerunicus* to different concentrations of estragoles. BioRxiv. https://doi.org/10.1101/2021.03.24.436726

GBIF.org (GBIF). 2024. *Elaeidobius kamerunicus* occurrence download. https://doi.org/10.15468/dl.kgmg6w (accessed 02.21.24)

Gunawan S., Sri B.M.T., Sutrisno J. & Wirianata H. 2020. Effects of organic materials and rainfall intensity on the productivity of oil palm grown under sandy soil condition. International Journal on Advanced Science, Engineering and Information Technology, 10: 356-361.

Haran, J., Abanda, F.X., Benoit, L., Bakoumé, C. & Ollivier, L. 2020. Multilocus phylogeography of the world populations of *Elaeidobius kamerunicus* (Coleoptera, Curculionidae), pollinator of the palm *Elaeis guineensis*. Bulletin of Entomological Research, 110: 1–9. https://doi.org/10.1017/S0007485320000218

Hosni, E.M., Al-Khalaf, A.A., Nasser, M.G., Abou-Shaara, H.F. & Radwan, M.H. 2022. Modeling the potential global distribution of honeybee pest, *Galleria mellonella* under changing climate. Insects 13: 484. https://doi.org/10.3390/insects13050484

IPCC (Intergovernmental Panel on Climate Change). 2014. Climate Change 2014: Impacts, adaptation, and vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Jiménez-Valverde, A. 2012. Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modelling. Global Ecology and Biogeography, 21: 498-507. https://doi.org/10.1111/j.1466-8238.2011.00683.x

Jones, C., Acker, S. & Halpern, C. 2010. Combining local and large-scale models to predict the distributions of invasive plant species. Ecological applications: A publication of the Ecological Society of America. 20: 311-26. https://doi.org/10.1890/08-2261.1

Latip, N., Fahmi, M., Hakim, L., Al-Talafha, H., Nasuha, N., Zainal Abidin, C.M.R. & Ghani, I. 2018. Effect of oil palm planting materials, rainfall, number of male inflorescence and spikelet on the population abundance of oil palm pollinator, *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae). Serangga, 23(1): 35-45.

Latip, N., Ghani, I., Hazmi, I.R. & Nasir, D. 2019. Morphometric comparison of the oil palm pollinator *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) from Malaysia, Indonesia, and Liberia. The Coleopterists Bulletin, 73: 746-756. https://doi.org/10.1649/0010-065X-73.3.746

Luqman H., Nasuha, N., Nasir, D., Latip, N., Fahmi, M., Teo, T.M., Ghani, I. & Hazmi, I.R. 2018. Diversity and composition of beetles (Order: Coleoptera) in three different ages of oil palms in Lekir oil palm plantation, Perak, Malaysia. Serangga, 23(1): 58-71.

MPOB. 2016. Laporan tahunan 2016. https://www.parlimen.gov.my/ipms/eps/2017-11-30/ST.154.2017%20-%20MPOB.pdf.

Montes Bazurto, L.G., Sanchez, L.A., Prada, F., Daza, E.S., Bustillo, A.E. & Romero, H.M., 2018. Relationships between inflorescences and pollinators and their effects on bunch components in *Elaeis guineensis*, in Colombia. Journal of Entomological Science, 53: 554–568.

Mohd Rizuan, C.F., Hisham, N. & Samsudin, A. 2013. Role of pollinating weevil (*Elaeidobius kamerunicus*) seasonal effect and its relation to fruit set in oil palm of FELDA. Journal of Oil Palm Research, 19: 21–27.

Najib A.M., Ali, S.R., Mohd Masri, M.M. & Wahid, M.B. 2009. Effect of *Bacillus thuringiensis*, terakil-1 (r) and teracon-1 (r) against oil palm pollinator, *Elaeidobius kamerunicus* and beneficial insects associated with *Cassia cobanensis*. Journal of Oil Palm Research, 21: 667-674.

Othman, S.S., Yahya, A. & Bani, A. 2021. Impact of climate change on foraging behavior of the stingless bee *Tetragonula laeviceps* (Hymenoptera: Meliponini) in Malaysia. Journal of Asia-Pacific Entomology, 24(1): 221-227.

Olatinwo, R., Adekanmbi, O., Adenekan, M., Sodimu, A., Olawoye, J., & Lawal, O. 2020. Potential effects of climate change on the geographical distribution of African oil palm weevil, *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae), in Nigeria. Global Ecology and Conservation, 24: 01292. https://doi.org/10.1016/j.gecco.2020.e01292

Phillips, S.J., Anderson, R.P. & Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling, 190(3-4): 231–259.

Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V, Garibaldi, L.A., Hill, R., Settele, J. & Vanbergen, A.J. 2016. Safeguarding pollinators and their values to human well-being. Nature, 540(7632): 220–229. https://doi.org/10.1038/nature20588

Rao, V. & Law, I. 1998. The problem of poor fruit set in parts of east Malaysia. Planter, 74: 463–483.

Saharul A.M., Siti N.A., Muhammad N.Y.S., Mohamad R.S., King J.H., Muhamad A. M. & Mohamed M.M.M. 2021. Population abundance of oil palm pollinating weevil, *Elaeidobius kamerunicus* faust and its relation to fruit set formation in mineral and peat soil areas in Peninsular Malaysia. Serangga, 26 (2): 107-117.

Saharul M. 2020. Population density of *Elaeidobius kamerunicus* Faust in different spikelet position at anthesising male inflorescence of *Elaeis guineensis* Jacq. in Sabah and Sarawak, Malaysia. Journal of Oil Palm Research, 33(1): 21-36. https://doi.org/10.21894/jopr.2020.0075

Saharul A.M., Mohamed M.M.M, Norman K., Mohamad R.S., Arnaud C., et. al. 2023a. Impact of *Elaeidobius kamerunicus* (Faust) introduction on oil palm fruit formation in Malaysia and factors affecting its pollination efficiency: A review. Journal of Oil Palm Research, 35(1): 1-22. https://doi.org/10.21894/jopr.2022.0021

Saharul A.M., King, J.H., Siti Nurulhidayah, A., Muhamad Azmi, M., Mohamad Rosman, S. & Mohamed M.M.M. 2023b. The insect pest management strategies and their influence on the emergence rate of *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) from the post-anthesising male inflorescence of oil palm, *Elaeis guineensis*. Malaysian Applied Biology, 52(5): 147-154. https://doi.org/10.55230/mabjournal.v52i5.icfic06

Saravanan, L., Suchitra, V. & Phanikumar, T. 2023. Pollination activity of *Elaeidobius kamerunicus* Faust in oil palm and cocoa (*Theobroma cacao* L.) intercropping system in India. Journal of Oil Palm Research, 36(2): 409-419. https://doi.org/10.21894/jopr.2023.0035

Syed, R.A., Law, I.H. & Corley, R.H.V.1982. Insect pollination of oil palm: introduction, establishment and pollinating efficiency of *Elaeidobius kamerunicus* in Malaysia. Planter, 58: 547-561.

Sulaiman, M.R., Mohamad, S.A., Syarif, M.N.Y., Ahmad, S.N., Masri, M.M.M., Masijan, Z., Moslim, R. & Kamarudin, N. 2018. Status on oil palm fruit set and pollinating weevil in Malaysia. Workshop on Insect Pollination Efficiency in Oil Palm. 1 March 2018. Selangor, Malaysia.

Swaray, S.Y., Rafii, M., Din Amiruddin, M., Firdaus Ismail, M., Jamian, S., Jalloh, M., Oladosu, Y., Mustakim Mohamad, M., Marjuni, M., Kolapo, O.K. & Chukwu, S.C. 2021. Assessment of oil palm pollinating weevil (*Elaeidobius kamerunicus*) population density in biparental dura × pisifera hybrids on deep peat-soil in Perak State, Malaysia. Insects, 12(3): 221. https://doi.org/10.3390/insects12030221

Tan, C.H., Lee, Y.P. & Lim, G.S. 2020. Potential of climate-smart oil palm pollination strategy in mitigating impacts of climate change. Agriculture, Ecosystems & Environment, 301: 107008. https://doi.org/10.1016/j.agee.2020.107008

Tambunan, V., Apriyanto, A., Ajambang, W., Etta, C., Bandung, S., Buchori, D. & Hidayat, P. 2020. Molecular identification and population genetic study of *Elaeidobius kamerunicus* Faust. (Coleoptera: Curculionidae) from Indonesia, Malaysia and Cameroon based on mitochondrial gene. Biodiversitas Journal of Biological Diversity, 21: 3263-3270. https://doi.org/10.13057/biodiv/d210749

Tuo, Y., Koua, H.K. & Hala, N. 2011. Biology of Elaeidobius kamerunicus and Elaeidobius plagiatus (Coleoptera: Curculionidae) main pollinators of oil palm in west Africa. European Journal of Scientific Research, 49: 426-432.

Yousefi, M., Rafie, A., Abd Aziz, S., Azrad, S. & Razak, A. 2020. Introduction of current pollination techniques and factors affecting pollination effectiveness by *Elaeidobius kamerunicus* in oil palm plantations on regional and global scale: A review. South African Journal of Botany, 132: 171-179. https://doi.org/10.1016/j.sajb.2020.04.017

Zahari, S.N.M., Rusli, R., Hussain, M.H. & Jalinas, J. 2019. Survival rate and development of larvae *Elaeidobius kamerunicus* (Coleoptera: Curculionidae) on artificial diets. Serangga, 24(1): 126-141.

Zulkefli, M.H.H., Jamian, S., Adam, N.A., Jalinas, J. & Mohd Masri, M.M. 2022. Laboratory rearing of *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) pollinator of oil palm inflorescence in Malaysia. IOP Conference Series: Earth and Environmental Science, 974(1): 012033. https://doi.org/10.1088/1755-1315/974/1/012033

Zalipah M.N., Ting, T.H., Nurul Izzah, A. Mohd Shuhaimi, M.H., Faiq Z.Z., Muhamad Azrul, S.L., Asraf M.I., Shahrul A.M.S., Nur Fariza M.S. & Norasmah B. 2023. Arthropod fauna of oil palm inflorescence (*Elaeis guineensis*), with notes on their ecological roles in a plantation in Terengganu, Malaysia. Journal of Oil Palm Research, 36 (1): 82-93. https://doi.org/10.21894/jopr.2023.0013

Zhu, Y., Wei, W., Li, H., Wang, B., Yang, X. & Liu, Y. 2018. Modelling the potential distribution and shifts of three varieties of *Stipa tianschanica* in the eastern Eurasian Steppe under multiple climate change scenarios. Global Ecology and Conservation, 16: e00501. https://doi.org/10.1016/j.gecco.2018.e00501