agriculture

MDPI

Communication

Prediction of the Potential Distribution of *Drosophila suzukii* on Madeira Island Using the Maximum Entropy Modeling

Fabrício Lopes Macedo [1,2], Carla Ragonezi [1,2,3,*], Fábio Reis [1], José G. R. de Freitas [1], David Horta Lopes [4], António Miguel Franquinho Aguiar [5], Délia Cravo [5] and Miguel A. A. Pinheiro de Carvalho [1,2,3]

1 ISOPlexis Centre Sustainable Agriculture and Food Technology, University of Madeira, Campus da Penteada, 9020-105 Funchal, Portugal; fabricio.macedo@staff.uma.pt (F.L.M.); fabior@staff.uma.pt (F.R.); jgrfreitas@staff.uma.pt (J.G.R.d.F.); miguel.carvalho@staff.uma.pt (M.A.A.P.d.C.)
2 Centre for the Research and Technology of Agro-Environmental and Biological Sciences (CITAB), Inov4Agro-Institute for Innovation, Capacity Building and Sustainability of Agri-Food Production, University of Trás-os-Montes and Alto Douro, 5000-801 Vila Real, Portugal
3 Faculty of Life Sciences, University of Madeira, Campus da Penteada, 9020-105 Funchal, Portugal
4 CE3C-Centre for Ecology, Evolution and Environmental Changes, Universidade dos Açores Rua Capitão João d'Ávila, Pico da Urze, 9700-042 Angra do Heroísmo, Portugal; david.jh.lopes@uac.pt
5 Laboratório de Qualidade Agrícola, Direção Regional de Agricultura, Secretaria Regional da Agricultura e Desenvolvimento Rural, Caminho Municipal dos Caboucos, 61, 9135-372 Camacha, Portugal; antonio.aguiar@madeira.gov.pt (A.M.F.A.); delia.cravo@madeira.gov.pt (D.C.)
* Correspondence: carla.ragonezi@staff.uma.pt; Tel.: +351-291-705-266

Abstract: *Drosophila suzukii* is one of the main pests that attack soft-skinned fruits and cause significant economic damage worldwide. Madeira Island (Portugal) is already affected by this pest. The present work aimed to investigate the potential distribution of *D. suzukii* on Madeira Island to better understand the limits of its geographical distribution on the island using the Maximum Entropy modeling (MaxEnt). The resultant model provided by MaxEnt was rated as regular discrimination with the area under the curve (AUC, 0.7–0.8). Upon scrutinizing the environmental variables with the greatest impact on the distribution of *D. suzukii*, altitude emerged as the dominant contributor, with the highest percentage (71.2%). Additionally, elevations ranging from 0 to 500 m were identified as appropriate for the species distribution. With the results of the model, it becomes possible to understand/predict which locations will be most suitable for the establishment of the analyzed pest and could be further applied not only for *D. suzukii* but also for other species that hold the potential for substantial economic losses in this insular region.

Keywords: habitat suitability; maximum entropy; ecological niche model; information system; modeling training; machine learning; Drosophilidae

Citation: Macedo, F.L.; Ragonezi, C.; Reis, F.; de Freitas, J.G.R.; Lopes, D.H.; Aguiar, A.M.F.; Cravo, D.; Carvalho, M.A.A.P.d. Prediction of the Potential Distribution of *Drosophila suzukii* on Madeira Island Using the Maximum Entropy Modeling. *Agriculture* **2023**, *13*, 1764. https://doi.org/10.3390/agriculture13091764

Academic Editor: Emmanouil Roditakis

Received: 4 August 2023
Revised: 1 September 2023
Accepted: 4 September 2023
Published: 6 September 2023

1. Introduction

Drosophila suzukii Matsumura (Diptera: Drosophilidae), commonly known as Spotted Wing Drosophila, is an insect native to the Asian continent, first described in 1931 [1]. The family Drosophilidae includes more than 4000 species distributed around the world, and the genus *Drosophila* is the most common, with about 1700 species [2]. Unlike most *Drosophila* species that breed in rotting material, *D. suzukii* has a modified serrated ovipositor that allows females to pierce the fruit skin and lay eggs in healthy ripening fruits. As a result, great damage to agriculture is caused by this type of insect [3–5], and, therefore, it is considered an economically important pest of small berries [6].

In 1980, *D. suzukii* was reported for the first time outside the Asian continent, on Oahu, Hawaii [7]. In 1997 and 1998, this species was already observed in Ecuador and Costa Rica [8]. The first records in Europe were in northern Spain (Tarragona) and Italy in 2008 [9]. The first official record in Portugal was reported to the European and Mediterranean Plant

Protection Organization (EPPO) in July 2012 in the municipality of Odemira by a raspberry producer [10].

The rapid spread of this pest may have been caused by passive dispersal through the export and import of fruits contained within the eggs of the pest [11]. This form of dispersal is one of the most common methods of transporting pests between different regions, as the eggs are often not visible in the transported products [11].

On Madeira Island, *D. suzukii* was first identified in 2014 in traps placed in vineyards in the following localities: Caniçal, Faial, São Jorge, Arco de São Jorge, São Vicente, and Estreito da Calheta, and although it is widespread on the island, it appears to be associated with vineyards [12]. It is thought that the species was probably introduced to Madeira through the importation of contaminated fruits or plants from mainland Portugal or Spain [12].

An important characteristic of the insect is the wide range of temperatures it can tolerate, with reproductive limits in the range of 10–30 °C and optimal conditions for development between 20 and 25 °C [13,14]. A limiting factor for *D. suzukii* is low relative humidity, which has a negative effect on it. However, it should be noted that the insect can develop resistance to desiccation [15].

Understanding the possible spread of a pest is one of the most important points for its control. Usually, there are two approaches using information on the appropriate environmental conditions for the development of a particular species: the mechanistic and the correlative approaches [16,17]. The mechanistic approach involves physiologically limiting mechanisms in the tolerance of species to environmental conditions and requires a detailed understanding of the physiological response to environmental factors [18]. According to the author, the main objective of the correlative approach is to estimate the appropriate environmental conditions for the development of a given species by linking occurrence data with environmental variables.

The correlative approach can be called "species distribution modeling", "ecological niche or environmental niche modeling", and "habitat suitability modeling" [19]. The modeling process is based on the niche concepts [20] introduced in 1924 [21] and in 1957 [22]. This type of modeling consists of converting the primary data on the occurrence of a given species into maps indicating the species' potential geographical distribution and demonstrating the likely presence or absence through algorithms [23].

Various studies already apply the species distribution models (SDMs) in different parts of the world in order to understand the current and potential distribution of *D. suzukii* [24–27]. One of the main software/algorithms used for this type of data modeling is the Maximum Entropy Model (MaxEnt) [23], which can determine the distribution probability of a given species using incomplete data [28]. One of the main advantages of MaxEnt is that it only requires data on the occurrence of a given species, together with environmental characteristics, and is sufficient to model an entire study area [23].

The present work aimed to investigate the potential distribution of *D. suzukii* on Madeira Island to better understand the limits of its geographical distribution on the island using the Maximum Entropy modeling.

2. Materials and Methods

2.1. Occurrence Sites

The occurrence of *Drosophila suzukii* in Madeira Island was determined through field surveys conducted by the Regional Directorate of Agriculture and Rural Development (DRA) and ISOPlexis-Center for Sustainable Agriculture and Food Technology from 2014 to 2021. Throughout the period, a total of 97 distinct points of occurrence of the species distributed throughout the island were counted (Figure 1).

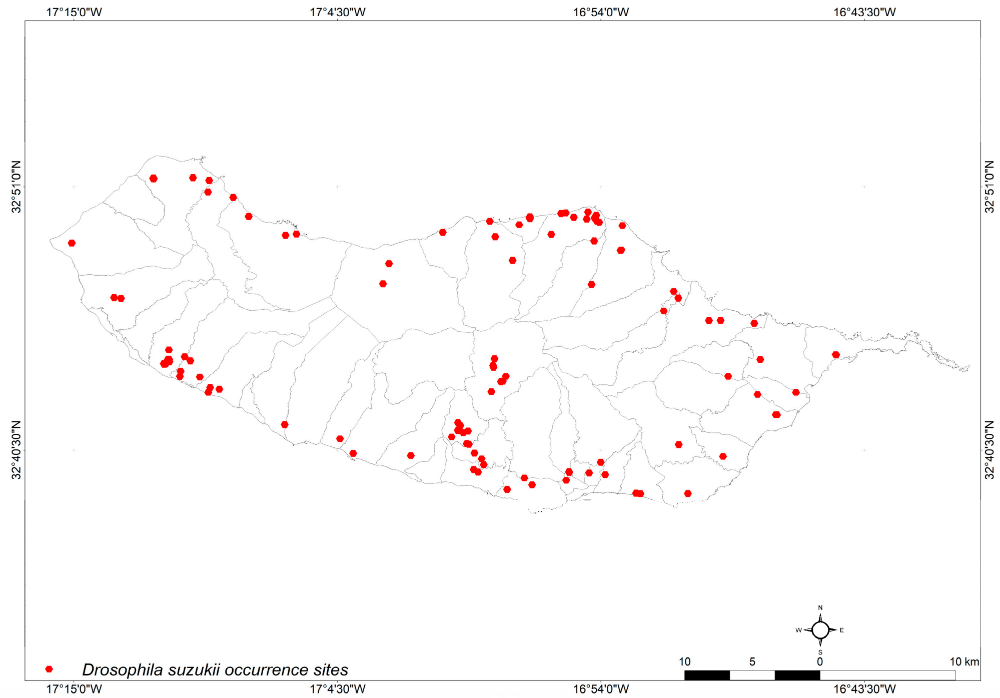

Figure 1. Occurrence sites of *Drosophila suzukii* on Madeira Island.

2.2. Environmental Variables

When using MaxEnt, it turns out that the environmental data used comes from Worlclim. However, due to the territorial dimension of Madeira Island (741 km^2) being too small, we chose not to use the data provided by Worlclim since the lowest resolution of the data is ~1 km^2) and the use of the data could cause pixel blending in the images generated by MaxEnt.

To overcome this obstacle, local climate data were then used (Table 1). These data were from 17 weather stations of the Portuguese Institute of Sea and Atmosphere (IPMA) from a historical series between 2012 and 2021. The climatic variables used were average, maximum, and minimum temperatures (°C), accumulated precipitation (mm), and average humidity (%). Data for each of the above variables were obtained initially for all months, and subsequently, a single annual average was obtained for each of the variables.

Table 1. Location of IPMA weather stations on Madeira Island.

Weather Station Location	Latitude (Decimal)	Longitude (Decimal)	Altitude (m)
Funchal/Observatório	32.65	−16.89	58
Funchal/Lido	32.64	−16.93	25
Santa Catarina/Aeroporto	32.69	−16.77	58
Lugar de Baixo/P. do Sol	32.68	−17.09	40
Calheta/P. do Pargo	32.81	−17.26	298
Santana/São Jorge	32.83	−16.91	257
Chão do Areeiro	32.72	−16.92	1.590
Caniçal/P. de São Lourenço	32.75	−16.71	133
Lombo da Terça	32.84	−17.21	931
Santana	32.81	−16.89	380
Bica da Cana	32.76	−17.06	1.560
São Vicente	32.80	−17.05	97
Santo da Serra	32.73	−16.82	660
Quinta Grande	32.66	−17.00	580
Pico Alto	32.69	−16.90	1.118
Pico do Areeiro	32.74	−16.93	1.799
Porto Moniz	32.87	−17.17	35

With the annual data of Average Temperature (Ave_T), Maximum Temperature (Max_T), and Minimum Temperature (Min_T), the Spatialization of Temperatures was carried out according to the procedure proposed by Santos et al. [29]. For the variables Accumulated Precipitation (Acc_P) and Average Air Humidity (Ave_H), data interpolation was performed using the Inverse Distance Weighting (IDW) method. Both processes were performed in ArcGIS 10.6.1 [30]. The altitude data of the island were obtained by processing the Shuttle Radar Topography Mission (SRTM) image available in CGIAR-CSI, V4.1 [31].

Once all the environmental variables were obtained, they were resampled to a grid size of 90 m based on the SRTM image. The variables were further converted to ASCII raster format in ArcGIS 10.6.1 [30] to be able to be used in the MaxEnt software (v.3.4.1) [23].

2.3. Data Modeling

The modeling process was carried out using MaxEnt software. The program was chosen for its simplicity, requiring only data on the presence of species associated with environmental variables and for the robustness in presenting the results. MaxEnt estimates the probability of occurrence of a given species, considering the actual occurrence records of that species in conjunction with a randomly selected background by determining the maximum entropy distribution. In the present work, 70% of the data was selected for model simulation and the remaining 30% for testing the obtained model. The following parameters were used in the modeling: auto features; output = logistic; random seed activated; regularization multiplier = 2; convergence threshold = 10^{-5}; maximum interactions = 500 (default); and the option to add samples to the background activated [23,32,33].

2.4. Evaluation of the Model

The Area Under the Curve (AUC) is the area under a Receiver Operating Characteristics (ROC) curve. This parameter is a direct indicator of the model's discriminative ability and is directly interpreted as the model's probability of correctly classifying a point of true presence and a point of true absence [23].

The results obtained by the AUC represent the category of a predictive model with values in a range that can be classified as failure (0.5–0.6), poor (0.6–0.7), regular (0.7–0.8), good (0.8–0.9) and excellent (0.9–1.0) [34]. After modeling, MaxEnt provides the distribution probability of the modeled species. These results can be classified into 5 classes of potential habitat: unsuitable habitat (0–0.2); barely suitable habitat (0.2–0.4); suitable habitat (0.4–0.6); highly suitable habitat (0.6–0.7); very highly suitable habitat (0.7–1.0) [35]. Furthermore, we used the jackknife test to identify important variables referring to the distribution of *D. Suzukii.*

2.5. Statistical Procedures

The statistical analysis was performed using Jamovi computer software version 2.3.16 (The Jamovi project [36]). The normality of a random sample was checked using the Shapiro–Wilk test, i.e., whether it comes from a normal or non-normal distribution. Based on this test, there was no evidence to reject the null hypothesis that the values came from a normal distribution, with a significance level of 1%.

Pearson's correlation coefficient (r) was used to assess the correlation between the environmental variables. The results obtained can be classified as very weak (0.00–0.19), weak (0.20–0.39), moderate (0.40–0.69), strong (0.70–0.89) and very strong (0.90–1.00) [37].

3. Results and Discussion

3.1. Modeling Results

Several simulations were carried out to verify the habitat on Madeira Island, especially testing several variations for the maximum interactions, but the model that fitted best was even with the use of 500 interactions, as presented in the materials and methods of this work.

When analyzing the results provided by MaxEnt for the AUC value of the test, it is verified that the model obtained was classified as presenting regular discrimination (0.7–0.8) (Figure 2). Since the value obtained for the AUC is above 0.70, this indicates a robust prediction model [23] with high predictive power for *Drosophila* in Madeira.

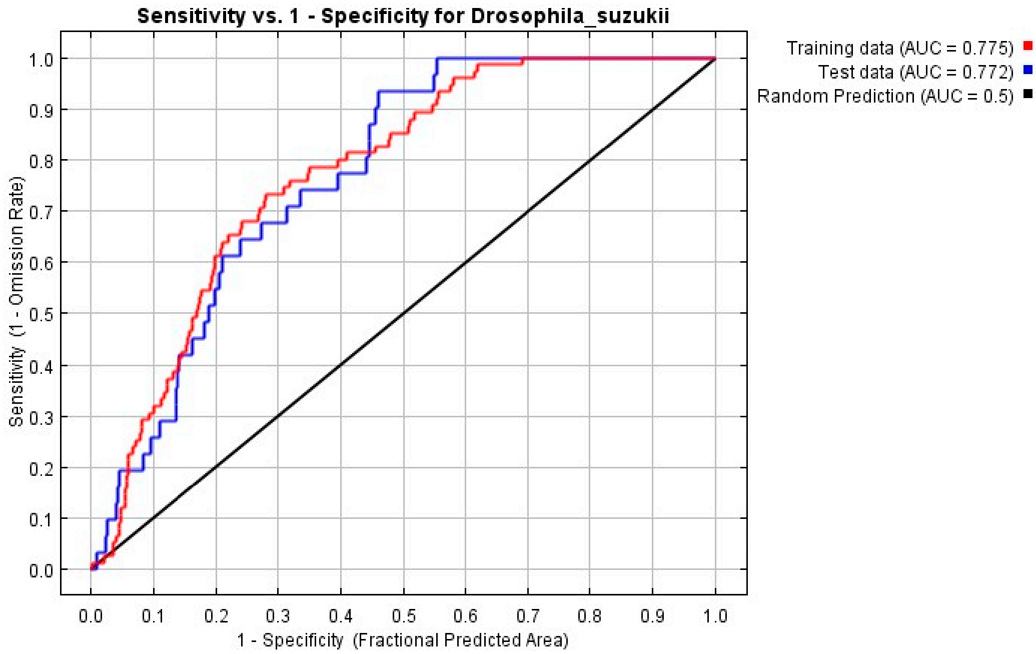

Figure 2. ROC curve obtained by the MaxEnt model.

3.2. Importance of Environmental Variables

Among all the environmental variables tested in this study, it was found that the parameter that produced the environmental factor with the highest explanatory power was Altitude (71.2%), followed by Max_T (8.9%), and Min_T and Ave_T (7.6%) (Table 2). The other environmental variables tested had no effect on the modeling obtained.

Table 2. Percentage contribution of environmental variables.

Bioclimatic Variables	Percent Contribution
Max_T	8.9
Min_T	7.6
Acc_P	2.8
Altitude	71.2
Ave_T	7.6
Ave_H	1.8

The results contrast with other studies on the potential distribution of *D. suzukii* at different sites. For example, in three species distribution models (SDMs-Native, European, and Global), the annual precipitation, mean temperature, and minimum temperature were the bioclimatic factors that most contributed to the predictive models [27]. In a study analyzing the potential distribution of *D. suzukii* in Mexico, the environmental variable that contributed most to the model was the mean temperature in the coldest quarter [24]. Also, analyzing the distribution of Drosophila, the low temperatures were the climatic variable that most influenced the distribution of the species in North America [38]. The environmental variables that most influenced the prediction of the MaxEnt Model, using data from sites with known occurrences worldwide, were the annual mean temperature, the maximum temperature of the warmest month, the mean temperature of the coldest quarter, and the annual precipitation [26].

The Jackknife test determines which individual climate variables contribute most to species distribution (Figure 3). This type of test is often used in studies to predict potential distribution [39–41]. Altitude was the environmental variable that contributed the most to more than 70% of the probability of species distribution.

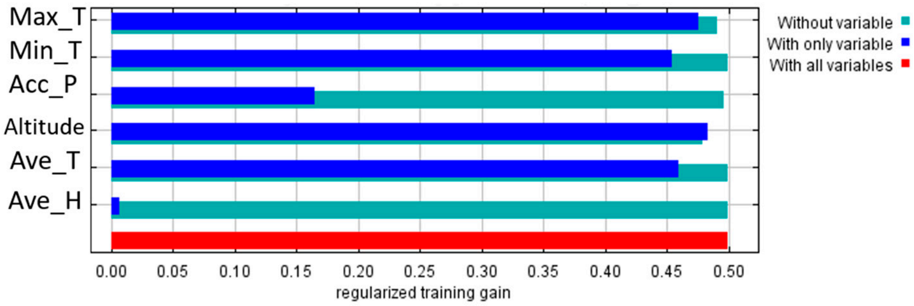

Figure 3. Jackknife test for environmental variables.

Once it had been ascertained that Altitude was the most significant variable in the model, a correlation analysis was carried out to ascertain how the environmental variables behaved (Table 3). After performing the Shapiro–Wilk normality test on the samples, there is no proof to discard the null hypothesis that the values are from a normal distribution with a significance level of 1%. Once this hypothesis had been verified, Pearson's test was used to obtain the correlation matrix.

Table 3. Pearson's correlation matrix between the study variables.

	Altitude	Ave_T	Max_T	Min_T	Acc_P	Ave_H
Altitude	–	–	–	–	–	–
Ave_T	−0.969 ***	–	–	–	–	–
Max_T	−0.952 ***	0.987 ***	–	–	–	–
Min_T	−0.971 ***	0.987 ***	0.952 ***	–	–	–
Acc_P	0.890 ***	−0.913 ***	−0.875 ***	−0.924 ***	–	–
Ave_H	−0.006	−0.055	−0.046	−0.070	0.120	–

Note: correlation is significant when: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

There were very strong negative correlations between Altitude and Average, Maximum, and Minimum Temperature ($p < 0.001$). As the altitude of the terrain increases, the three temperatures analyzed in the present study decrease. A strong correlation was found between Altitude and Accumulated Precipitation ($p < 0.001$), where, according to the results, the higher the altitude, the greater the volume of accumulated precipitation in the study area. As for the Average Relative Humidity variable, there was no correlation of any kind.

3.3. Individual Response Curves

Analyzing the individual responses of the different environmental variables (Figure 4), the most suitable habitat conditions for the development of *D. suzukii*, from the point of view of Average, Minimum, and Maximum Temperature, a range varying from 4 °C to 26 °C would be ideal for the development of the species since it is easily verified an evolution of the different curves presented in the figure mentioned above. The results obtained by the model for Madeira cover a wider range, especially for the minimum temperature, than that proposed by Rosa [13], in which the range would be 10–30 °C.

The analysis regarding Altitude shows that as elevations in the terrain are verified, the species tends to have a lower presence; the ideal range for the development of the species is located between 0 and 500 m. It should be noted that Madeira has mountainous characteristics, and the agricultural range is located exactly in this same altitude range proposed by the response curve.

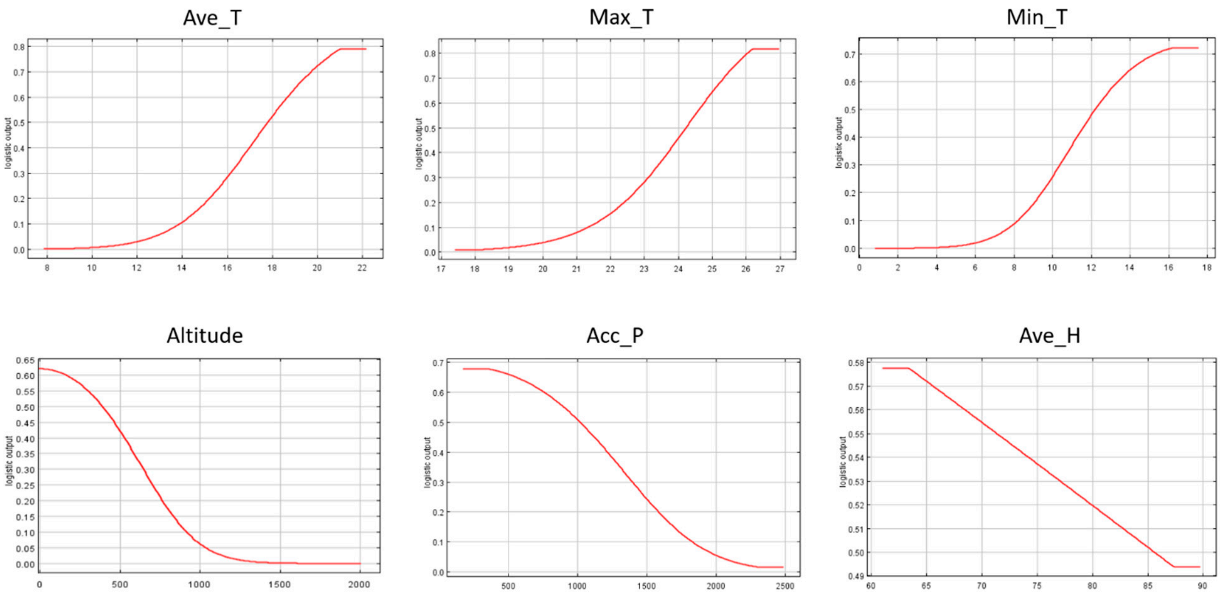

Figure 4. Mean response curves for the tested predictor variables for the *D. suzukii* distribution model created by MaxEnt.

Regarding the accumulated precipitation variable, it is possible to note that, as higher volumes of precipitation are verified, they provide a lower appearance of the analyzed species. For this variable, the ideal range for the development of *D. suzukii* would be between 0 and 500 mm. For the average relative humidity variable, it was found that the humidity range between 60 and 90% could favor the spread of the species.

To improve the visualization of the results obtained by Maxent, a hypsometric map of Madeira was drawn up associated with the points of presence of *D. suzukii*. Analyzing this map, it can be seen that the highest concentration of points with the presence of the insect is located between the 0 and 500 m altitude range, with a few other points above this level (Figure 5).

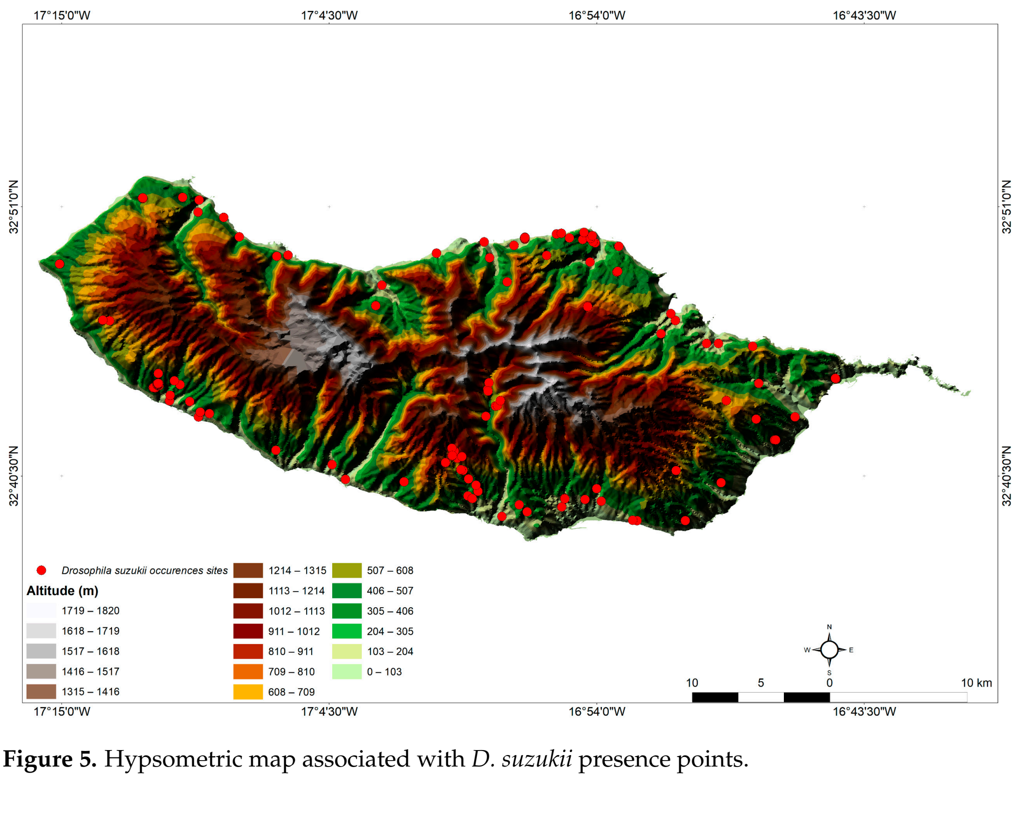

Figure 5. Hypsometric map associated with *D. suzukii* presence points.

3.4. *Potential Distribution of Drosophila suzukii*

The potential distribution map of *D. suzukii* was created by reclassifying the data from the MaxEnt simulations using ArcGIS 10.6.1. Areas were reclassified as unsuitable habitat, not very suitable habitat, suitable habitat, highly suitable habitat, and very highly suitable habitat for all years analyzed (Figure 6).

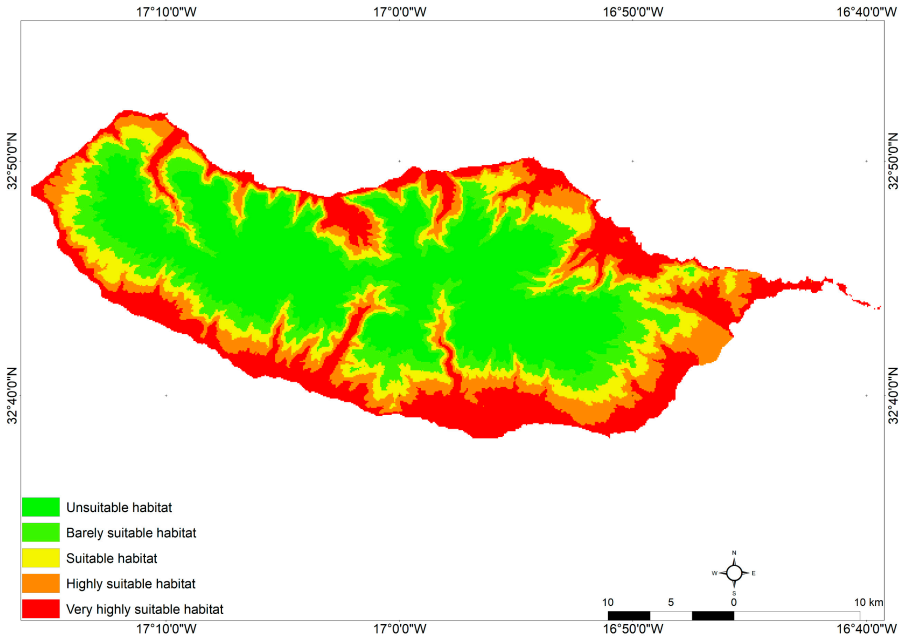

Figure 6. Habitat suitability of occurrence probability maps for *Drosophila suzukii*.

Analyzing the generated map, it is possible to easily verify a great correlation between the potential distribution of *D. suzukii* with the Altitude of Madeira. Since the central part of the island has the highest altitudes, which can reach up to 1.861 m (at Pico Ruivo). Note that in the central area (green shades), the species currently receives the classifications of Unsuitable habitat and Barely suitable habitat; that is, the presence of the species analyzed in the present study is practically nil.

An intermediate zone currently classified as suitable habitat demonstrates the limit that the insect currently occupies; however, it should be noted that this could be changed in the not-too-distant future since agriculture in Madeira has tried to expand its cultivation areas to higher areas, which have become increasingly warmer and suitable for growing crops that were previously impossible to grow [42].

However, the two other zones classified as Highly suitable habitat and Very highly suitable habitat cover the entire coast of Madeira Island. These are arable areas that have a wide distribution of *D. suzukii,* according to the results from MaxEnt.

4. Conclusions

The results presented by MaxEnt were useful to better understand the distribution of *Drosophila suzukii* on Madeira Island. The model obtained was classified as reasonable.

When analyzing the environmental factors that most contribute to the dispersal of *D. suzukii*, it was found that Altitude has the highest percentage of contribution. Altitudes between 0 and 500 m are considered suitable for the distribution of the species studied.

This study emphasisesthe importance of modeling research not only for *D. suzukii* but also for other species, which can cause significant economic losses.

It is also highlighted that modeling can be a valuable tool for decision-making, with the establishment of monitoring points and the implementation of strategies to limit the growth of a given population.

Author Contributions: Conceptualization: F.L.M., F.R., J.G.R.d.F., D.H.L. and M.A.A.P.d.C.; Investigation: F.L.M., F.R., J.G.R.d.F., A.M.F.A. and D.C.; Writing—original draft preparation: F.L.M., C.R. and D.H.L.; Writing—review and editing; F.L.M., C.R. and M.A.A.P.d.C.; Supervision: M.A.A.P.d.C.; Funding acquisition: M.A.A.P.d.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Programa Operacional Madeira 14-20, Portugal 2020, and the European Union through the European Regional Development Fund, [M1420-01-0145-FEDER-000011-CASBio]; Cooperation Program INTERREG-MAC2014-2020, with European Funds for Regional Development-FEDER [MAC2/1.1a/231-CUARENTAGRI].

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors acknowledge the support by National Funds FCT-Portuguese Foundation for Science and Technology, under the projects UIDB/04033/2020 and UIDP/04033/2020 and the Secretarias Regionais de Agricultura e Desenvolvimento Rural e Recursos Naturais e Alterações Climáticas for partnership and support.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kanzawa, T. Research into the fruit-fly *Drosophila suzukii* Matsumura (preliminary report). In *Yamanashi Prefecture Agricultural Experiment Station Report*; Hoshino Printing: Kofu-Shi, Japan, 1935.
2. Bächli, G. TaxoDros: The Database on Taxonomy of Drosophilidae. Available online: https://www.taxodros.uzh.ch/ (accessed on 10 May 2023).
3. Atallah, J.; Teixeira, L.; Salazar, R.; Zaragoza, G.; Kopp, A. The Making of a Pest: The Evolution of a Fruit-Penetrating Ovipositor in *Drosophila suzukii* and Related Species. *Proc. R. Soc. B* **2014**, *281*, 20132840. [CrossRef] [PubMed]
4. Karageorgi, M.; Bräcker, L.B.; Lebreton, S.; Minervino, C.; Cavey, M.; Siju, K.P.; Grunwald Kadow, I.C.; Gompel, N.; Prud'homme, B. Evolution of Multiple Sensory Systems Drives Novel Egg-Laying Behavior in the Fruit Pest *Drosophila suzukii*. *Curr. Biol.* **2017**, *27*, 847–853. [CrossRef] [PubMed]
5. Crava, C.M.; Zanini, D.; Amati, S.; Sollai, G.; Crnjar, R.; Paoli, M.; Rossi-Stacconi, M.V.; Rota-Stabelli, O.; Tait, G.; Haase, A.; et al. Structural and Transcriptional Evidence of Mechanotransduction in the *Drosophila suzukii* ovipositor. *J. Insect Physiol.* **2020**, *125*, 104088. [CrossRef]
6. Gabarra, R.; Riudavets, J.; Rodríguez, G.A.; Pujade-Villar, J.; Arnó, J. Prospects for the Biological Control of *Drosophila suzukii*. *BioControl* **2015**, *60*, 331–339. [CrossRef]
7. O'Grady, P.M.; Beardsley, J.W.; Perreira, W.D. New Records for Introduced Drosophilidae (Diptera) in Hawaii. *Bishop Mus. Occas. Pap.* **2002**, *69*, 34–35.
8. Hauser, M.A. Historic Account of the Invasion of *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae) in the Continental United States, with Remarks on Their Identification. *Pest. Manag. Sci.* **2011**, *67*, 1352–1357. [CrossRef]
9. Calabria, G.; Máca, J.; Bächli, G.; Serra, L.; Pascual, M. First Records of the Potential Pest Species *Drosophila suzukii* (Diptera: Drosophilidae) in Europe. *J. Appl. Entomol.* **2012**, *136*, 139–147. [CrossRef]
10. European and Mediterranean Plant Protection Organisation (EPPO). First Report of Drosophila suzukii in the United Kingdom. Available online: https://gd.eppo.int/reporting/article-2414 (accessed on 10 May 2023).
11. Deprá, M.; Poppe, J.L.; Schmitz, H.J.; De Toni, D.C.; Valente, V.L.S. The First Records of the Invasive Pest *Drosophila suzukii* in the South American Continent. *J. Pest. Sci.* **2014**, *87*, 379–383. [CrossRef]
12. Rego, C.; Aguiar, A.F.; Boieiro, M.; Cravo, D. Invasive Fruit Flies (Diptera: Drosophilidae) Meet in a Biodiversity Hotspot. *J. Entomol. Res.* **2017**, *19*, 61–69.
13. Rosa, P.J.G. Determinação da Curva de voo e Possíveis Hospedeiros Alternativos da Praga *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae) na Cultura da Framboesa na Região do Algarve. Master's Thesis, Escola Superior Agrária—Instituto Politécnico de Beja, Beja, Portugal, 27 July 2016.
14. Emiljanowicz, L.M.; Ryan, G.D.; Langille, A.; Newman, J. Development, reproductive output and population growth of the fruit fly pest *Drosophila suzukii* (Diptera: Drosophilidae) on artificial diet. *J. Econ. Entomol.* **2014**, *107*, 1392–1398. [CrossRef]
15. Consejería de Agricultura, Ganadería, Pesca y Aguas Gobierno de Canarias (CAPMA) Drosophila Suzukii; Gestión de Medio Rural de Canarias, SAU Área de Agricultura—División de Proyectos Dirección General de Agricultura. Available online: https://gmrcanarias.com/wp-content/uploads/2020/10/REVISTA-A5-DROSOPHILA-SUZUKII_WEB.pdf (accessed on 10 May 2023).
16. Pearson, R.G. Species distribution modeling for conservation educators and practitioners. *Synthesis. Am. Mus. Nat. Hist.* **2007**, *50*, 54–89.

17. Kearney, M.R.; Wintle, B.A.; Porter, W.P. Correlative and Mechanistic Models of Species Distribution Provide Congruent Forecasts under Climate Change: Congruence of Correlative and Mechanistic Distribution Models. *Conserv. Lett.* **2010**, *3*, 203–213. [CrossRef]
18. Trindade, W.C.F. Modelagem de Distribuição das Formações Vegetais do Estado do Paraná: Passado, Presente e Futuro. Master's Dissertation, Universidade Estadual de Ponta Grossa, Ponta Grossa, Brazil, 11 February 2019.
19. Ricklefs, R.E. *A Economia Da Natureza*, 6th ed.; Grupo Gen—Guanabara Koogan: Rio de Janeiro, Brazil, 2010; 546p.
20. Guisan, A.; Thuiller, W. Predicting Species Distribution: Offering More than Simple Habitat Models. *Ecol. Lett.* **2005**, *8*, 993–1009. [CrossRef] [PubMed]
21. Grinnell, J. Geography and Evolution. *Ecology* **1924**, *5*, 225–229. [CrossRef]
22. Hutchinson, G.E. Cold Spring Harbor Symposium on Quantitative Biology. In *Concluding Remarks*, 1st ed.; Cold Spring Harbor Laboratory Press: Long Island, NY, USA, 1957; Volume 22, pp. 415–427.
23. Phillips, S.J.; Anderson, R.P.; Schapire, R.E. Maximum Entropy Modeling of Species Geographic Distributions. *Ecol. Model.* **2006**, *190*, 231–259. [CrossRef]
24. Castro-Sosa, R.; Castillo-Peralta, M.D.R.; Monterroso-Rivas, A.I.; Gomez-Díaz, J.D.; Flores-González, E.; Rebollar-Alviter, Á. Potential Distribution of *Drosophila suzukii* (Diptera: Drosophilidae) in Relation to Alternate Hosts in Mexico. *Fla. Entomol.* **2017**, *100*, 787–794. [CrossRef]
25. De La Vega, G.J.; Corley, J.C. *Drosophila Suzukii* (Diptera: Drosophilidae) Distribution Modelling Improves Our Understanding of Pest Range Limits. *Int. J. Pest Manag.* **2019**, *65*, 217–227. [CrossRef]
26. Dos Santos, L.A.; Mendes, M.F.; Krüger, A.P.; Blauth, M.L.; Gottschalk, M.S.; Garcia, F.R.M. Global Potential Distribution of *Drosophila Suzukii* (Diptera, Drosophilidae). *PLoS ONE* **2017**, *12*, e0174318. [CrossRef]
27. Ørsted, I.V.; Ørsted, M. Species Distribution Models of the Spotted Wing *Drosophila* (*Drosophila suzukii*, Diptera: Drosophilidae) in Its Native and Invasive Range Reveal an Ecological Niche Shift. *J. Appl. Ecol.* **2019**, *56*, 423–435. [CrossRef]
28. Elith, J.H.; Graham, C.P.; Anderson, R.; Dudík, M.; Ferrier, S.; Guisan, A.; Hijmans, J.R.; Huettmann, F.; Leathwick, R.J.; Lehmann, A.; et al. Novel Methods Improve Prediction of Species' Distributions from Occurrence Data. *Ecography* **2006**, *29*, 129–151. [CrossRef]
29. Santos, A.R.; Ribeiro, C.A.A.S.; Sediyama, G.C.; Peluzio, J.B.E.; Pezzopane, J.B.M.; Bragança, R. *Espacialização de Dados Meteorológicos No ArcGIS 10.3: Passo a Passo*; CAUFES—Centro Agropecuária da Universidade Federal do Espírito Santo: Vitória, Brazil, 2015.
30. ESRI Inc Esri Support ArcMap 2021. Available online: https://desktop.arcgis.com/en/quick-start-guides/10.6/arcgis-desktop-quick-start-guide.htm (accessed on 10 May 2023).
31. Farr, T.G.; Kobrick, M. Shuttle Radar Topography Mission Produces a Wealth of Data. *Eos Trans. AGU* **2000**, *81*, 583–585. [CrossRef]
32. Pinto, M.A.D.S.; Gonçalves, A.P.S.; Santos, S.A.P.; de Almeida, M.R.L.; Azevedo, J.C.M. de Invasão biológica de *Corythucha ciliata* em espaços verdes urbanos de portugal: Modelação do nicho ecológico com o método de máxima entropia. *Ciênc. Florest.* **2014**, *24*, 597–607. [CrossRef]
33. Plasencia-Vázquez, A.H.; Escalona-Segura, G.; Esparza-Olguín, L.G. Modelación de la distribución geográfica potencial de dos especies de psitácidos neotropicales utilizando variables climáticas y topográficas. *AZM* **2014**, *30*, 471–490. [CrossRef]
34. Krzanowski, W.J.; Hand, D.J. *ROC Curves for Continuous Data*, 1st ed.; CRC Press, Taylor & Francis Group: Boca Raton, FL, USA, 2009; p. 332.
35. Chang, Y.L.; Xia, Y.; Peng, M.W.; Chu, G.M.; Wang, M. MaxEnt modelling for predicting impacts of climate change on the potential distribution of *Anabasis aphylla* in northwestern China. *Appl. Ecol. Env. Res.* **2020**, *18*, 1637–1648. [CrossRef]
36. The Jamovi Project. Jamovi (Version 2.3.16) 2023. Available online: https://www.jamovi.org (accessed on 15 August 2023).
37. Akoglu, H. User's Guide to Correlation Coefficients. *Turk. J. Emerg. Med.* **2018**, *18*, 91–93. [CrossRef] [PubMed]
38. Gutierrez, A.P.; Ponti, L.; Dalton, D.T. Analysis of the Invasiveness of Spotted Wing Drosophila (*Drosophila suzukii*) in North America, Europe, and the Mediterranean Basin. *Biol. Invasions* **2016**, *18*, 3647–3663. [CrossRef]
39. Esfanjani, J.; Ghorbani, A.; Zare Chahouki, M.A. MaxEnt Modeling for Predicting Impacts of Environmental Factors on the Potential Distribution of Artemisia aucheri and Bromus tomentellus-Festuca ovina in Iran. *Pol. J. Environ. Stud.* **2018**, *27*, 1041–1047. [CrossRef]
40. Yan, H.; He, J.; Xu, X.; Yao, X.; Wang, G.; Tang, L.; Feng, L.; Zou, L.; Gu, X.; Qu, Y.; et al. Prediction of Potentially Suitable Distributions of Codonopsis Pilosula in China Based on an Optimized MaxEnt Model. *Front. Ecol. Evol.* **2021**, *9*, 773396. [CrossRef]
41. Mahatara, D.; Acharya, A.; Dhakal, B.; Sharma, D.; Ulak, S.; Paudel, P. Maxent Modelling for Habitat Suitability of Vulnerable Tree *Dalbergia Latifolia* in Nepal. *Silva Fenn.* **2021**, *55*. [CrossRef]
42. Pinheiro de Carvalho, M.Â.A.; Ragonezi, C.; Oliveira, M.C.O.; Reis, F.; Macedo, F.L.; de Freitas, J.G.R.; Nóbrega, H.; Ganança, J.F.T. Anticipating the Climate Change Impacts on Madeira's Agriculture: The Characterization and Monitoring of a Vine Agrosystem. *Agronomy* **2022**, *12*, 2201. [CrossRef]