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# Predicting with the Pest Status of Two Main Insects that Attacking Honey Bee Colonies in Africa Based on the Future Climatic Changes

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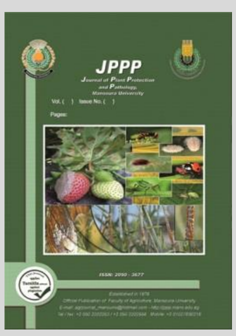


## ABSTRACT

The effects of future climate changes on the prevalence of *Palarus latifrons* Kohl. and *Philanthus triangulum* Fab that attacking honey bee colonies in Africa have not been studied before. Ecological modeling using Maxent and geographical information system (GIS) was used to achieve the study objective. The highest contribution in the model was to the annual mean temperature followed by mean temperature of the coldest quarter. The model performance was high and perfect in light of the used evaluation parameters. Some areas in southern and northern parts of Africa were suitable for the prevalence of *P. latifrons* Kohl. and *P. triangulum* Fab under current conditions. The study maps for future conditions during 2050 and 2070 highlighted the negative effects of climate change on the prevalence of these pests in specific parts in Africa. The consequences of such prevalence/limitation of *P. latifrons and P. triangulum* on beekeeping in Africa were discussed.

***Keywords*:** beekeeping, Maxent, GIS, Modeling, honey bees

## INTRODUCTION

Some bee pests are mainly dominant in some parts of Africa including the bee pirate, *Palarus latifrons* Kohl and European beewolf, *Philanthus triangulum* Fabricius (Hymenoptera: Carbonidae) (Mally, 1908; Brauns, 1912; Mungai *et al.*, 2009). In fact, these pests have similar behavior and biology. Each of *P. latifrons* (commonly known as bee pirates) and *P. triangulum* (commonly known as bee wolves) can prey upon adult honey bee workers (Mally, 1908; Al-Ghamdi, 2004), causing decline in populations of bee colonies. The high numbers of these pests in the apiary location especially in front of hives can interrupt the normal flight activity of forager workers (Mally, 1908; Guy, 1972; Clauss, 1983; Mungai *et al.*, 2009). Basically, these pests are solitary insects belong to digger wasps and females attack bee workers to feed their larvae (Mally, 1908; Smith, 1961). The high numbers of bee pirates/bee wolves in the apiary location can greatly affect bee colonies especially the weak ones.

The available studies and information about these pests in Africa are very limited. It is well known that Africa represents the homeland for other bee pests including the small hive beetles (Neumann *et al.*, 2016) and the large hive beetles (Oldroyd and Allsopp 2017). The prevalence and potential effects of climate change on these beetles were previously studied (Abou-Shaara *et al.*, 2021 and Jamal *et al.*, 2021). So far, the studies on the possible prevalence of these pests in Africa under current and future climate conditions are not available. Indeed, the potential effects of climate change on the bee pests are expected to be high (Le Conte and Navajas, 2008; Abou-Shaara *et al.*, 2021; Jamal *et al.*, 2021). Understanding the potential spread of *P. latifrons* and *P. triangulum* in Africa under current and future environmental conditions can be achieved using Maxent and GIS models (Hosni *et al.*, 2020; Abou-Shaara *et al.*, 2021; Jamal *et al.*, 2021).

Further, specific environmental variables especially those related to temperature can be perfectly used to track the effects of future conditions on pest status (Abou-Shaara *et al.*, 2021; Abou-Shaara and Darwish, 2021; Jamal *et al.*, 2021) and beekeeping (Yoruk and Sahinler, 2013; Abou-Shaara, 2016). Such environmental variables are available for different time points in Worldclim website (Hijmans *et al.*, 2005). This website is used widely in modeling studies (Hosni *et al.*, 2020; Abou-Shaara *et al.*, 2021; Abou-Shaara and Darwish, 2021; Jamal *et al.*, 2021). The objective of this study therefore is to predicate the prevalence of *P. latifrons* and *P. triangulum* in Africa using the present and future climatic data. Accordingly, the possible damages to beekeeping due to the prevalence of these pests might be expected.

## MATERIALS AND METHODS

### 1. Occurrence records

The records in Africa were downloaded from Global Biological Information Facility (GBIF) for *Palarus latifrons* (https://doi.org/10.15468/dl.4aexqx) and for *Philanthus triangulum* (https://doi.org/10.15468/dl.rrpd75). Only the accurate occurrences were included in the study.

### 2. Environmental variables for current conditions

Six environmental variables with a spatial resolution of 5 $km^2$ were downloaded from WorldClim (worldclim.org, v2.1, January 2020) and used in this study according to previous publications (Jamal *et al.*, 2021; Abou-Shaara and Darwish, 2021; Abou-Shaara *et al.*, 2021). These variables were annual mean temperature, mean diurnal range, maximum temperature of the warmest month, minimum temperature of the coldest month, mean temperature of the warmest quarter, and mean temperature of the coldest quarter.

### 3. Environmental variables for future conditions

The six variables for future conditions during two time points 2050 and 2070 were obtained from the Beijing Climate Center (BCC-CSM2-MR) (Eyring *et al.*, 2016).

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These variables were downloaded at a Shared Socio-economic Pathway of 245 (SSP245). The SSP is used to predict future changes according to the Intergovernmental Panel on Climate Change (the 6$^{th}$ article).

**4. Maxent and GIS ecological models**

The ecological modeling was done using Maxent v 3.4.1 (Phillips *et al.*, 2020) following the steps used by Jamal *et al.* (2021), Abou-Shaara and Darwish (2021), and Abou-Shaara *et al.* (2021). Typically, the model used 25% and 75% of the records for testing and training the model, respectively. Separated maps for each bee pest were firstly obtained from Maxent and were classified into suitability classes (Phillips, 2017, Hosni *et al.*, 2020, Jamal *et al.*, 2021; Abou-Shaara and Darwish, 2021; Abou-Shaara *et al.*, 2021). Then, these maps were analyzed using geographical information system (GIS) to compare the two bee pests according to Abou-Shaara *et al.* (2021). The maps allowed the comparisons between the occurrences of the two bee pests in Africa under current and future climate conditions.

**5. Accuracy of the model**

Some parameters for test and training data were used during the analysis to assessed the accuracy of the model (Phillips, 2017; Jamal *et al.*, 2021; Abou-Shaara and Darwish, 2021; Abou-Shaara *et al.*, 2021). Typically, the jackknife tests and area under the curve (AUC) were applied.

## RESULTS AND DISCUSSION

**Results**

**1. Contribution percentages of variables in the model.**

The highest contribution was to the annual mean temperature followed by mean temperature of the coldest quarter for *P. latifrons* and *P. triangulum* (Table 1). This indicates the importance of these variables in the prevalence of these two pests. The third rank was to maximum temperature of the warmest month for *P. latifrons* and mean temperature of the warmest quarter for *P. triangulum*. The other three variables had percentages of 7.2 for *P. latifrons* and 3.3 for *P. triangulum*. It could be said the models used with each pest depended on two main variables related to annual mean temperature and coldest quarter of the year with a total percentage of 77.5 and 83.1 for *P. latifrons* and *P. triangulum*, respectively.

**Table 1. Contribution percentages of environmental variables in the model.**

| Variable | *Palarus latifrons* | *Philanthus triangulum* |
|---|---|---|
| Annual mean temperature | 59.9 | 68.2 |
| Mean diurnal range | 1.8 | 1.3 |
| Maximum temperature of the warmest month | 15.2 | 1.1 |
| Minimum temperature of the coldest month | 2.4 | 0.9 |
| Mean temperature of the warmest quarter | 3 | 13.7 |
| Mean temperature of the coldest quarter | 17.6 | 14.9 |

**2. Current distribution.**

The distribution of P. latifrons and P. triangulum is mainly in the southern parts of Africa and some parts in north Africa (Fig. 1A and B). The areas with the highest suitability for these pests are located in South Africa, Namibia, Botswana, Zimbabwe, Madagascar, and some parts of Egypt, Libya, and Morocco. The unsuitable areas for these two bee pests are located in desert areas in north Africa and some areas in the Sub-Saharan Africa. The more suitable areas for both pests are clearly shown in Fig. 2. Some areas in southern parts of Africa, Egypt and Libya are highly suitable mainly for P. latifrons while some areas in Algeria, Morocco, Kenya and Tanzania are highly suitable mainly for P. triangulum.

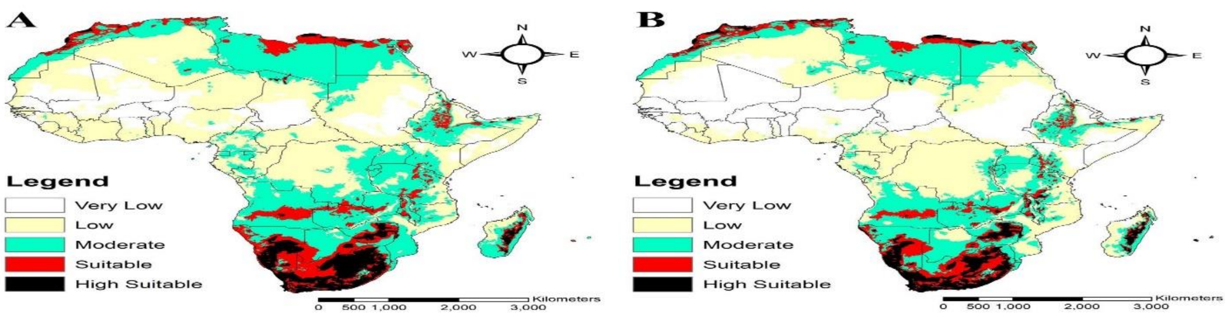


**Fig. 1. The potential prevalence of *Palarus latifrons* (A) *and Philanthus triangulum* (B) in Africa under current climatic conditions.**

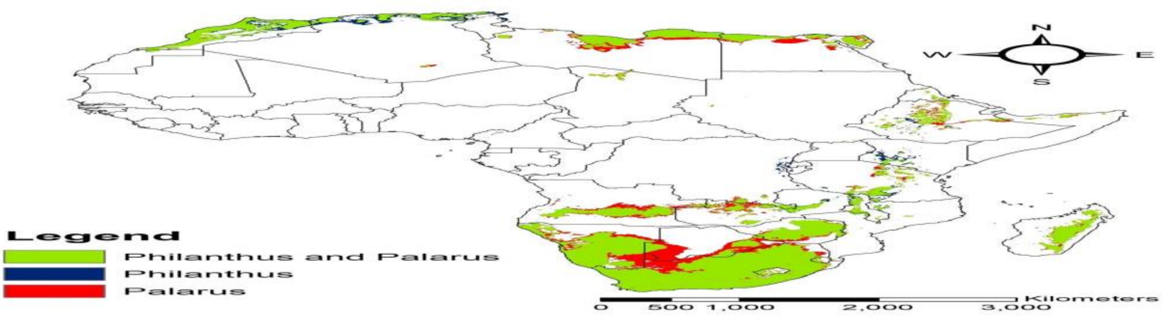


**Fig. 2. The suitable areas for *Palarus latifrons* and *Philanthus triangulum* in Africa under current climatic conditions.**

**3. Future distribution during 2050.**

The high suitable areas for the two pests are expected to be mainly in South Africa and nearby countries, Madagascar, and in some parts in north Africa mainly in Morocco, Libya and Egypt during the near future (2050) as shown in Fig 3A and B. The highly suitable areas for both pests are highlighted in Fig. 4. Some areas in South Africa, Namibia, Egypt and Libya are especially suitable for *P. latifrons* while some areas in Algeria, Morocco, Kenya and Tanzania are highly suitable for P. triangulum.

The gain/loss map (Fig. 5A and B) shows the variations between current conditions and future conditions in the prevalence of the two pests. It is clear that some areas in southern and northern parts of Africa (Fig. 5A) are expected to be negatively impacted by climatic conditions in the future causing limitation in the spread of *P. latifrons*. The negative effects on the spread of P. triangulum during future (Fig. 5B) are expected to be less than those on P. latifrons.

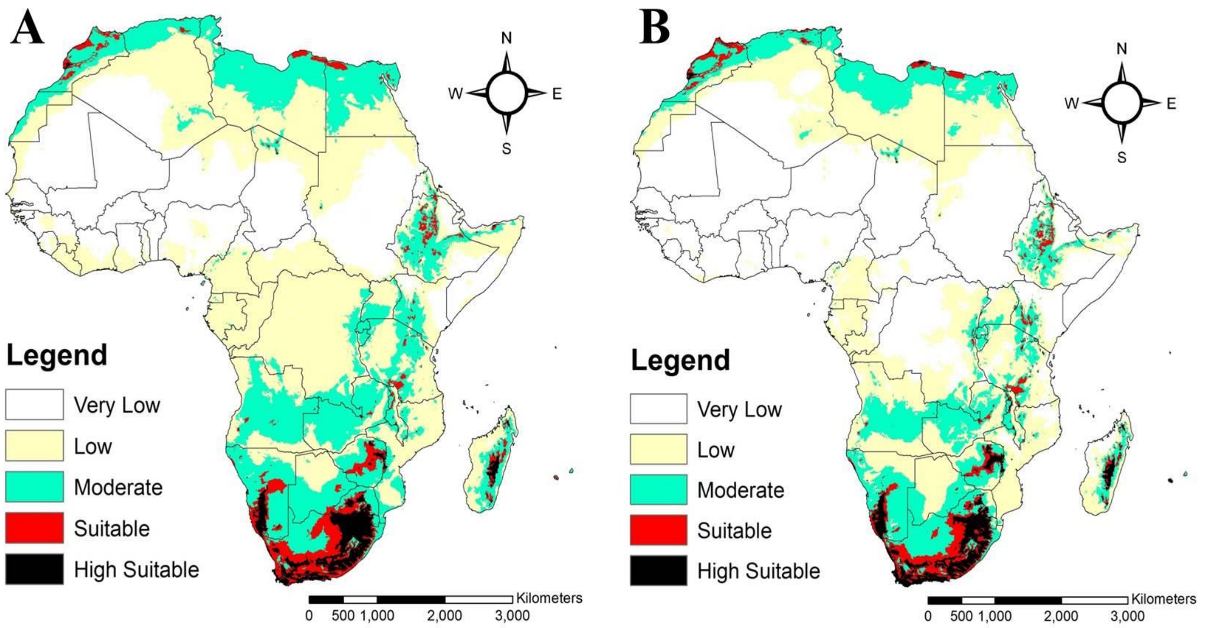


**Fig. 3. The potential prevalence of *Palarus latifrons* (A) *and Philanthus triangulum* (B) in Africa under future climatic conditions (2050).**

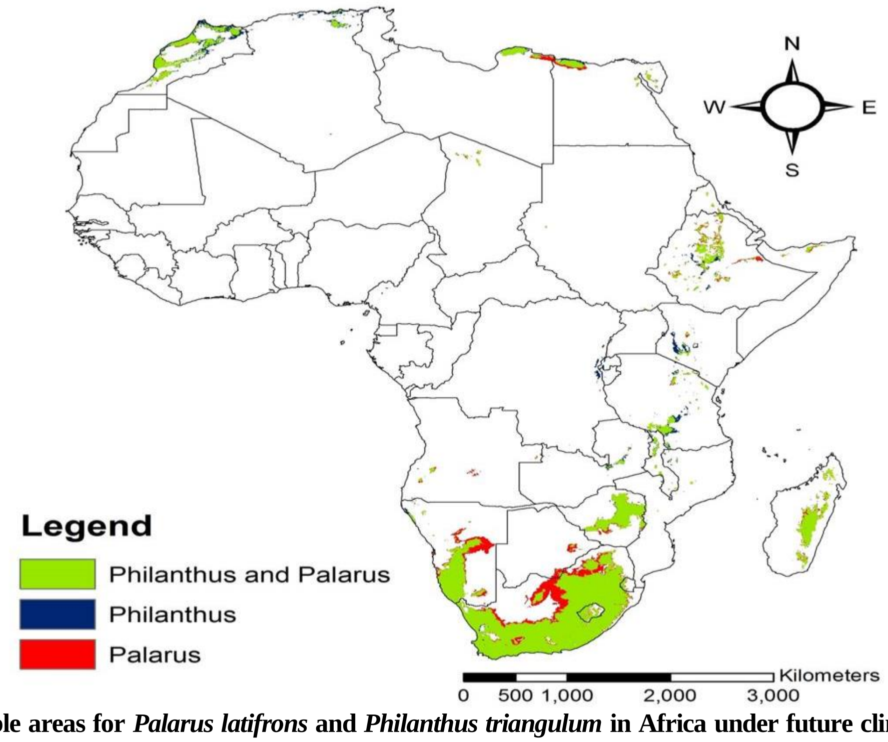


**Fig. 4. The suitable areas for *Palarus latifrons* and *Philanthus triangulum* in Africa under future climatic conditions (2050).**

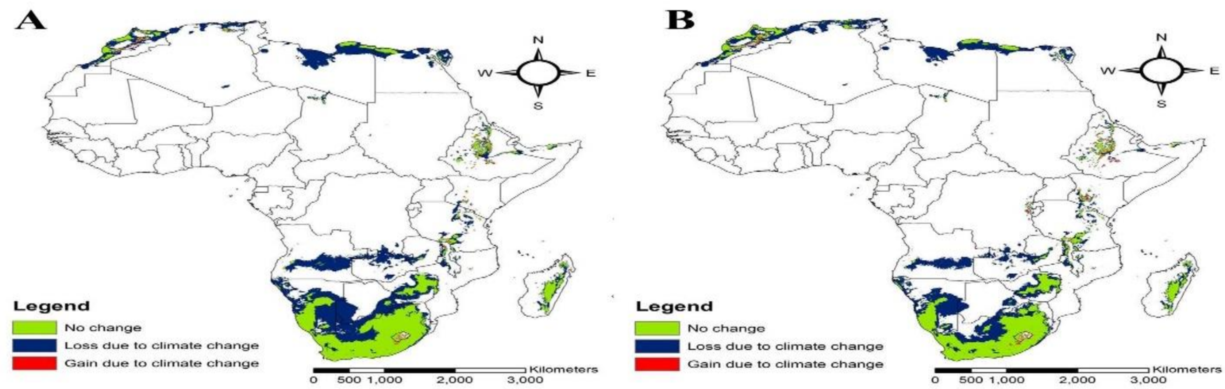


**Fig. 5. Map showing gain/loss in suitable areas for *Palarus latifrons* (A) *and Philanthus triangulum* (B) in Africa due to future climatic conditions (2050).**

**4. Future distribution during 2070.**

The moderate and suitable areas for P. latifrons (Fig. 6A) and P. triangulum (Fig. 6B) showed clear decline during 2070 than current conditions. The high suitable areas are expected to concentrate mainly in South Africa and some areas of Namibia. The prevalence in the other African countries is expected to be less than current prevalence especially in northern parts of Africa. The low suitable areas are expected to include mainly deserts and Sub-Saharan region. Fig. 7 highlights the suitable areas for P. latifrons and P. triangulum in Africa during 2070. Few areas in South Africa are expected to be mainly suitable for P. latifrons while some areas in Egypt, Morocco, Tanzania, and Kenya are expected to be mainly suitable for P. triangulum.

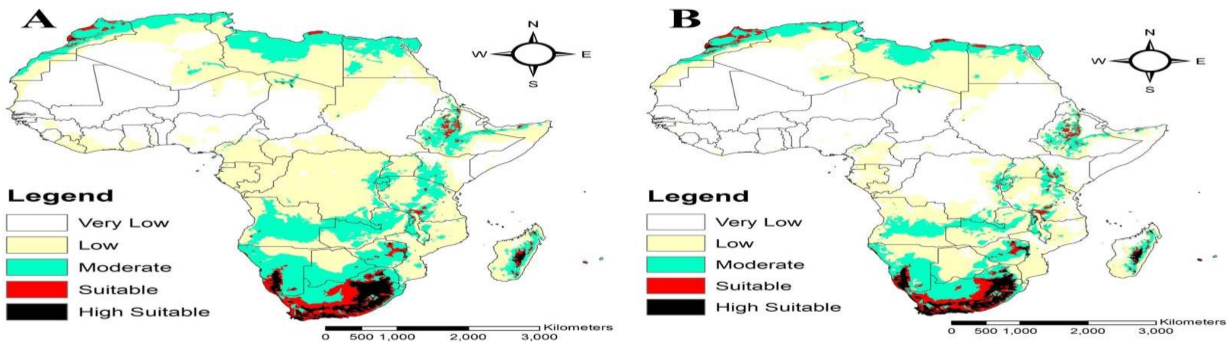


**Fig. 6. The potential prevalence of *Palarus latifrons* (A) *and Philanthus triangulum* (B) in Africa under future climatic conditions (2070).**

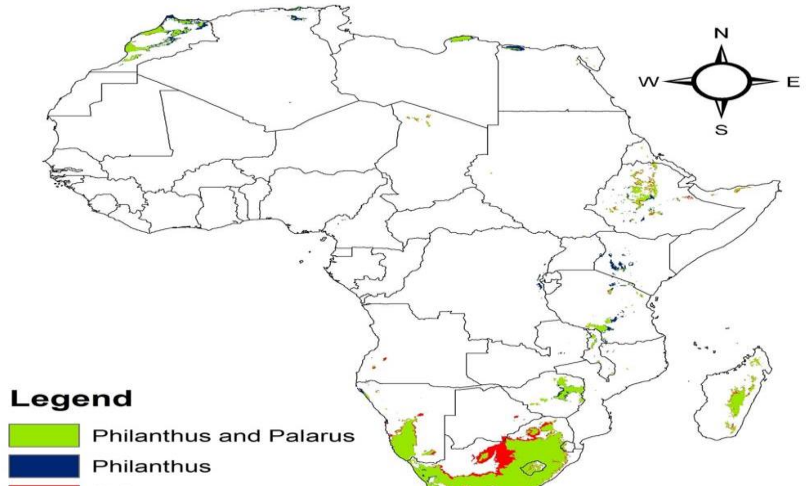


**Fig. 7. The suitable areas for *Palarus latifrons* and *Philanthus triangulum* in Africa under future climatic conditions (2070).**

The gain/loss map (Fig. 8A and B) highlights the variations between current conditions and future conditions during 2070 in the prevalence of the two pests. It is clear that some areas in southern and northern parts of Africa are expected to be negatively impacted by climatic conditions in the future causing limitation in the spread of *P. latifrons* and *P. triangulum*. The gain areas due to climate change are expected to be mainly located in South Africa.

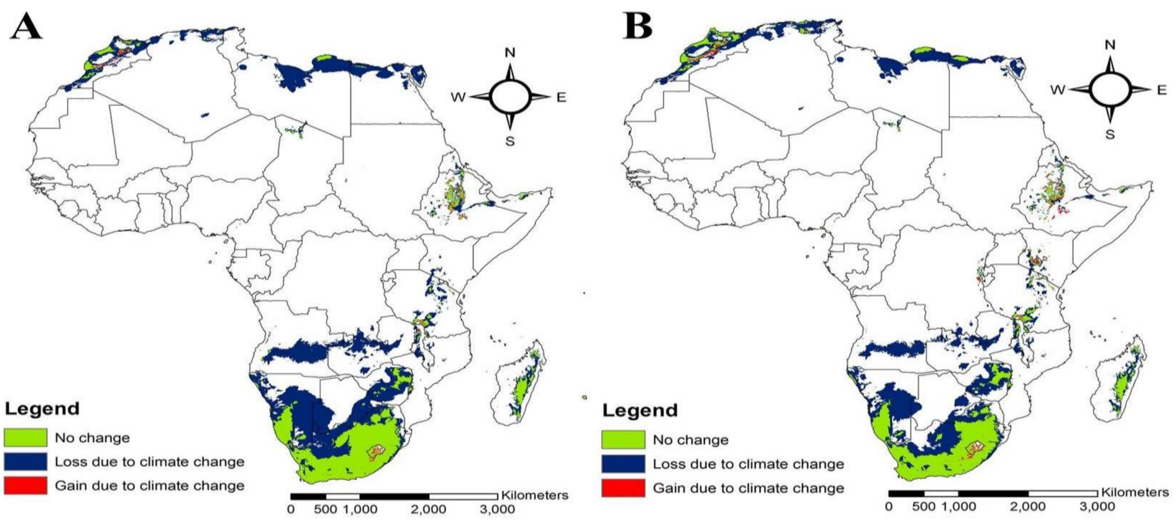


**Fig. 8. Map showing gain/loss in suitable areas for *Palarus latifrons* (A) *and Philanthus triangulum* (B) in Africa due to future climatic conditions (2070).**

**4. Model accuracy.**

The evaluation of the model accuracy based on specific parameters is shown in Fig. 9 and Fig. 10. The receiver operating characteristic (Sensitivity versus 1-Specificity) show high values of area under curve (AUC) for *P. latifrons* (Fig. 9A) with values of 0.953 and 0.940 and *P. triangulum* (Fig. 9B) with values of 0.903 and 0.945 for test and training data, respectively. Indeed, all values are high and close to 1.

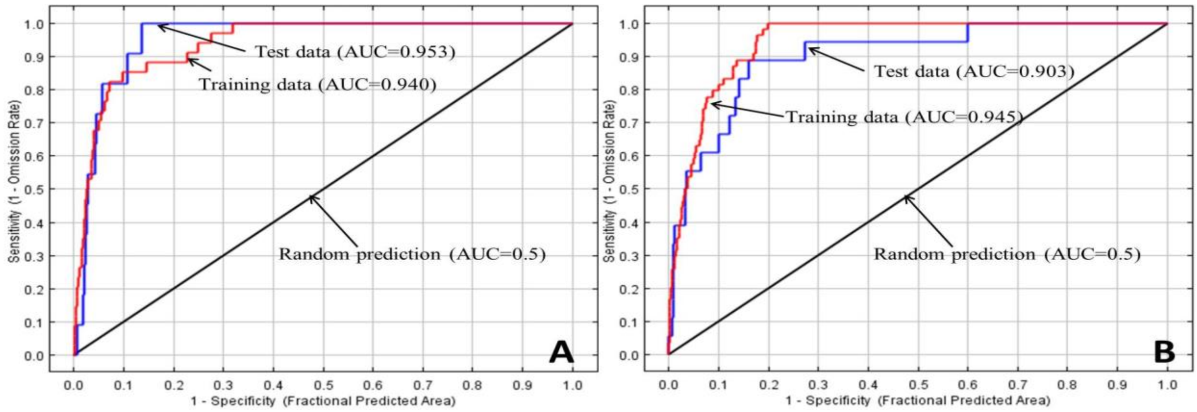


**Fig. 9. The receiver operating characteristic (Sensitivity versus 1-Specificity) for *Palarus latifrons* (A) *and Philanthus triangulum* (B). AUC: area under curve.**

Fig. 10 shows the values of the jackknife test for the used environmental variables in the model. The area under curve for all variables were higher than 0.80 except mean diurnal range for *P. latifrons* (Fig. 10A) and were higher than 0.70 except mean diurnal range for *P. triangulum* (Fig. 10B).

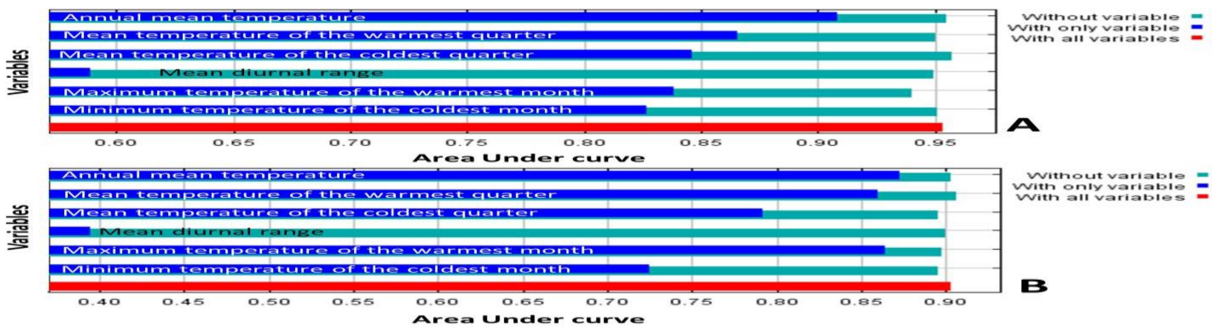


**Fig.10. The jackknife test for the six variables used in the analysis for *Palarus latifrons* (A) *and Philanthus triangulum* (B).**

## Discussion

### 1. Contribution percentages of variables in the model.

It is well known that temperature is very important for the development of organisms including different bee pests (Dama, 2014; Thomas *et al.*, 2016). The two pests were similar in regard to the contribution of annual mean temperature followed by mean temperature of the coldest quarter in forming the ecological model. This reflects the specific importance of these two variables for *P. latifrons* and *P. triangulum*. Indeed, these pests are similar in their biology and damages to bee colonies.

### 2. Current distribution.

The map for current prevalence of *P. latifrons* and *P. triangulum* in Africa highlighted the occurrence in some southern and northern parts of Africa. This distribution is fit with the actual distribution of these pests in Africa. It seems that *P. latifrons* and *P. triangulum* are able to adapt with various environmental conditions including coastal regions in north Africa and tropical/sub-tropical regions in southern parts of Africa. It is expected that damages to apiaries located in the high suitable areas for *P. latifrons* and *P. triangulum* are high. So, studies to follow the prevalence of these pests are required.

### 3. Future distribution during 2050.

Future conditions during 2050 are expected to limit the spread of *P. latifrons* and *P. triangulum* to some areas in southern and northern parts of Africa. The distribution in the near future (2050) is expected to less than that of current conditions. However, South Africa, Madagascar, some parts in Morocco, Libya and Egypt are expected to be highly suitable for these pests. Therefore, damages to bee colonies are expected to occur in the high suitable regions during the near future. In fact, the negative effects of climate change during 2050 on these pests can be considered as an advantage for beekeeping. Therefore, tracking areas without high infestation for the establishment of apiaries is expected to be a good option to reduce damages from these pests.

### 4. Future distribution during 2070.

The maps for future conditions during 2070 showed high effects of climate changes on the prevalence of *P. latifrons* and *P. triangulum* in Africa. Many areas are expected to be less suitable for these pests in southern and northern parts of Africa during 2070 than the current conditions. Further, such limited spread is expected to be more than spread during 2050. However, South Africa and some areas of Namibia are expected to be highly suitable for these pests but with less degree than current conditions and future conditions in 2050. The damages for beekeeping due to these pests in Africa are anticipated to be less than current conditions. It worth to mention that beekeeping is an important activity to Africa especially countries in north Africa (Abou-Shaara, 2015; Abou-Shaara, 2016; Al-Ghamdi *et al.*, 2016), but it is developed rapidly in other African countries (Chemurot, 2011; Carroll and Kinsella, 2013; Brodschneider, 2020). In fact, there are no specific data about damages to apiaries. Therefore, studies to specify damages from these pests are recommended. Furthermore, there are no more options to control these pests except damaging nests or trapping adults. Thus, developing methods for the control of these pests are important including the search for a biological control agent (Abou-Shaara and Staron, 2019).

### 4. Model accuracy

The model accuracy was high and perfect based on the results of obtained parameters. The values of area under curve for training and test data were high and close to 1 in case of *P. latifrons* and *P. triangulum*. Such high values indicate the perfect performance of the model (Mulieri & Patitucci, 2019; Hosni *et al.*, 2020; Abou-Shaara et al., 2021; Abou-Shaara and Darwish, 2021; Jamal *et al.*, 2021). Therefore, the jackknife tests for all variables used with *P. latifrons* and *P. triangulum* showed high values over 0.70 except one variable. This supports the good performance of the used models.

## CONCLUSION

Effects of climate changse during 2050 and 2070 on the prevalence of *Palarus latifrons* and *Philanthus triangulum* in Africa were studied using ecological modeling utilizing Maxent and GIS. The performances of the used models were high and perfect according to the used evaluation parameters. Two temperature variables contributed highly in the used models (namely; annual mean temperature and mean temperature of the coldest quarter). The maps of current and future conditions showed the expected prevalence of these pests in southern and northern parts of Africa. The suitable areas for these pests are expected to be negatively impacted by future conditions especially during 2070. The low prevalence for these pests was mainly in desert areas and some parts close to Sub-Saharan. Beekeeping in the highly suitable areas for these pests is expected to suffer greatly. So, it is recommended to establish apiaries away from the highly suitable areas for these pests. Also, studies on the damages of these pests to bee colonies are required. Moreover, developing effective control methods for these pests are recommended.

**Authors' contributions**

H.A. and K.E. designed, performed, wrote and revised the manuscript. The authors read and approved the final manuscript.

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## تأثيرات تغير المناخ علي انتشار إثنين من آفات نحل العسل ( *Palarus latifrons , Philanthus triangulum* ) في أفريقيا

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آفتي نحل العسل *Palarus latifrons* ، *Philanthus triangulum* يوجدا تقريبا في نفس الأجزاء من أفريقيا. ولهاتين الآفتين دورات حياة وأضرار متشابهة علي طوائف نحل العسل. وتأثيرات تغير المناخ في المستقبل علي انتشار هاتين الآفتين في أفريقيا لم يتم دراستها من قبل. وهذه النقطة هي محور اهتمام الدراسة الحالية. وقد تم استخدام النمذجة البيئية باستعمال برنامج Maxent ، نظم المعلومات الجغرافية (GIS) وذلك لإنجاز هدف الدراسة. ووجد أن أعلي مساهمة في النموذج كانت من خلال متوسط درجات الحرارة السنوية متبوعة بمتوسط درجات حرارة الربع السنوي الأكثر برودة. كما وجد أن للنموذج أداء عالي ومثالي في ضوء مؤشرات التقييم المستخدمة. وكانت بعض المناطق في الأجزاء الجنوبية والشمالية من أفريقيا مناسبة لانتشار كلا من *P. latifrons* ، *P. triangulum* تحت الظروف الحالية. كما أن خرائط الدراسة للظروف المستقبلية المتوقعة خلال الفترة من ٢٠٥٠-٢٠٧٠ سلطت الضوء علي التأثيرات السلبية لتغير المناخ علي انتشار تلك الآفات في أجزاء محددة من أفريقيا. أيضا تم مناقشة عواقب انتشار/انحسار آفتي الدراسة *P. latifrons* ، *P. triangulum* علي النحالة في أفريقيا.

***الكلمات المفتاحية***: النحالة، Maxent ، GIS ، النمذجة ، نحل العسل