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Model Predicts a Future Pine Processionary Moth Risk in Artvin and Adjacent Regions

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ABSTRACT

In recent decades, climate change has been receiving a lot of attention from researchers as it is believed to be proceeding at an extraordinary rate during the last 1,300 years and many studies have attempted to document and predict its environmental effects. Eastern winter pine processionary moth (PPM), *Thaumetopoea wilkinsoni* (Lepidoptera, Notodontidae), an economically important pest of pines in the Eastern Mediterranean Basin, distributed through almost all coastal regions within Turkey. Even though, its European sister species, *T. pityocampa* is known to be an aggressive invader under global warming in Europe and proved to expand its range towards northern latitudes; there is a lack of knowledge about species current and future status through Turkey, especially Artvin and adjacent regions (Eastern Black Sea Region) where it has not have much effect yet. In this study, we aimed to predict PPM's current and future distribution through Artvin and adjacent regions by using Maximum Entropy Modeling (Maxent) software. We used 65 sampling points in conjunction with 7 climatic variables that were least inter-correlated and with greatest significant contribution to the distribution model. As the statistical tests showed that the fit of the generated model is good, we further carried on using this model for future predictions. Our results indicated that PPM would expand its range towards Artvin and adjacent regions. Even though, currently this region is not under risk of PPM invasion, models suggest that future climatic conditions might trigger PPM invasion in near future - by 2050 - 2080.

Key Words: Pine processionary moth, *Thaumetopoea wilkinsoni*, climate change, Artvin, distribution

Artvin ve Çevresinde Çam Kese Böceği Riskinin Geleceğe Yönelik Modellenmesi

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ÖZET

Son 1.300 yılın en yüksek oranlarına ulaşan iklim değişimi son zamanlarda araştırmacıların ilgisini çekmekte ve çevresel etkilerini tahminleyen birçok araştırmaya konu olmaktadır. Çam kese böceği (ÇKB), *Thaumetopoea wilkinsoni* (Lepidoptera, Notodontidae), Doğu Akdeniz Havzası'ndaki çamlarda son derece önemli zararlara neden olan ve ülkemizde de neredeyse tüm sahil şeridini işgal etmiş bir güvedir. Avrupalı kardeş türü olan *T. pityocampa*'nın küresel ısınmanın etkisiyle yayılış alanına kuzey enlemlere doğru genişlettiği bilinmektedir. Ancak söz konusu türün Türkiye'deki mevcut ve gelecekteki durumu ile ilgili bilgilerimiz eksiktir. Bu çalışmada Türkiye'deki ÇKB populasyonlarının bugünkü ve gelecekti dağılımının Maksimum Entropi Modellemesi (Maxent) kullanılarak tahmin edilmesi amaçlanmıştır. 65 örnekleme noktası ve birbiriyle en az ilişkili ve dağılım modeline en çok katkı sağlayan 7 iklimsel değişken ile birlikte kullanılmıştır. İstatistiksel sınamalar oluşturulan modelin iyi bir şekilde uyum sağladığını gösterdiğinden, bu model gelecek tahminlemesinde kullanılmıştır. Modelimiz çam kese böceğinin dağılım alanını Türkiye'nin kuzeydoğusuna doğru genişleteceğini tahminlemiştir. Günümüzde iklimsel olarak ÇKB istila riski taşımayan Artvin ve civarı modele göre 2020 ve 2050 yıllarında ÇKB istilası için uygun hale gelecektir.
Anahtar kelimeler: Çam kese böceği, *Thaumetopoea wilkinsoni*, iklim değişimi, Artvin, dağılım

INTRODUCTION

Climate is such a pivotal parameter of species distribution that even slight deviation in average climatic conditions over time can cause differentiation of species' ranges (Davis and Shaw 2001; Hughes 2000; Walther et al. 2002). During the last century, climatic studies showed mean global temperature rises consistent with the onset of a significant warming event that is coupled with anthropological forces (IPPC 2007). Even the recent anthropogenic climatic changes are enough to affect species distributions, as proved in many recent studies (Battisti et al. 2005; Hughes 2000; Parmesan and Yohe 2003; Root et al. 2003; Volney and Fleming 2000). Some of these studies showed that insects are particularly sensitive and respond relatively quickly to the climatic changes, by shifting their distributions either latitudinally or altitudinally or both (Bale et al. 2002; Battisti et al. 2005; Harrington et al. 2001). Especially, phytophagous insects can quickly adapt to new environments where their host plants exist (Bale et al. 2002). When the host plant does not exist in the new environment, host switching is also possible (Harrington et al. 2001). Phytophagous insects whose distribution is limited by low winter temperatures are particularly expected to be affected by global warming (Leather et al. 1993).

As a species complex, eastern pine processionary moth (hereafter PPM), *Thaumetopoea wilkinsoni* Tams, 1924 (Lepidoptera, Notodontidae), and its western vicariant *T. pityocampa* (Denis and Schiffermüller, 1775) are among the most important defoliators of pine in the Mediterranean forests (Avcı 2000; Battisti 1988; Démolin 1969; Breuer and Devkota 1990; Halperin 1990; Mendel 1990). The larvae feed on pine needles and urticating larval hair are allergenic especially for mammals (Denis and Schiffermüller 1776; Vega et al. 1997). PPM larval development occurs in autumn and winter. The gregarious larvae build silken nests on tips of pine branches in winter and pupate underground in summer. Adults emerge at the end of summer, live a few days, and die after reproduction (Démolin 1969).

Low winter temperature is a limiting factor for PPM's geographical range (Démolin 1969; Hódar et al. 2011). Therefore increasing winter temperature is expected to encourage its range expansion. Indeed, PPM is known to have undergone both altitudinal and latitudinal range expansion during the last three decades through Europe (Battisti et al. 2005, 2006; Buffo et al. 2007; Hódar et al. 2003; Robinet et al. 2007). Furthermore, the Intergovernmental Panel on Climate Change (IPCC) (2007) predicts that the world's average temperature will rise by 1.8 - 4 °C by 2100, changes which could allow for further range expansions of PPM.

PPM is currently present through almost all of the coastal regions of Turkey except the north-eastern coasts called Eastern Black Sea Region - particularly Artvin and adjacent provinces. Climatic patterns of this region could be one of the parameters interfering PPM's distribution in the region. In order to understand the effects of current climate and predict influences of future climate change on PPM's distribution through Artvin and adjacent provinces (Figure 1), we modelled the current distribution and used this model to predict the probability of future range expansion of PPM through this particular region of Turkey.

Figure 1. Artvin Province of Turkey

MATERIAL AND METHODS

We gathered PPM sampling coordinates from our previous studies and carried out additional fieldwork in 2013. All of the 65 sampling points and their distribution can be seen in Figure 2. These sampling points cover all of Turkey rather than the centre of interest which is the Eastern Black Sea Region of Turkey so that climatic conditions of surrounding providences would be included within the model enabling a more reliable output.

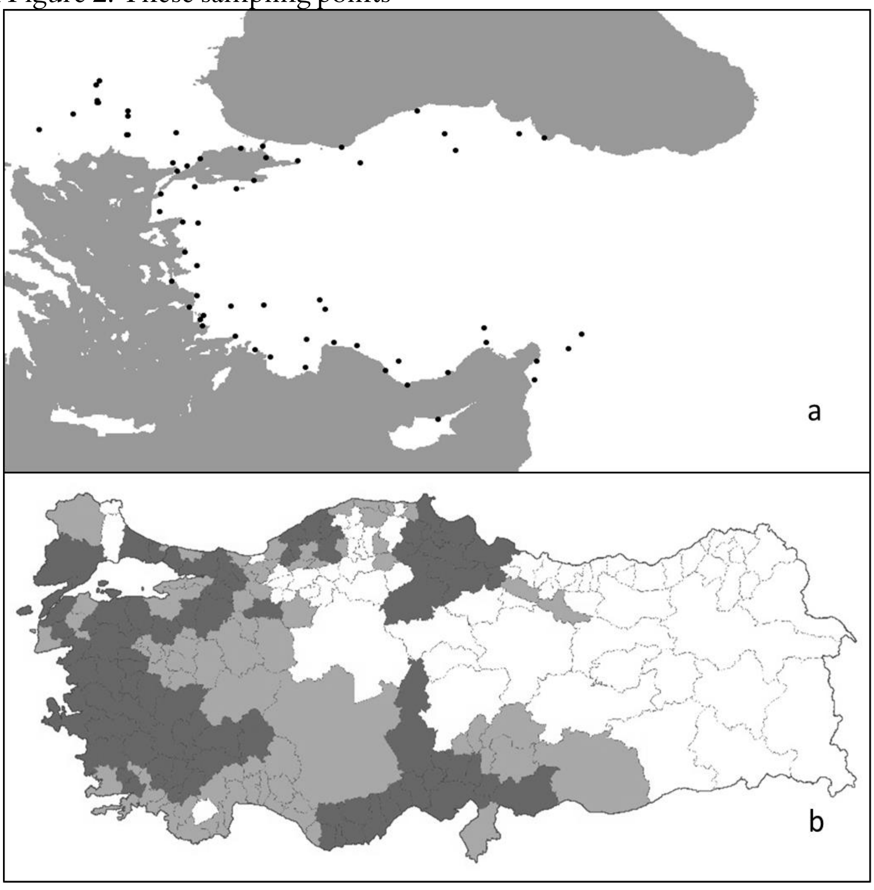


Figure 2. (a) Sampling locations gathered from our previous studies and from 2013 fieldworks, **(b)** current distribution of PPM (dark grey: common; light grey: partly) (Avcı and İpekdal, 2015)

We began modelling with 19 bioclimatic parameters which we downloaded from the WorldClim database (Hijman et al. 2005) (Table 1). In order to select the most ecologically relevant parameters with least correlation within this dataset, we calculated the correlation between each parameter and choose those that were least correlated while most likely to affect the distribution of the species in regard to species' ecology. This procedure contributes to elimination of the confounding effects of correlation among parameters. We then estimated the contribution of each remaining parameter to the output of our distribution model, discarding those parameters with no significant contribution from further analyses. Consequently, 7 parameters that were least inter-correlated and with greatest significant contribution to the distribution model were selected for further analysis (Table 1).

Table 1. Entire dataset downloaded from WorldClim database. 7 parameters used in modelling are underlined.

No	Data type
1	Annual Mean Temperature
2	Mean Diurnal Range (Mean of monthly (max temp – min temp))
3	<u>Isothermality (No 2/No 7) (* 100)</u>
4	<u>Temperature Seasonality (standard deviation *100)</u>
5	Max Temperature of Warmest Month
6	<u>Min Temperature of Coldest Month</u>
7	Temperature Annual Range (No 5-No 6)
8	Mean Temperature of Wettest Quarter
9	Mean Temperature of Driest Quarter
10	Mean Temperature of Warmest Quarter
11	<u>Mean Temperature of Coldest Quarter</u>
12	Annual Precipitation
13	Precipitation of Wettest Month
14	Precipitation of Driest Month
15	<u>Precipitation Seasonality (coefficient of variation)</u>
16	Precipitation of Wettest Quarter
17	<u>Precipitation of Driest Quarter</u>
18	Precipitation of Warmest Quarter
19	<u>Precipitation of Coldest Quarter</u>

Then Maximum Entropy Modeling (Maxent) software is used as it is one of the most commonly used methods for modelling species distributions and predicting effects of climate change on these distributions. It has a very straightforward logic and depend its predictions on known presence points of the species (Fitzpatrick et al. 2013; Phillips et al. 2006). One of the most detailed reviews of this modelling technique is written by Elith et al. in 2011, discussing the assumptions underlying Maxent, and providing different examples and ways of using the algorithm. We used 5 replicate cross validation techniques for choosing samples while running the model. First we evaluated the success of the model by comparing its current distribution with the modelled distribution. Once we were convinced that this model succeeded in predicting the current distribution, we conducted the model for 2050 and 2080 by using relatively optimistic b2a scenario of the Canadian Centre for Climate Modelling and Analysis -the Second Generation Coupled Climate Model (CCCMA-GCCM2). Finally, we compared current and predicted distributions by drawing binary maps. We used "equal model sensitivity and specificity threshold" while constructing binary maps for this purpose. Eventually we focused on the predictions around the north-eastern Black Sea Region of Turkey where PPM does not exist today.

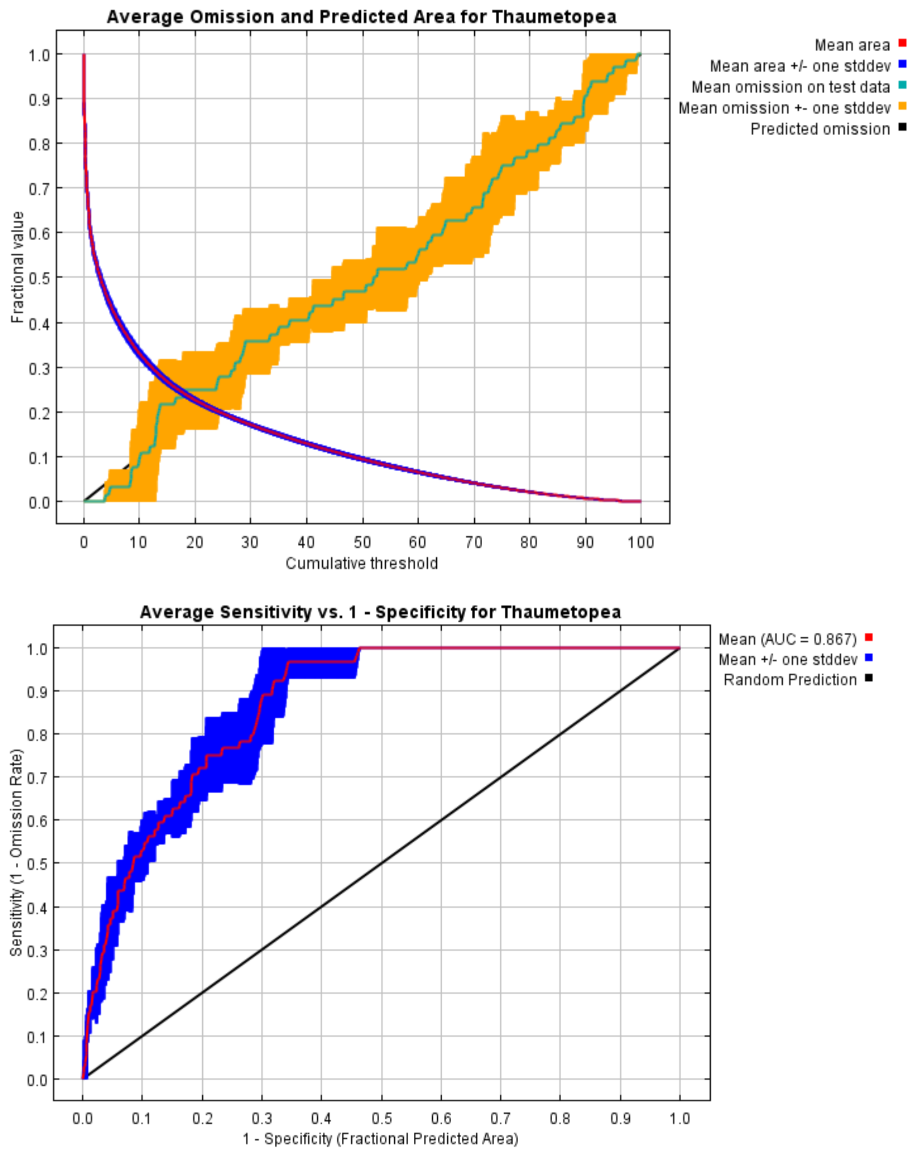
RESULTS AND DISCUSSION

Table 2 gives estimates of relative contributions of each of the used environmental parameter to the Maxent model. Here we can understand that temperature seasonality, mean temperature of the coldest quarter and precipitation of the driest quarter had the highest overall contribution to the model. Meanwhile, precipitation of the driest quarter and minimum temperature of the coldest month were the most important parameters during each different permutation.

Table 2. Estimates of the relative contributions of the environmental variables to the model. Values shown are averages over replicate runs.

Variable	Percent contribution	Permutation importance
Temp. seasonality	28.3	1.4
Mean temp.-coldest quarter	21.5	0
Precipitation-driest quarter	19.5	39.4
Precipitation-coldest quarter	12.6	1.3
Min. temp.-coldest month	12.5	52.1
Precipitation seasonality	4.6	2.9
Isothermality	1.1	2.9

Figure 3 shows the plots of test omission rate and predicted area as a function of the cumulative threshold (Figure 3a) and of receiver operating characteristic (ROC) curve (Figure 3b) which are two basic analyses testing the success of fit of the model. As we can see in Figure 3a the omission rate is close to the predicted omission indicating that the model succeeds in representing the given distribution of the species. Also, ROC curve analysis results show that the average test AUC for the replicate runs is 0.867 and the standard deviation is 0.018, accordingly supporting that the fit of the generated model to the available data is good.



a

b

Figure 3. (a) The test omission rate and predicted area as a function of the cumulative threshold, averaged over the replicate runs and **(b)** The receiver operating characteristic (ROC) curve for the same data, averaged over the replicate runs. Note that the specificity is defined using predicted area, rather than true commission.

Figure 4 shows the results of the jackknife tests of variable importance. It shows results of the jackknife test of regularized training gain. The environmental variable with highest gain when used in isolation is temperature seasonality which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain most when it is omitted is precipitation of driest quarter, which therefore appears to have the most information that is not present in the other variables.

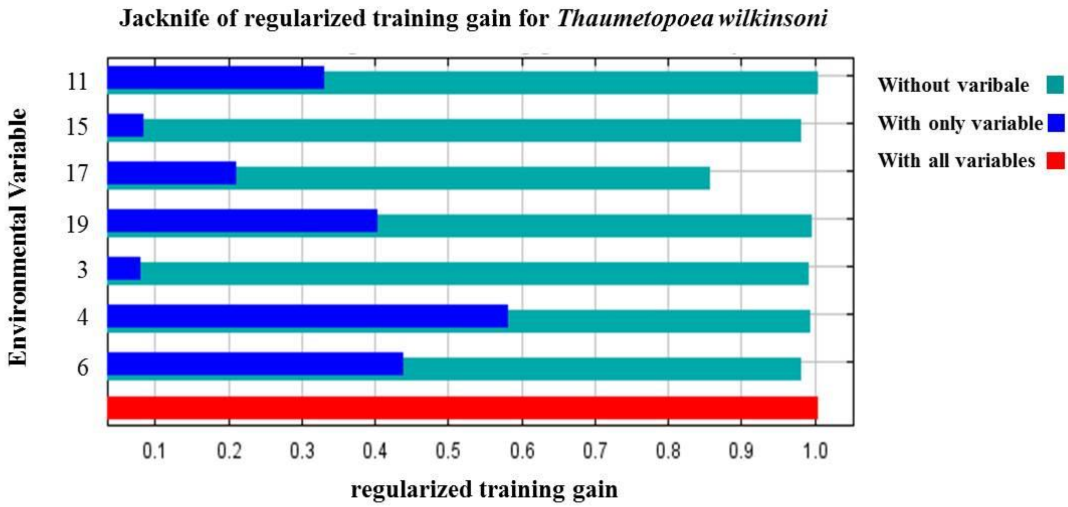


Figure 4. Jackknife tests of variable importance using training gain

Figure 5 shows current distribution of *T. wilkinsoni* in Turkey (Figure 5a) and Artvin and adjacent regions (Figure 5b), 2050 (Figure 5c) and 2080 scenarios (Figure 5d), predicted by the model. According to these maps current distribution will slightly expand in the future. Especially Artvin and adjacent regions, including Black Sea coasts of Georgia and even Russia, seem to be under risk of PPM invasion in next 70 years.

It could be suggested that currently PPM does not present at north-eastern coasts due to low host plant availability in the region; thus a future PPM invasion risk may not be seen as a possibility. Although low plant availability is an important factor, it is not enough alone to explain why *T. wilkinsoni* does not use small *Pinus nigra* stands and even individual trees (planted in school yards etc.) to spread towards east. Furthermore, it could be transported accidentally to available pine stands as it has happened to *T. pityocampa* in France (Robinet et al. 2012). Apart from these possibilities, shifting host preference is the main reason of pestiferous organisms being such an overwhelming diversity today and it should never be ignored in future management plans. *Pinus sylvestris*, the dominant pine species in north-eastern Turkey, can serve as the new host for range-expanding PPM populations as it has already shown by Hódar et al (2003) for *T. pityocampa* in Spain.

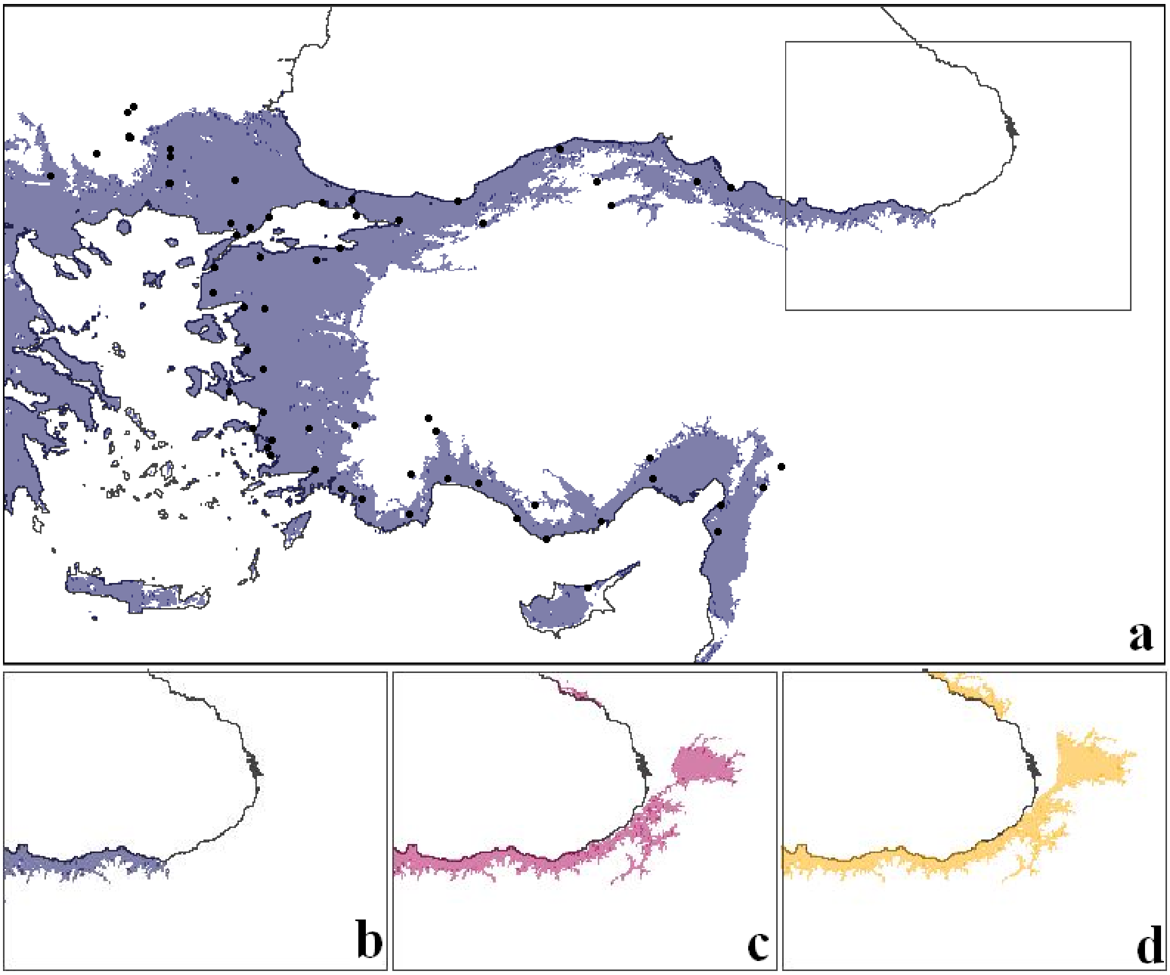


Figure 5. Distribution maps modelled by Maxent for *T. wilkinsoni* showing **(a)** current range through Turkey (available distribution points in black); and predicted range through Artvin and adjacent regions for **(b)** current range, **(c)** 2050 scenario and **(d)** 2080 scenario.

The most important parameters to influence PPM distribution in the model used seem to be temperature seasonality, mean temperature of the coldest quarter and precipitation of the driest quarter. The first and second parameters were already mentioned above as the main limiting factors for PPM distribution. Therefore, parameter estimation of the model is compatible with the reality. Temperature seasonality shows a negative correlation (Figure 6a) and mean temperature of coldest quarter shows a positive correlation (Figure 6b) with the probability of PPM to present at a certain locality. The third parameter, precipitation of the driest quarter, has never been mentioned as a limiting factor for PPM distribution in the relevant literature. However, precipitation can affect PPM pupae that rest underground during the driest months by supporting fungal community. In fact it was shown in Spain that fungus infection during the pupal period cause population contractions (Hódar pers. com.). Thus, a negative correlation between precipitation during pupal period (driest quarter) and PPM's viability in a region, as the model showed, could be expected (Figure 6c).

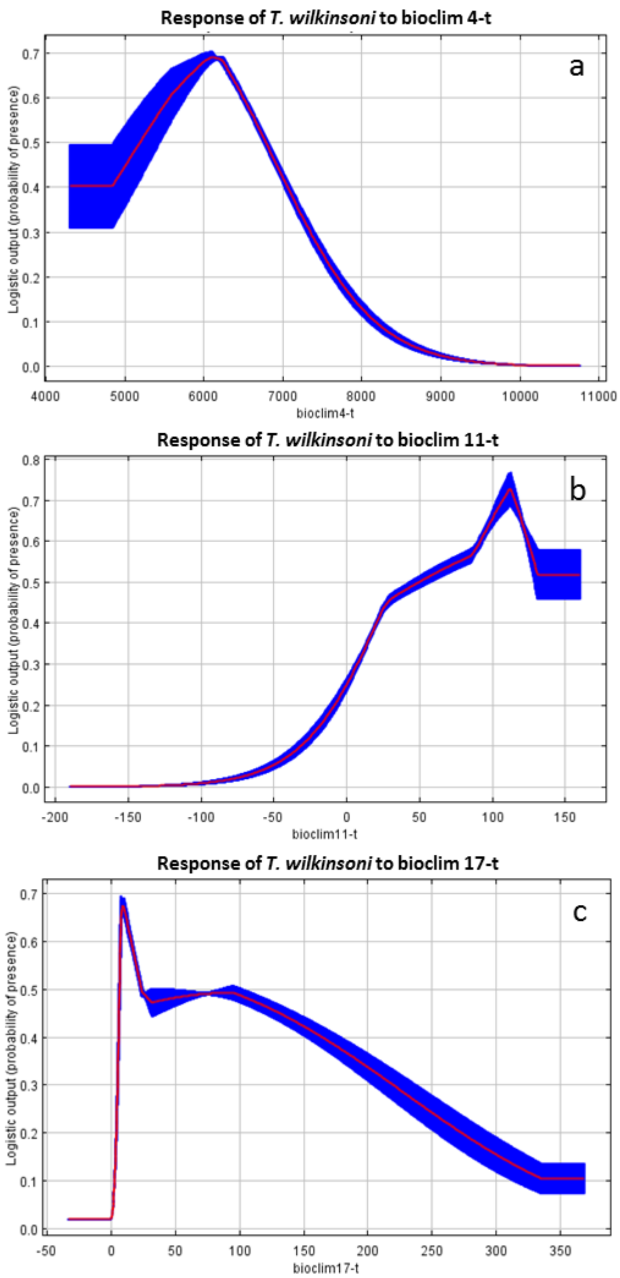


Figure 6. Response curves showing how each environmental variable affects the Maxent prediction; how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value (the mean response of the 5 replicate Maxent runs (red) and and the mean +/- one standard deviation [blue, two shades for categorical variables]): y axis represents the probability of PPM to present in a locality with that actual value of the variable indicated on x-axis; **(a)** temperature seasonality (standard deviation*100), **(b)** mean temperature of coldest quarter (°C*10), **(c)** precipitation of driest quarter (mm).

CONCLUSION

This study is the first trial to predict future distribution of the PPM especially through Artvin and adjacent regions and made important predictions. North-eastward cross-border expansion is one of them and should be handled and repeated carefully in order to be able to predict the future effect of the pest on Caucasian forests successfully.PPM is one of the most important pine forest pests around the Mediterranean and one of the main management concerns of the Turkish Department of Forestry. Its management is challenging and costly and climate change, apparently, will not make management easier or more affordable. Climate models are important tools to predict future invasion risks and could be used widely for the PPM in Turkey, too, in order to better direct research into control strategies.

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