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Spatial Distribution and Abundance of *Chrysomya bezziana* in Jazan Province, Saudi Arabia Using GIS

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ABSTRACT

Myiasis caused by Calliphorid and Oestrid flies constitute a major threat to the development of livestock industry in Kingdom of Saudi Arabia. Increased veterinary concerns recently paid to the frequent reports on enteric pathogens caused by the larvae of these flies. Although the importance of sheep and goats in Saudi Arabia, the geographic distribution limits of Calliphorid and Oestrid infestation in caprine livestock has never been highlighted. ArcGIS software was used to assess the spatial distribution of myiasis causing flies in Jazan Province, Saudi Arabia. Implemented Evolutionary algorithms in maximum entropy (MaxEnt) was used to predict the distribution map for myiasis causing flies. Bioclimatic and topographic data layers from Worldclim was analyzed to estimate the percent contribution of variables predicting suitable habitats of flies causing myiasis. Field validation was occurred to evaluate the habitat suitability produced by the model. The predictive ecological niche model was found high with an AUC value of 0.95 and 0.93 for train and test occurrence records, respectively, with a standard deviation equal 0.032. About eighteen variables were found to contribute in spatial predictive occurrence of myiasis causing flies. Precipitation variables enhanced the model predictive power with (57.7%) in Jackknife test. Besides, elevation, NDVI and tree cover shared reduced effect in predicting myiasis causing flies distribution.

Key words: Myasis, MaxEnt, Spatial distribution modelling, Oestrid flies, Field validation

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INTRODUCTION

The Kingdom of Saudi Arabia is an extremely arid area, except for some coastal and mountains regions (Byrd & Castner, 2010). It lies in the southwestern part of Asia and extended through three ecological zones (Palearctic, Afrotropical and Oriental regions) (Clement, Hellier, Elberson, Staska, & Evans, 2007). Jazan Province, the southwestern part of the kingdom, is intermingled between three distinct topographical zones: Sarawat Mountains, Asir Plateau and Tihama lowlands (Mullen & Durfen, 2009). The diversity in topography alongside with significant variation in weather give the chance of wide variation in insect fauna in spatial and temporal scales especially for parasitic species such as myiasis causing flies (Nasser, Alahmed, & Shobrak, 2016; Al Ahmed et al., 2020).

Myiasis cause a serious reduction in livestock production in Southern Saudi Arabia including Jazan Province. Sporadic and consistent cases were recorded in previous studies from different areas in Saudi Arabia. The previous studies addressed seasonal fluctuation and abundance of different flies' taxa causing myiasis (Ansari & Oertley, 1982; Omar & Abdullah, 1992; Fatani & Hilali, 1994; Alahmed, 2002, 2004; El Azzazyz & El Metenawy, 2004; Abu Shehada, 2005; Alahmed, Al Dawood, & Kheir, 2006; Dawah & Abdullah, 2009; Zaglool et al., 2013; Setyaningrum & Al Dhafer, 2014; Hosni et al., 2019; Al Ahmed et al., 2020). At least four families have been incriminated in causing myiasis in the Kingdom, of which family Calliphoridae (blow flies) was the most important (Deeming, 2008). Thirty-four calliphorid species were reported from the Kingdom (Setyaningrum & Al Dhafer, 2014), but species of genus *Chrysomya* are known to cause myiasis in man and domestic animals (Deeming, 1996; Alahmed, et al., 2006, Nasser et al., 2021). In Saudi Arabia, *C. albiceps* and *C. megacephala* have been implicated as causing myiasis in camels (Gadallah & Bosly, 2006), whereas *C. albiceps* and *C. bezziana* were reported to cause myiasis in sheep and goats (Alahmed, 2002, 2004; Alahmed et al., 2006).

The significance of investigating the spatial distribution of blow flies stems from their importance in myiasis, pollination, and forensic tool (Kurahashi, 1989). Few previous studies tried to predict the geographic distribution of myiasis causing flies in response to climate variables. Although, many works concluded some correlations between infestation intensity and few climate parameters such as temperature and humidity (Fatani & Hilali, 1994) or between flies' development and temperature (Siddig et al., 2005), their findings were focal, lack consistent sampling design, and may not be applicable in large scale areas. To address limitations of previous studies, Geographic information system (GIS) and modeling tools were used to assess the geographic distribution range of flies causing myiasis in response to climatic, topographic, and land cover related variables in Jazan Province in other studies.

Geospatial mapping using GIS and modeling tools proved significant potentiality in predicting suitable habitats of insect pests in a large scale to a degree that is difficult or impossible using conventional ground survey (Sallam, Ahmed, Abdel-Dayem, & Abdullah, 2013; Al Ahmed, Naeem, Kheir, & Sallam, 2015; Hosni, Nasser, Al-Ashaal, Magda, & Mohamed, 2020; Abou-Shaara et al., 2021). Recently, distribution modeling tools were widely applied using different approaches/methods such as generalized linear model (GLM), generalized additive model (GAM), multivariate adaptive regression splines model (MARS), hierarchical modeling, artificial neural network (ANN), random forest, genetic algorithm for rule-set prediction (GARP), maximum entropy and boosted regression tree (BRT) (Conley et al., 2014). The potentiality of each modeling tool in predicting species distribution depends on the sensitivity and specificity. Some of these tools depends on using presence/absence records such as BRT, however, the occurrence of absence and presence record at the same sampling site negatively affect the sensitivity of the analysis (Phillips, Anderson, & Schapire, 2006). In addition, most of the modeling tools is sample size dependent and their accuracy is positively correlated with the sample size. Nevertheless, MaxEnt is less sensitive to the sample size (Hosni et al., 2020).

The generation of risk maps for parasitic insects such as *Chrysomya bezziana* will help decision makers at the veterinary sector of Ministry of Agriculture to evaluate the risk of myiasis cases and give them the upper hand in its control. Consequently, this work aims at implementing modeling and GIS techniques in studying the spatial distribution of *Chrysomya bezziana* through Jazan province and giving notes on ecological and climatological parameters governing such distribution.

RESEARCH MATERIAL AND METHODOLOGY

Study area

Kingdom of Saudi Arabia (KSA) occupies approximately 2,250,000 km^2 of the Arabian Peninsula with a variable topography including areas of arid, semiarid, and forested landscape. (CDSI, 2010). The current study was conducted in Jazan Province, which is located in southwestern Saudi Arabia (Fig. 1) and includes ~13,432 km^2 (SGS 2012) inhabited by 1,365,110 people averaging 117 people/km^2 (CDSI, 2010). Topology and climate of Jazan can be categorized into three distinct sectors: the eastern Sarawat Mountains range 2,000-2,500 m Above sea level (a.s.l.) with an annual precipitation rate >300mm; hilly middle areas north to south with elevation range 400-600m a.s.l. and <300mm rain/year; and the coastal western plains with elevation <400m a.s.l. and little, if any, annual precipitation (Fig. 2). Overall, the Province has typically two rainy seasons, May-July and September-November (Ageel &Amin, 1997).

Jazan Province is divided into nine administrative districts (Fig. 1): Al Shaquiq (69,134 people/3632 km^2), Baysh 774, 421people /827 km^2) Sabya (22,8375 epeopl /1,983 km^2), Al Eidaby (60,799 people/1,290 km^2), Abu Areish (197,112people /927 km^2), Al Ardah (76,705people /852 km^2), Jazan (157,536 people/887 km^2), Ahad Al Msarhah (110,710 people/1,348 km^2), and Farasan (17,999 people /686 km^2) (CDSI 2010) (Fig. 3).

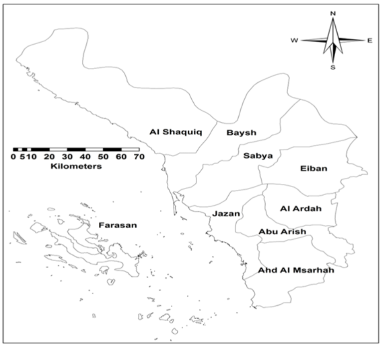

Figure 1. Map of Jazan Province and its administrative districts.

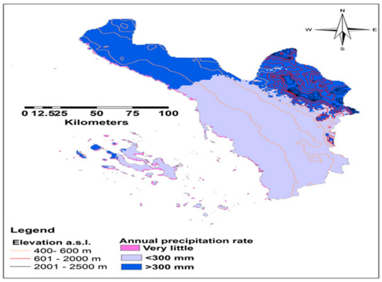

Figure 2. Map of Jazan Province representing different elevation levels and annual precipitation rate.

Spatial distribution of myiasis causing flies using Geographical Information System (GIS).

The adult flies were trapped using Red Top Fly Catcher (Matthew Hicks, Ashmoat Ltd, Suffolk, U.K.) baited with decomposed beef liver while the larvae were collected from infected animal cases (Camels, Goats and Sheep) with forceps. The adult flies were dried and preserved on separated plastic petri dishes, on the other hand the larvae were firstly preserved on 70% ethical alcohol and then some sample mounted on the slide for identification. The collected samples were identified according to Zumpt (1965), Hall & Smith (1993), Deeming (2008),Rognes (2002) and Setyaningrum & Al Dhafer (2014). To identify the spatial distribution of myiasis causing flies, occurrence records of predominant adult and larval flies causing myiasis and spatial statistics tools in ArcGIS software were used. Characterization of suitable habitats for myiasis causing flies and model its spatial distribution in response to climate, land cover and topographic variables, nineteen bioclimatic variables (11 layers of temperature and 8 precipitation indices) and elevation layer were obtained from the WorldClim database ver.1.4 (www.worldclim.org) (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005). These layers are available at a 30 arc-seconds (~1km) resolution. Also, aspect ratio, slope, curvature, and hill shade were developed from the digital elevation model (DEM) using ArcGIS ver. 10.5.

Since vegetation has a significant importance for grazing sheep and shepherding activities, vegetation data was used in our model to assess the association between myiasis and type of vegetation. Therefore, normalized vegetation index (NDVI) was used as indicator for the vegetation type that may be associated with myiasis records. Also, it was reported in previous investigations that infestation with myiasis may be associated with certain land cover types; therefore, land cover data layer was included in our model. In addition, from the standing point that larval stage of myiasis causing flies need to pupate in soil, the distribution of emerged adult flies may be correlated with the soil type. Thereby, we used soil data layer to figure out the dependency of dipterous flies' distribution on soil as well.

Total of thirty-one bioclimatic, topographic, vegetation, soil types and surface water layers were then clipped to match dimensions of Jazan Province and saved as ASCII grids using Model Builder in ArcGIS software v.10.5 Jazan Province digital maps representing boundary, administrative districts were imported from Diva-GIS spatial database (http://www.diva-gis.org/Data).

Ecological niche model of myiasis causing flies

Maximum Entropy (MaxEnt) software v. 3.4 (Phillips et al*.,* 2006; Phillips & Dudik, 2008) was used to assess the spatial distribution and predict the ecological habitats of myiasis causing flies over the study area. The software uses only the occurrence records of recorded flies either adult or larvae and model their spatial distribution in response to the climatic and non-climatic variables.

The software was configured to the "Auto Features" mode as suggested by Phillips and Dudik (Elith et al., 2006), the logistic output format, and ASCII output file type. Since our model was counting on the occurrence records, the model was run with almost ~ 10,000 background data to represent pseudo-negative data beside the positive records we collected during the field visits.

MaxEnt reduces the duplicate records within ~1km of the same cell size (Zhou Munga, Minakawa, Githeko, & Yan, 2007). Records of myiasis causing flies (larvae and adults) were randomly partitioned for model evaluation into two subsamples: 75% of the records used for training and building up the model, and the remaining records (25%) were used for testing the model's accuracy. In this model, two indicators have been used to examine the performance accuracy. Extrinsic omission was evaluated at fixed threshold (10 percentile training presence) and the area under the curve (AUC) of the receiver operating characteristics (ROC). Although, MaxEnt uses only presence records data, negative (absence) data records of flies causing myiasis collected during surveillance were used to validate the produced prediction maps from MaxEnt. JackKnife analysis in MaxEnt was used to estimate the percent contribution of predicting variables to the model.

A total of 31 bioclimatic, topographic, vegetation, surface water, and soil types of data layers (Table 1) were used to predict the habitat suitability, and spatial distribution of myiasis causing flies. To represent the spatial range of myiasis causing flies, the predicted habitat probability was categorized into three classes: very low-low (0-0.2), medium (>0.2-0.4), and high-very high (>0.4) using natural breaks in the symbology tools in ArcGIS software v.10.5.

Table 1. Percent contribution of the thirty-one variables used in the MaxEnt niche model to predict the spatial distribution and risk assessment of myiasis causing flies (adult and larvae) in Jazan Province, Kingdom of Saudi Arabia.

Variable	Variable name	Percent contribution
bio16	Precipitation of Wettest Quarter	39.3
bio7	Temperature Annual Range (BIO5-BIO6)	17.1
slope	Slope	15.2
alt	Elevation in meters	9.6
ndvi_sept	Normalized Difference Vegetation Index in September	3.9
bio13	Precipitation of Wettest Month	3.3
bio19	Precipitation of Coldest Quarter	3.1
bio14	Precipitation of Driest Month	1.6
tree	Tree cover	1.3
bio3	Isothermality (BIO2/BIO7) (* 100)	1.2
hillshade	Hill shade	0.8
bio1	Annual Mean Temperature	0.7
bio15	Precipitation Seasonality (Coefficient of Variation)	0.7
bio12	Annual Precipitation	0.5
curvature	Land Curvature	0.5
bio4	Temperature Seasonality (standard deviation *100)	0.4
ndvi_may	Normalized Difference Vegetation Index in May	0.4
bio11	Mean Temperature of Coldest Quarter	0.3
soil_jazan	Soil types	0
bio8	Mean Temperature of Wettest Quarter	0
bio6	Min Temperature of Coldest Month	0
lancover	Land cover	0
ndvi_march	Normalized Difference Vegetation Index in March	0
bio5	Max Temperature of Warmest Month	0
bio2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	0
bio18	Precipitation of Warmest Quarter	0
bio17	Precipitation of Driest Quarter	0
bio9	Mean Temperature of Driest Quarter	0
bio10	Mean Temperature of Warmest Quarter	0
aspect	Aspect ratio	0
water	Surface water streams/bodies	0

Field validation of the model:

The field validation was done at the best climatological condition of the Jazan region which known for its Afrotropical climate. So, A field survey was carried out for 15 days during January 2015, to evaluate the habitat suitability produced by our model. For the field validation, 77 sampling points were randomly selected and visited. Sampling design tool (SDT) in ArcGIS was used to randomly select field validation points representing the three-predicted habitat suitability. In this regard, the generated prediction maps from MaxEnt were used to select the validation points.

RESULTS

Ecological niche model of myiasis causing flies

The model was performed using 24 points (75%) for training and 7 points (25%) for testing. The predictive performance was found high with an AUC value of 0.95 and 0.93 for train and test occurrence records, respectively, with a standard deviation of 0.032. The fractional predicted area, at 10 percentile training presence was 0.136 and the test point's omission rate was 0.143. These points were classified as significantly better than random (P<0.0001). MaxEnt predicts 670.43 km^2 of very high suitable habitat (predicted risk probability >0.60), which is 4.99% of the total area of Jazan Province (Fig. 4).

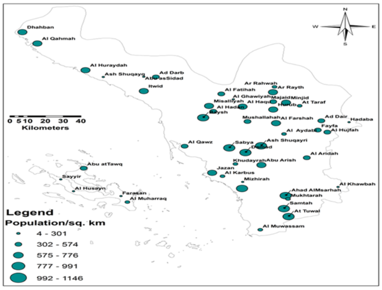

Figure 3. Map of Jazan Province representing distribution of human population.

Generally, the MaxEnt created model for myiasis causing flies supported two topographic sectors representing elevations ranges from 30-600 m. The very high predicted suitable habitat was found to be spotty in two main sectors with different elevations. The prediction map indicated consistent major distribution of high-very high suitable predicted habitats in hilly middle near the cities of Abu Areish, Al Eidaby, Sabya, Ahd Al Masarhah, and Al Ardah within the elevation range of ~600 m a.s.l. Also, another area was indicated as high-very high suitable predicted habitat along the western coast of the Jazan Province at an elevation range 0-30m (Fig. 4).

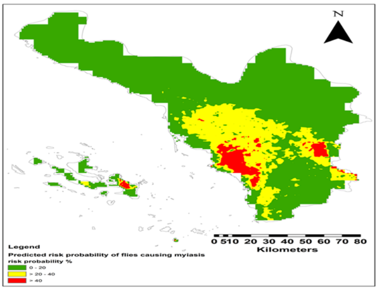

Figure 4. Predicted risk probability and spatial distribution range of *Chrysomya bezziana* through Jazan Province, Saudi Arabia.

Contribution of the variables to the model

Among the 31 variable layers used for spatial predictions using MaxEnt software, 18 variables were found to contribute in predicting occurrence of myiasis causing flies

(Table 1). The Jackknife test showed the precipitation variables significantly improved predictive power (57.7%) with the highest training gain compared to other environmental variables. The precipitation of the wettest quarter variable (bio16) presented the utmost training gain in the model. Furthermore, the temperature related variables shared a significant reduced training gain (19.7%) with precipitation in the model.

In addition, elevation, NDVI and tree cover shared reduced effect in predicting myiasis causing flies distribution (9.6, 4.3, and 1.3). Whereas the hill shade and curvature showed the least influence on spatial distribution of flies (0.8, and 0.5).

Field validation of the model

Out of 77 randomly selected field validation points, 53 sites (68.83%) were positive for dipterous myiasis causing flies (larvae and adult), whereas 24 (31.17%) were negative (Table 2). Of these positive collection sites, twelve (85.71%) in high-very high, nine (23.08%) in medium, and four (16.67%) in low-very low risk predicted areas were recorded.

Table 2. Risk probability percent in field validation of the model.

Risk probability %	Longitude	Latitude	Result
0 - 20	42.59	17.61667	negative
	42.5	17.54667	negative
	42.64	17.53667	negative
	42.76	17.50667	negative
	42.44	17.43667	negative
	42.87	17.35667	negative
	43.1	17.31667	negative
	42.94	17.16667	positive
	42.92	17.12667	positive
	42.98	16.95667	negative
	42.99	16.89667	negative
	42.96	16.84667	positive
	42.9	16.83667	positive
	42.9	16.77667	negative
	43.01	16.76667	negative
	42.87	16.73667	negative
	43.06	16.73667	negative
	43	16.66667	negative
	42.93	16.65667	negative
	43.06	16.62667	negative
	42.75	16.59667	negative
	42.97	16.56667	negative
	42.86	16.55667	negative
	43.07	16.55667	negative
> 20 - 40	42.57	17.43667	positive
	42.5	17.40667	positive
	42.63	17.40667	positive
	42.68	17.37667	positive
	42.75	17.35667	positive
	42.53	17.34667	positive
	42.62	17.34667	positive

Table 2. continued

Risk probability %	Longitude	Latitude	Result
	42.6	17.30667	positive
	42.48	17.29667	positive
	42.65	17.29667	negative
	42.57	17.28667	negative
	42.85	17.27667	negative
	42.5	17.26667	negative
	42.74	17.26667	negative
	42.43	17.24667	negative
	42.66	17.23667	negative
	42.55	17.22667	negative
	42.72	17.21667	negative
	42.52	17.19667	negative
	43.01	17.19667	negative
	42.76	17.17667	negative
	42.61	17.14667	negative
	43.03	17.14667	negative
	42.57	17.11667	negative
	42.7	17.11667	negative
	42.75	17.04667	negative
	43.01	17.01667	negative
	42.78	16.95667	negative
	43.07	16.94667	negative
	43.12	16.90667	negative
	43.16	16.81667	negative
	42.96	16.76667	negative
	43.16	16.76667	negative
	43.23	16.76667	negative
	42.8	16.73667	negative
	42.82	16.63667	negative
	42.8	16.54667	negative
	42.82	16.45667	negative
	42.84	16.38667	negative
> 40	42.77	17.12667	positive
	42.78	17.07667	positive
	42.6	17.04667	positive
	43.07	17.04667	positive
	42.68	17.02667	positive
	43.07	17.00667	positive
	43.11	17.00667	positive
	42.66	16.98667	positive
	42.73	16.98667	positive
	42.62	16.97667	positive
	42.65	16.92667	positive
	42.66	16.88667	negative
	42.71	16.84667	positive
	42.76	16.73667	negative

DISCUSSION

In the last two decades many investigations have demonstrated that GIS and modeling techniques tools are important tools in producing spatial prediction maps to give better understanding of the ecological factors affecting transmission of infectious diseases (Dambach et al., 2012) and to study the spatial and temporal patterns of vector borne diseases (Kulkarni, Desrochers, & Kerr, 2010, Abdel-Dayem, Annajar, Hanafi, & Obenauer 2012, Sallam et al*.,* 2013). The GIS and modeling tools were previously used potentially in mapping other vectors of diseases such as mosquito in Jazan Province (Sallam et al., 2013) and other regions (Zhou et al., 2007; Rohani et al., 2010). Similarly, these tools may potentially help in characterizing myiasis causing flies and their suitable habitats, and ultimately predicting the spatial risk of their occurrence. Accordingly, this will substantially help in producing risk maps to be used in decision making and implementing targeted control measures.

The habitat suitability model and risk maps summarize the distribution range of flies' suitable habitats. Moreover, a niche model for these myiasis causing flies in Jazan Province, KSA was built using most recent field data set on species occurrence and incidences of animal cases. In addition, the model was evaluated using independent field validation data records in assistance with the produced risk map. Moreover, the model examined the spatial heterogeneity of suitable habitats and resulting risk distribution range of myiasis causing flies.

This study elucidated the dependency of myiasis causing flies on climate and environmental variables (Precipitation, temperature, NDVI and tree) in Jazan Province. Previous studies either highlighted seasonal fluctuation and abundance of different flies' taxa (Abo Shehada 2005; Ansari & Oertley 1982; Alahmed, 2002, 2004; Alahmed et al., 2006; Dawah & Abdullah, 2009; El Azazy & El Metenaw, 2004; Fatani & Hilali, 1994; Omar & Abdullah, 1992; Setyaningrum & Al Dhafer, 2014; Zaghlool, Tayeb, Khodari, & Farooq, 2013) or the incidence rate and development of flies (Fatani & Hilali, 1994; Siddig et al., 2005). Although the importance of sheep and goats in Saudi Arabia, the geographic distribution range of Calliphorid infestation in livestock has never been highlighted. So, this work form the first study that applied the biogeographical tools in studying one of the most important myiasis causing fly of the Arabian Peninsula.

Sporadic previous studies addressed some correlations between few species of myiasis causing flies and some climate variables. Al Ahmed et al*.* (2006) highlighted the influence of seasonal activity of myiasis causing flies in livestock in Riyadh Region by the prevailing climatic conditions and availability of hosts. Similar studies concluded that variation in percentage of camels' infestations with *Cephalopina titillator* in the Eastern Region of Saudi Arabia were negatively correlated with monthly mean temperature and positively correlated with relative humidity (Fatani & Hilali, 1994). Moreover, they found that the percentage of infested camels and the mean monthly total number of larvae per camel showed two peaks during February (96.06% and 25.06 larvae per camel) and September (88.9% and 27.5 larvae per camel).

In addition, the pupal development of *C. bezziana* in Iraq was found to be limited by the low temperatures during winter, whereas the hot/dry summer conditions limit the geographic dispersal of adult flies. In these foci, the pupal development was fastest during the autumn months (Siddig et al., 2005). On the other hand, the continuous changes and variations in precipitation also lead to wider geographic range of flies (Fischer, Thomas, Neteler, Tjaden, & Beierkuhnlein 2014), but may also reduce fly-related risks in other region. In regards to temperature, a small increase in temperature under laboratory conditions, can increase the hatchability of many of fly eggs (Shiravi, Mostafavi, Akbarzadeh, & Oshaghi, 2014; Roe & Higley, 2015). Also, higher temperatures increase the rate of trans-stadial development, so the insect proceeds to next stage in a shorter time (Shiravi et al., 2014). However, the positive influence of temperature on fly development may be limited as higher temperature will adversely affect their survival, such as when temperature reaches a survival threshold that can be lethal. Many fly species survive a wide range of temperature ranges spanning temperate, tropic, subtropics, and even Polar Regions. Also, temperature impacts the geographic range of flies in a local and regional scales. In the last decade, many flies species expanded their distribution range because of global warming and changes in the occurrence of suitable habitats in the trophic cycle (Cannon, 1998; Peňuelas, Filella, & Comas, 2002). The significance of the geographic expansion of flies to new areas, attributed to climate warming, causes nuisance and epidemiological situations through disease transmission or economic losses.

On the other hand, higher temperature may negatively influence the survival of flies and the development of disease pathogens inside their bodies. In regard to fly maggots that live on carcasses, the successive development of the maggots is solely dependent on the duration of the decay process, which eventually depends on climatic condition. In summer seasons, carcasses decay at much faster rate than in winter and spring. The increased temperature in summer speeds up the temporal succession of waves, whereas, in winter the rate of development of maggots slows down. Also, the maggot's activity leads to increased temperature of the corpse, which eventually results in quick decay. *Chrysomya megacephala* and *Chrysomya rufifacies* are very good examples of Calliphorids fly that are found in all the seasons of the year.

Accordingly, our model showed that humidity, temperature, and vegetation cover were found to be the play key role in the distribution of old-world screwworms (OWS) in Jazan province. Subsequently, application of Geographical Information System (GIS) tools is very valuable in understanding the distribution of OWS in relation to vegetation and watercourses. The very high and high predicted suitable habitats were shown to be sporadic in two main regions of this province representing two elevation ranges, the low and moderate elevations in Al Ardah, Sabya, Al Eidaby, Abu Areish, and Ahd Al Msarhah Districts. The animal incidence cases recorded during the validation phase of our model confirmed the risk map produced of this work. Further investigations need to be conducted in order to delineate the type of NDVI and tree cover highlighting types of plants and trees or shrubs correlated with the incidence of these cases.

It is well known that flies solely depend in part of their life cycle on the rainfall as a signature for the emergence of the adult stage from their pupae in soil. Thereby, precipitation shared the utmost gain in predicting establishment of larval and aerial stages of myiasis causing flies in infested areas. Precipitation during the wettest quarter (May-August), has the great influence on emergence of flies pupated in soil, in general, and especially myiasis causing flies. The influence of each climate and environmental data layer on the model was evaluated via a Jackknifing procedure. Both precipitation and temperature are the two major predictors of flies. Since insects are ectothermic and depend on external temperatures to warm their body, air and land surface temperatures are believed to accelerate/suppress the development rate of insects (Lin & Lu, 1995, Murty, Rao, & Arunachalam, 2010). However, the contributions of NDVI and tree cover play a minor role in predicting flies' distribution alongside with precipitation and temperature.

The field validation collection points for our model demonstrated that the percentages of the positive sites corresponded with the predicted suitability values of the model. This can be attributed to the suitable niches that include wet soil and temperature ranges 25-35^{o}C. Negative records of myiasis causing flies were found in higher elevations, where farms are exposed to direct sunlight or high sanitation and hygiene are being practiced.

The ecological niche model was potentially proven to grasp the correlations between myiasis causing flies and their predicting variables. Moreover, it was very helpful in delineating the ecological variables that are necessary for supporting myiasis causing flies and their distribution range. However, other variables such as farms sanitation/hygiene, type of vegetation, and land use may contribute in determining the ecological niche habitats of these flies.

This novel distribution model and risk maps is the first in kingdom of Saudi Arabia. It potentially demonstrated that the distribution of myiasis causing flies is spatially clustered. In addition, different correlations between myiasis causing flies and climate and environmental variables have been highlighted. The novelty of the habitat suitability model represented that these myiasis causing flies preferred farms at low and moderate elevations (plateau areas) with relatively low and moderate precipitation at the wettest quarter and temperature range 25-35^{o}C. These suitable habitats occurred near the cities of Abu Areish, Al Eidaby, Sabya, Ahd Al Masarhah, and Al Ardah. The acquired data and risk map will be very effective tool on the hand of veterinary sector on Ministry of Agriculture on the Saudi Arabia in developing very effective control program for this fly and ensure the successfulness of the control strategy. Although MaxEnt ecological niche and land cover modeling are useful tools in predicting suitable habitats of dipterous flies in response to climate and environmental variables, more variables such as farms sanitation, type of vegetation, and land use need to be included in further study in Jazan Province.

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