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Research Article

Geographical Distribution of *Nezara viridula* L. (Heteropteran: Pentatomidae) in Yazd Province of Iran Using Maximum Entropy Modeling

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ABSTRACT

Understanding the features that affect the distribution of invasive species has always been one of the principles of IPM strategy. Modeling the potential distribution makes it impossible to apply the necessary management tactics for controlling the invading species before damage begins. Yazd province, located in the dry belt of the Iranian plateau, is one of the most critical regions for pistachio production, and *Nezara viridula* L., which belongs to the category of Pentatomid bugs, is a cosmopolitan polyphagous pest that has numerous plant hosts, including pistachio. The sampling pattern of *N. viridula* concentrated on dividing provinces and pistachio orchards. According to a distribution prediction model, six climate layers plus altitude were selected, and datasets were performed through maximum entropy modeling (MaxEnt). The climates were chosen based on the climatic stratification method introduced by the International Center for Agricultural Research in the Dry Areas (ICARDA). Modeling the distribution maps for *N. viridula* based on Maxent and the areas under the receiver operating characteristic (AUC) illustrated climate changes including A-C-W, A-K-W, SA-K-M. It represented that small parts of the southern and northern regions of A-C-V-W were suitable for the presence and distribution of *N. viridula* in Yazd Province. The AUC value was more significant than 0.5, indicating that the selected environmental parameters had significantly affected the distribution of *N.viridula*. Eventually, it was concluded that the expansion of quasi-natural vegetation (primarily Pistachio orchards) could be considered an essential factor in the distribution of *N. viridula* compared to other environmental factors in this province.

Key words: *Nezara viridula*, Distribution models, Maxent, Pistachio orchards, Yazd province

INTRODUCTION

Determining the distribution of insects considering the geographical and climatic conditions is one of the main topics to predict the fluctuation in insect population in the studied areas. Due to the dynamics of insect populations, pests, or natural enemies, knowledge of biogeography and the interactions between their biological aspects and climate can play an essential role in maintaining the activity of beneficial organisms and managing the harmful ones. On the other hand, understanding the features that influence the dispersion of invasive species has always been one of the principles of IPM strategy (Philip *et al*. 2006). This ecological approach is achieved through analyzing the distribution patterns and how they change in the environment over time (Price, 1975). Since the early 19th century, Scientists have been interested in how climatic conditions affect the development and the outbreak of insect pests. As Wallace (1876), Andrewartha and Birch (1954), and Williamson (1996) have pointed out, the leading cause of fluctuations in insect population is exclusively related to climatic and geographical features.

The biogeographic region, rather than the single homogenous field, may often be the appropriate unit for researching insect dispersal and pest management (Levins and Wilson, 1979). Studies on the ecology of such organisms must consider the processes devised for individuals and regional sites. (Price, 1975; Levins and Wilson, 1979; Duelli *et al*.,1990).

In general, the dispersion patterns of living organisms are determined by the phenomena such as topography, climate, and interactions between organisms. Kemp *et al*. (2002) argued that climatic variables such as the annual temperature, rainfall averages, climate change, and vegetation all play crucial roles in the dispersion of insect species. Climatic conditions, especially temperature fluctuations, have considerably affected potential geographical insect pests. (Merriam and Lanoue, 1990; Sutherst *et al*., 2007). In fact, after discerning the effect of environmental variables such as climate, we can estimate the species distribution, even if no record of the species is detected. However, applying environmental variables has proven difficult in estimating species with limited distribution due to the risk of an increase in the error rate. (Ladle and Whittaker, 2011). Overall, the heterogeneity of distribution in plant populations can influence herbivore distribution. Accordingly, the heterogeneity of herbivore distribution can influence the effect of predators and parasitoids on the herbivores.

Interpreting the invasion history and the ecological features that underpin the geographical

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distribution of insect pests is a daunting task (Brooks *et al*., 2020). However, by designing the distribution potential model, it is possible to apply the necessary management tactics to control the invading species before the damage begins (Ladle and Whittaker, 2011). Using geographic distribution software such as maximum entropy modeling (Maxent) can create a temporary awareness of insect distribution to make pest management decisions. The estimation of the organism distribution based on climatic data was first defined by Pearson and Dawson (2003) and called the BIM or Bioclimate model. This methodology was created to find statistical relationships between environmental variables and species distribution. In order to manage invasive species biologically, it is necessary to use the appropriate tool to predict invasion patterns in the studied areas. (Roura-Pascual *et al*., 2008). Maxent is a commonly used method for describing or determining the probability of the distribution of a species using the existing data (Berger *et al*.,1996; Phillips and Dudik, 2008; Parvizi *et al*., 2018). The comparison of the ecological niche modeling software shows that Maxent performs better and provides more realistic results than the software that handles presence-only data, especially if the number of species presence data is inconsiderable (Elith *et al*. 2006; Hernandez *et al*. 2006; Thorn *et al*. 2009; Crawford and Hoagland. 2010; Parichehreh *et al*. 2020).

Nezara viridula L. (Het: Pentatomidae) is a cosmopolitan polyphagous pest with numerous plant hosts, such as pistachio and almond orchards. This pest has caused heavy losses in Iran due to the direct damage caused by the insects and the transmission of the fungal pathogen, *Nematospora coryli* Peglion. a pathogen of pistachio nuts (Behdad, 2002; Mehrnezhad *et al*., 2013). Meanwhile, *N. viridula* is an important vector of disease -causing pathogens of cotton and other crops (Esquivel *et al*. 2018). Adults overwinter in sheltered areas such as bushes, the bark of trees, and soil. *N. viridula* attacks many wild and cultivated plants, including Leguminose, Alfalfa, cotton, and soybean (Behdad, 2002) but *N.viridula*'s host preference has been focused on pistachio orchards in recent years (Mehrnezhad *et al*. 2013). Nymphs are seen in reddish-orange color at primitive instars, but gradually, with age, their color turns green. Multiple generations occur annually (3 to 5 generations) with overlap typical (Greene *et al*. 2001). Later generations, however, frequently are the most damaging to crops because of the presence of plant fruiting structures (Behdad, 2002; Mehrnezhad *et al*., 2013). Therefore, studying the distribution of *N. viridula* in Yazd province is justified because of its importance as a critical pest of pistachio orchards and the relatively vast climatic differences and fluctuations in short geographical distances in this region. Furthermore, the lack of credible records in the existing body of literature available on this subject is a clear attestation to the significance of the current study on the distribution of *N. viridula* in Yazd province.

The objectives of this research are to determine the appropriate ecological niche of the green stink bug to monitor the fluctuation of *N.viridula*'s populations using Maximum entropy modeling and analyze the effect of environmental parameters and selected factors climates on the incidence and distribution of *N. viridula* in Yazd province.

MATERIALS AND METHODS

The sampling process of *N. viridula* was performed in the span of three years (2017 to 2020) throughout the different climates of Yazd Province. In order to follow a standard methodology for sampling, the natural and quasi-natural vegetation was monitored, and *N. viridula* adults were collected through 'Netting' and 'Light traps.' Most of the sampling locations where these insects had transformed into pests were within the pistachio and almond orchards. In order to achieve more records, voucher specimens from the Entomological Museum of Islamic Azad University (Yazd branch) were also considered record samples. A total of 2779 insect specimens were used in this study for three years. A GPS device performed specifications such as latitude, longitude, and altitude simultaneously during the sampling process. *N. viridula* specimens were distinguished from other Pentatomids using the identification keys provided by Linnavori (1986) and Linnavori (2008). After identifying the species, sample information, including scientific name, family, subfamily, tribe, altitude, latitude, and longitude, was recorded in an Excel file (Figure 1).

1	Species	Family	Tribus	Genus	Altitude							x	y	Local	Number
2															
3	Nezara viridula	Pentatomida	Pentatomir	Nezara	1483	53	23	22	31	11	19	53.38944444	31.18861111	abarkoh	4
4	Nezara viridula	Pentatomida	Pentatomir	Nezara	1486	53	23	5	31	11	20	53.38472222	31.18888889	abarkoh	11
5	Nezara viridula	Pentatomida	Pentatomir	Nezara	1487	53	22	12	31	10	51	53.37	31.18083333	abarkoh	3
6	Nezara viridula	Pentatomida	Pentatomir	Nezara	1488	53	22	2	31	10	50	53.36722222	31.18055556	abarkoh	2
7	Nezara viridula	Pentatomida	Pentatomir	Nezara	1490	53	21	52	31	10	53	53.36444444	31.18138889	abarkoh	2
8	Nezara viridula	Pentatomida	Pentatomir	Nezara	1491	53	21	31	31	11	3	53.35861111	31.18416667	abarkoh	2
9	Nezara viridula	Pentatomida	Pentatomir	Nezara	1495	53	20	36	31	10	12	53.34333333	31.17	abarkoh	4
10	Nezara viridula	Pentatomida	Pentatomir	Nezara	1228	54	22	3	31	53	50	54.3675	31.89722222	yazd	1
11	Nezara viridula	Pentatomida	Pentatomir	Nezara	1603	54	22	2	30	2	46	54.36722222	30.04611111	harat	3
12	Nezara viridula	Pentatomida	Pentatomir	Nezara	1612	54	22	20	30	2	23	54.37222222	30.03972222	harat	1
13	Nezara viridula	Pentatomida	Pentatomir	Nezara	1612	54	22	52	30	2	28	54.38111111	30.04111111	harat	1
14	Nezara viridula	Pentatomida	Pentatomir	Nezara	1399	56	1	26	31	53	19	56.02388889	31.88861111	bahabad	2
15	Nezara viridula	Pentatomida	Pentatomir	Nezara	1395	56	0	54	31	53	21	56.015	31.88916667	bahabad	4
16	Nezara viridula	Pentatomida	Pentatomir	Nezara	1394	56	0	55	31	53	26	56.01527778	31.89055556	bahabad	4
17	Nezara viridula	Pentatomida	Pentatomir	Nezara	1034	54	1	44	32	19	38	54.02888889	32.32722222	ardekan	4
18	Nezara viridula	Pentatomida	Pentatomir	Nezara	1030	53	59	12	32	19	9	53.98666667	32.31916667	ardekan	1
19	Nezara viridula	Pentatomida	Pentatomir	Nezara	1027	53	58	43	32	19	28	53.97861111	32.32444444	ardekan	3
20	Nezara viridula	Pentatomida	Pentatomir	Nezara	1026	54	0	56	32	20	20	54.01555556	32.33888889	ardekan-A	1
21	Nezara viridula	Pentatomida	Pentatomir	Nezara	1019	53	58	10	32	20	55	53.96944444	32.34861111	tork abad	1
22	Nezara viridula	Pentatomida	Pentatomir	Nezara	1019	53	58	7	32	20	53	53.96861111	32.34805556	tork abad	3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 1. Screenshot showing an example of locally collected *N.viridula*'s data, including Scientific name, Family, Subfamily, Tribe, Genus, altitude, Latitude (shown as x), and Longitude (shown as y), implemented in Excel.

Mapping the climatic distribution of *N. viridula*, taking into account the coordinates of Yazd province and its seven climates, was performed by ARC GIS 9.3. Climates were selected based on the climatic stratification described by the International Center for Agricultural Research in the Dry Areas ICARDA (2004) In Yazd Province (Table 1). At least five zones were selected in the four cardinal zones, and each climatic zone's center of the climate. In the next step, environmental variables were considered to determine the environmental factors affecting the distribution of *N. viridula* (Table 2). The research hotspots were validated based on more than twenty samples (Figure 4).

Table 1. Abbreviations and features of the climatic layers in Yazd province.

Code (Abbreviations)	Moisture	Winter	Summer
A-C-VW	Arid	Cool	Very Warm
A-C-W	Arid	Cool	Warm
A-K-W	Arid	Cold	Warm
A-M-VW	Arid	Mild	Very Warm
SA-K-M	Semi-Arid	Cold	Mild
SA-K-W	Semi-Arid	Cold	Warm
SA-C-W	Semi-Arid	Cold	Warm

Table 2. Environmental variables used in predicting the species' geographic distribution models. For a description of each parameter, refer to the text.

Environmental Parameter (Unit)	Parameter Code
Annual Mean Temperature (°C)	Bio 1
Maximum Temperature of Warmest Month(°C)	Bio 5
Maximum Temperature of Coldest Month(°C)	Bio 6
Annual Precipitation (mm)	Bio 12
Precipitation of Wettest Month (mm)	Bio 13
Precipitation of Driest Month (mm)	Bio 14
Altitude (m)	Elevation

Maxent software introduced by Phillips *et al*. (2006) was used to predict the distribution of *N. viridula* based on environmental parameters presented in Table 2. The data used in Maxent was selected as presence-only, and the Excel file was applied in CSV formation. Then, the possible distribution of *N. viridula* was evaluated using Maxent in each pixel of the studied space. In order to regulate the Maxent settings, 10000 instances of background data were selected as quasi-locations with ten replications (with a maximum iteration of 500 or 1000), and one convergence threshold was performed for the studied species (*N.viridula*). The logistic method was used to describe the habitat prediction model. Spreadsheets created in Excel were also changed and saved as ASC files.

Maxent's data was analyzed via Jacknife® and areas under the receiver operating characteristic (AUC) values. AUC values were used to assess the distribution model and measure its accuracy. The species' distribution can be predictable optimally, and the samples show more compliance with environmental parameters shown in Table 1 when the AUC model is (or is close to) 1. In contrast, the model is predicted spontaneous if it has been (or less than) 0.5. On the other hand, the most reliable results can be obtained in AUC 0.7 or more. Nevertheless, values less than 0.5 are not acceptable nor cited in the analysis of distribution models (Philip *et al*., 2006).

Jacknife® analysis was used to assess the importance of each variable separately in order to predict the species distribution model. Furthermore, the effect of each variable in predicting the probability of the incidence of *N. viridula* was plotted and graphed (Figure 2).

Species distribution models, in which the dispersion potential and suitable habitats are demonstrated, were prepared by Maxent with ten replications. Habitat suitability for *N. viridula* was recorded in blue and red for suitable and less suitable habitats, respectively (Figure 3).

RESULTS

The distribution model map of *N. viridula* showed that climates, including A-C-W, A-K-W, SA-K-M, and small parts of the southern and northern regions of A-C-VW, were probably more suitable for the presence and distribution of *N. viridula* in Yazd Province. Conversely, climates including S-A-KW, A-M-VW, and S-A-CW, located approximately in desert areas and snow-capped heights, did not seem to have the proportionate habitats necessary for *N. viridula*'s activity (see Figure 4 and Figure 5).The value of AUC being higher than 0.5 indicated that selected environmental parameters significantly affected *N. viridula*'s distribution.

Jacknife® test's results highlighted that the altitude and maximum temperature of the warmest month (Bio 5) and the annual precipitation (Bio12) provided more ecological information when used separately. Consequently, these three factors seemed to be more effective than the others (Fig 3). Moreover, altitude change over short geographical distances seemed to play a decisive role in the presence of *N. viridula* in Yazd province. Brooks *et al*. (2020) indicated that mean temperature for the warmest quarter was the best predictor for estimating the climatic suitability of *N. viridula*, and the contribution of mean humidity was meager. The driest month's precipitation (Bio 14) had the lowest value for the *N. viridula* distribution model. Response graphs for the annual mean temperature (Bio1) showed that *N. viridula* was most likely present in the temperature range of 5 to 17 °C.

The probability of *N. viridula* incidence was enhanced due to representing the maximum temperature of the warm months of the year factor in the temperature range of 28 to 39 °C as well as the temperatures mentioned above. The species' distribution gradually decreased (shown in Figure 2 and Figure 3).

The annual precipitation results (Bio 12) illustrated that the probability of *N. viridula* incidence decreased to less than 70 mm. This rate of decline was gradual in the range of 60 to 70 mm, while it was observed suddenly in the range of 40 to 60 mm. The annual precipitation

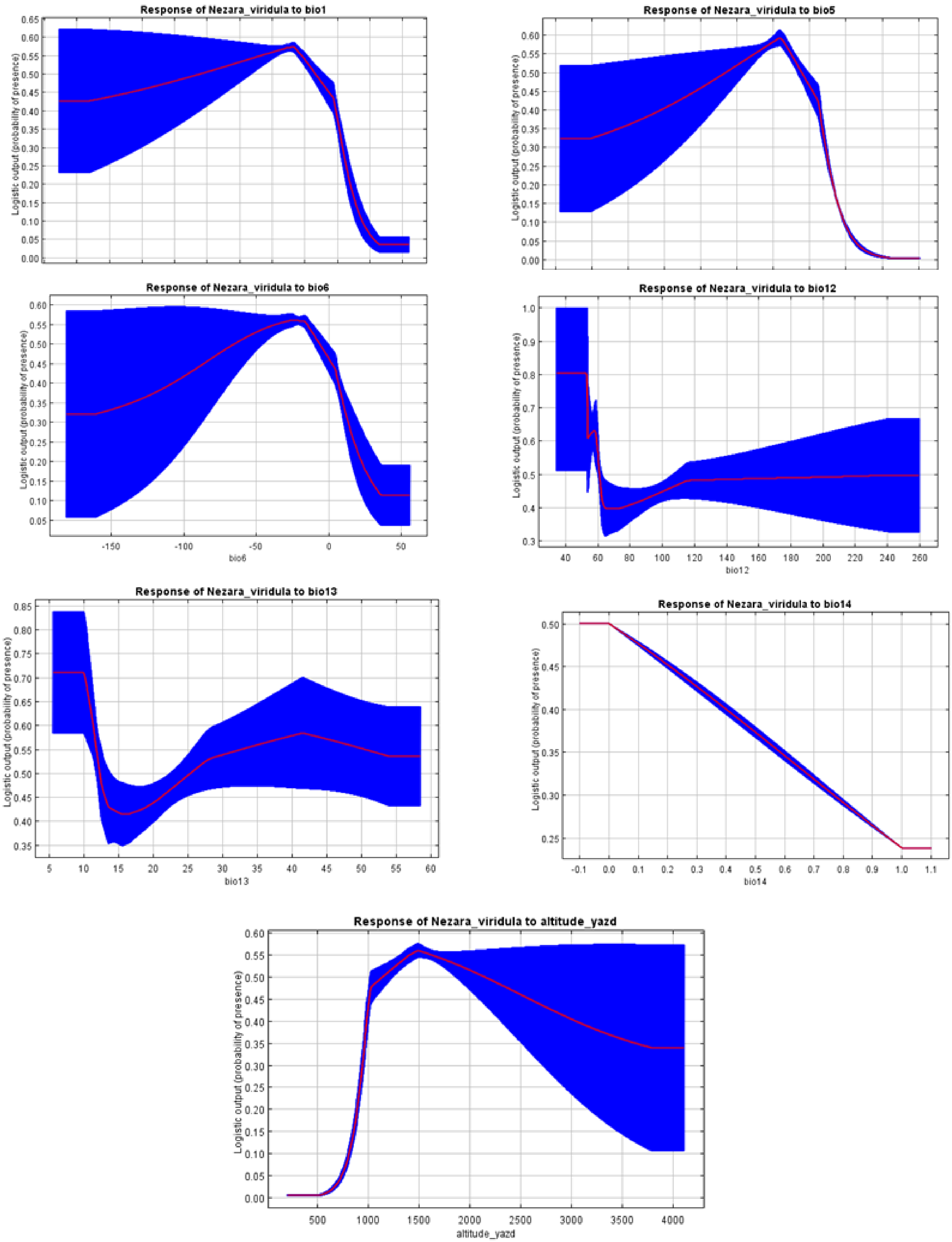

Figure 2. Experiments of the environmental variables' importance and marginal response curves of contribution variables to predict the incidence probability of *Nezara viridula* in Yazd Province of Iran were performed by MaxEnt. See Table 2 for the definition of Bio variables. No significant influence of the driest month's precipitation (Bio 14) is detected, while the interference of other variables is significantly visible in the distribution of *N. viridula* in Yazd Province. The minimum influence of the precipitation in the driest Month (Bio 14) can be justified due to the location of Yazd in the dry belt of the Iranian plateau. In addition, the amount of precipitation in the mountainous areas of the province could not compensate for this shortage.

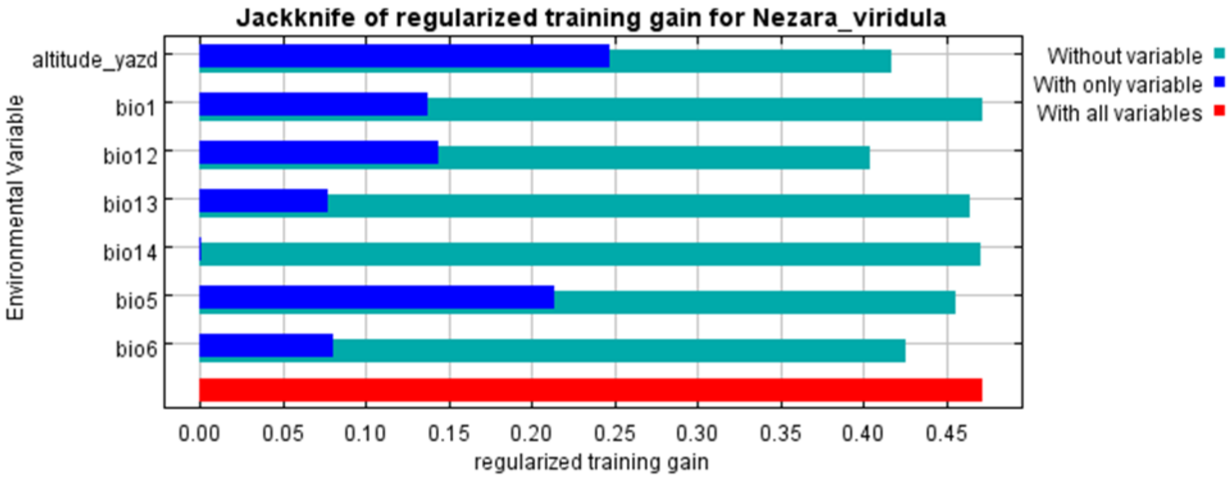

Figure 3. Correlation between environmental variables and regularized training gain based on Jackknife tests. These variables are categorized into three categories: without variable (green), with only variable (blue), and with all variables (red). Jacknife test's results illustrate the massive effect of altitude, the maximum temperature of the warmest month (Bio 5), and the annual precipitation (Bio12) on the distribution of *Nezara viridula*. In contrast, the driest month's precipitation (Bio 14) is the least effective variable. The difference between the annual precipitation (Bio12) and precipitation of the driest month (Bio 14) showed the existence of different climatic conditions in short geographical distances in Yazd province (Ladle and Whittaker, 2011). Also, considering the location of Yazd province in the dry belt of the Iranian plateau and the temperature difference between cold and warm months of the year, the significant effect of temperature on the distribution of *N. viridula* was Inevitable.

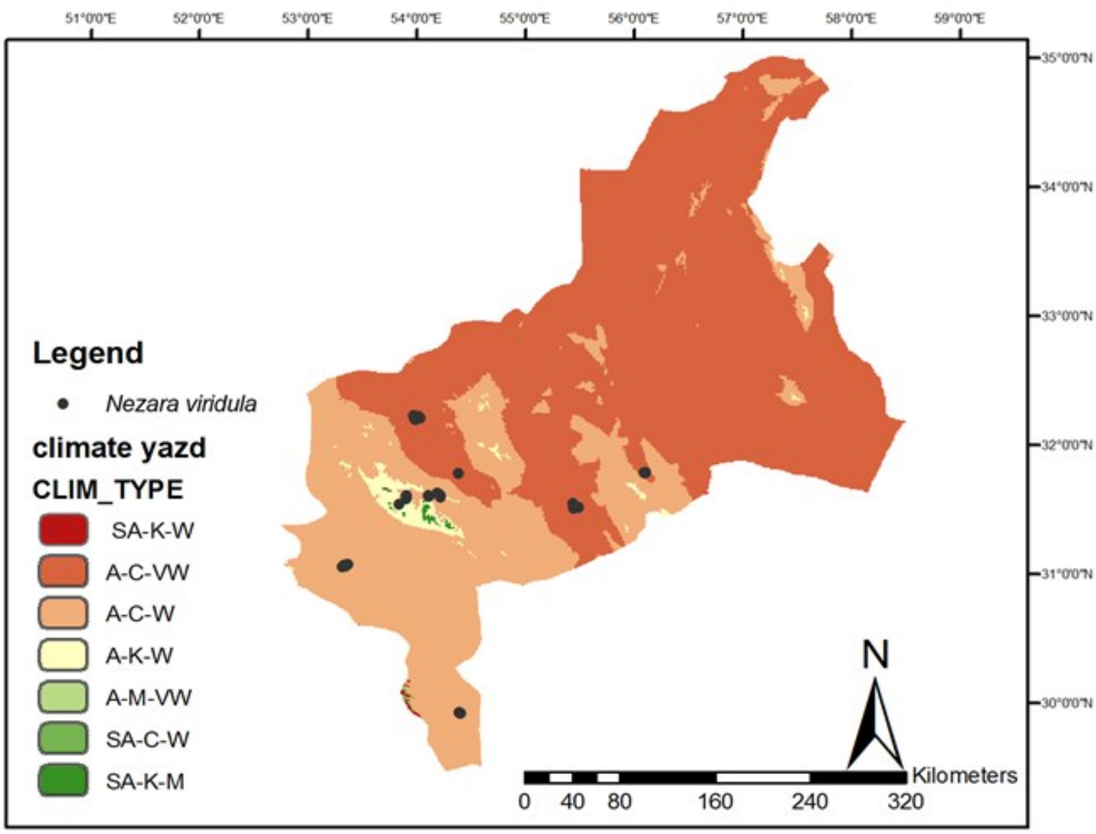

Figure 4. Prediction of climate suitability for *Nezara viridula* in Yazd province of Iran. The distribution model map shows that climates including A-C-W, A-K-W, SA-K-M, and small parts of the southern and northern regions of A-C-VW habitats are more suitable for the distribution of *N. viridula* in Yazd Province. However, In a broad scope of SA-K-W, located in desert areas, no record of *N. viridula* specimens was traced.

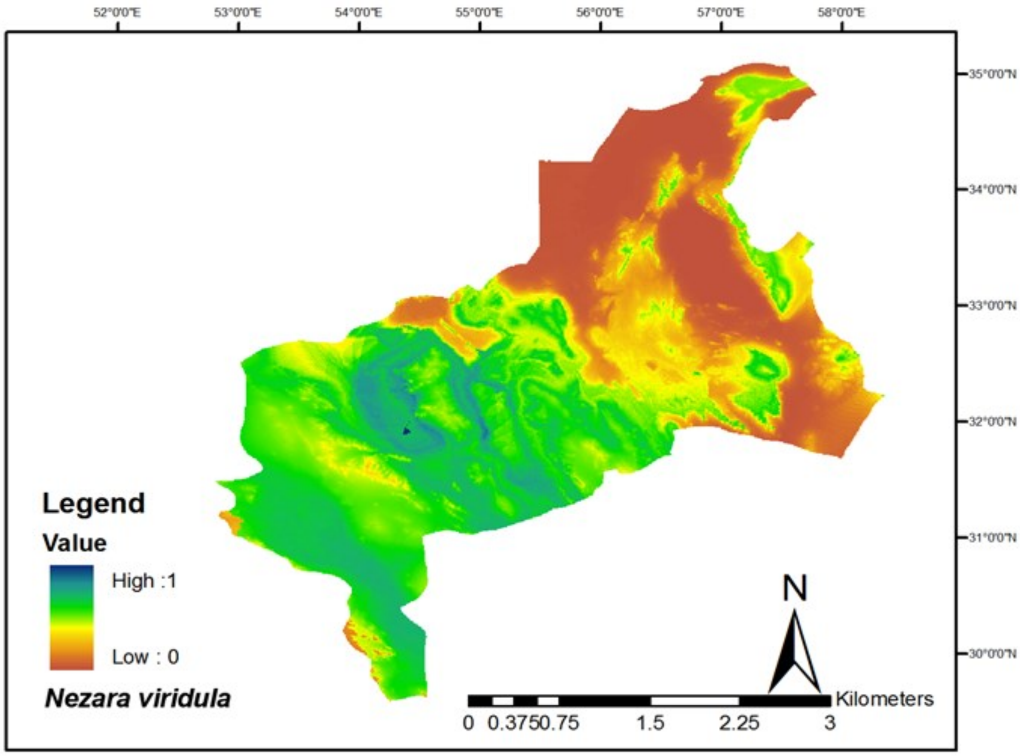

Figure 5. Prediction of habitat suitability for *Nezara viridula* in Yazd province of Iran. Suitable habitats are shown in blue, while less suitable ones are shown in red.

results (Bio 12) demonstrated that if the rainfall range reached about 120mm, there was a positive correlation between the precipitation quantity and the probability of *N. viridula* distribution. In other words, increasing rainfall directly influenced the expansion of *N. viridula* in the studied areas. The precipitation results of the wettest month (Bio 13) showed that the *N. viridula* presence probability decreased with a positive and steep slope in the range of 10 to 15 mm. No significant influence on the precipitation of the driest month (Bio 14) was detected in association with *N.viridula*'s distribution (shown in Figure 2 and Figure3). Meanwhile, Elevation had a positive effect on *N. viridula* distribution, so that according to increasing altitude, the probability of the species incidence enhanced and reached maximum range at 1500 meters.

DISCUSSION

Considering the high thermal threshold and the cosmopolitan activity of *N.viridula*, we concluded that increasing the temperature and decreasing the humidity (precipitation) simultaneously reduced *N.viridula*'s distribution in Yazd province. Brooks *et al*. (2020) indicated that mean temperature for the warmest quarter was the best predictor for climatic suitability of *N.viridula*, and mean humidity contributed little. According to Musolin's (2007) results, temperature changes have affected the activity and geographical distribution of Green stinkbugs such as N.viridula. These alternations have manifested themselves as changes in morphology, behavior, and, most importantly, distribution (Musolin *et al*., 2010). Furthermore, Vivan and Panizzi (2006) attributed the decrease in *N.viridula*'s distribution to an exponential enhancement in the temperature during the year's warm seasons. In contrast, Panizzi (1997) emphasized that species living in the tropics have high thermal thresholds, and rising temperatures have rarely reduced their distribution. Therefore, such an approach was somewhat explainable given the incidence of *N. viridula* in the temperature range of 28 to 40 °C in the present study (see Figure 2 and Figure 3).

Contrary to Solhjoy-fard *et al*. (2013), which indicated that there had been no record of Green stinkbugs in Yazd province, we reached out to a considerable number of Green bugs, including *N.viridula*, in 3 years. This discrepancy in results may be explained via the migration or vegetation expansion in recent years. In some areas, including Nodushan and Chah-Afzali (located in SA-K-W climatic zonation), where *N. viridula* samples were collected significantly in the first year, almost no samples were found in the same area the following year, which probably implied the migration of *N. viridula* in the said areas. Similarly, Vivan and Panizzi (2006) reached a similar conclusion about *N.viridula*'s migration in Brazil.

Shaefer and Panizzi's research (2000) showed that green stink bugs disperse rapidly and have considerable ability to move through long distances in a minimum period. Such significant mobility was also evident in our studies, despite the relatively long distances of Pistachio orchards in desert areas. Based on this, geographical distance did not seem to be a limiting factor for the distribution of *N. viridula* in Yazd province. On the other hand, considering *N.viridula*'s remarkable dispersal ability, it can be concluded that *N.viridula*'s migration is strongly inevitable (Kiritani, 1970; Panizzi *et al*.,1996; Solhjoy-fard *et al*., 2013).

One of the main reasons for the non-incidence of *N. viridula* in some arid hotspots in Yazd province was climate limitations. The distribution model map of *N. viridula* showed that climates including A-C-W, A-K-W, S-A-KM, and small parts of A-C-VW were probably more suitable for the presence and distribution of *N. viridula* in Yazd province. Conversely, Climates including SA-K-W and A-M-VW, located in the Lut Desert, did not have proportionate habitats for *N.viridula*'s populations (Fig. 4). Addykairovna (2011) demonstrated that a group of green stink bugs (Genus of *Brachynema*) is more active in desert areas with sparse vegetation and dunes. According to Tougu *et al*.'s results (2009), *N.viridula*'s distribution source is often located in the mountains and inland hills. Furthermore, *N.viridula*'s considerable richness in the mountainous climates of Yazd province (S-A-KM) was significantly confirmed by Tougu *et al*.'s findings (2009).

Vegetation is one of the pertinent variables to climatic conditions, especially rainfall (Ladle and Whitaker, 2011). So, we assumed that it could be a critical factor in the distribution of *N. viridula* in Yazd province. As discussed earlier (Kiritani, 1979; Panizzi, 1997; Mosulin, 2007), the distribution of *N. viridula* is not limited by the factors that typically limit insect distribution ranges because this species is multivoltine and very polyphagous. However, the lack of food resources, including Pistachio and Pomegranate orchards, seemed to be one of the main reasons for the non-incidence of *N. viridula* in some arid hotspots with thin vegetation in Yazd province.

Species have also regularly shifted their geographical ranges in response to the biological and physical forces, climate changes, and vegetation, sometimes becoming less common and becoming more widespread (Wares *et al*., 2002; Williamson, 1996). However, the vast majority of the species are not distributed broadly because most species have limited dispersal capabilities (Price, 1975). This paradox manifested itself in our studies. Several studies suggest that the vegetation settings associated with particular crop fields (such as the pistachio orchards in the present study) influence the kind, abundance, the times of arrival, and, above all, their distribution (Price *et al*. 1991).

According to Todd (1989), More than 30 families of plants have been introduced as *N.viridula*'s hosts, most of which are agricultural and horticultural products. Thus, it is evident that vegetation can play a decisive role in the distribution of *N. viridula* populations. The vegetation structure best explains the dependence of green stink bugs' distribution on rainfall, confirming previous findings regarding its positive correlation with *N.viridula*'s dispersal (Duelli *et al*., 1990; Roura-Pascual *et al*., 2008; Ladle and Whitaker,2011; Tavanpour *et al*. 2016). Although little vegetation and low precipitation have caused unfavorable conditions for the distribution of *N. viridula* (shown in Figure 4 and Figure 5), the conversion of natural to quasi-natural vegetation through pistachio planting and the construction of aqueducts and deep wells in the desert has created a suitable ecological niche for *N. viridula* in Yazd province. Therefore, we concluded that the spread of quasi-natural vegetation (especially pistachio orchards) has probably caused the flow of *N.viridula*'s populations from the mountains to the plains.

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REFERENCES

Abdykairovna, Y.P. (2011) Fauna of Heteroptera in the deserts of Kazakhstan. Journal of Arid Land 3 (4). 303-305.DOI: content/uploads/2020/05/izdaniya/statiyi/etmologiya/Yesenbekova,% 202011.pdf

Andrewartha, H. G., Birch, L. C. 1954.The distribution and abundance of animals. Univ. Chicago Press, Chicago.

Behdad, E. 2002. Introductory entomology and important plant pests in Iran. Yadboud Press.[In Persian].

Berger, A.L., Della Pietra, S.A., Della Pietra, V.J. 1996. A maximum entropy approach to natural language processing. Computer Linguist 22(1): 39-71.

Brooks, D.R., Hereward, J.P., Wilson, L.J., Walter, G.H. 2020. Multiple invasions of generalist herbivore -Secondary contact between two divergent lineages of *Nezara viridula* L. in Australia. Evolutionary Applications 13: 2113-2129.DOI: https://doi.org/10.1111/eva.12971

Cohen, Y., Cohen, A., Hetzroni, A., Alchanatis, V., Broday, D., Gazit, Y., Timar, D. 2008. Spatial decision support system for medfly control in citrus. Computer and Electronic in Agriculture 62(2): 107-117.DOI: 10.1016/j.compag.2007.12.005

Crawford, P., Hoagland, B. W. 2010. Using species distribution models to guide conservation at the state level: The endangered American burying beetle (*Nicrophorus americanus*) in Oklahoma. Journal of Insect Conservation 14(5):511-521.DOI: 10.1007/s10841-010-9280-8

Duelli, P., Studer, M., Marchand, I., Jakob, S. 1990. Population movements of arthropods between natural and cultivated areas. Biological Conservation 54: 193-207.DOI: https://doi.org/10.1016/0006-3207(90)90051-P

Elith, J., Graham, C.H., Anderson, R.P., Dudık, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S.J., Richardson, K., Scachetti-Pereira, R., Schapire, R.E., Soberon, J., Williams, S., Wisz, M.S., Zimmermann, N.E. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecogeography 29, 129-151.DOI: https://doi.org/10.1111/j.2006.0906-7590.04596.x

Esquivel, J. F., Droleskey, R. E., Ward, L. A., Harvey, R. B. 2018. Morphometrics of the Southern Green Stink Bug [*Nezara viridula* (L.) (Hemiptera: Pentatomidae)] Stylet bundle. Neotropical Entomology 48, 78-86. DOI: 10.1007/s13744-018-0603-x

Greene, J.K., Turnipseed, S. G., Sullivan, S. G., May, O. L. 2001. Treatment thresholds for stink bugs (Hemiptera: Pentatomidae) in cotton. Journal of Economic Entomology 94, 403-309. DOI: 10.1603/0022-0493-94.2.403

Hernandez, P.A., Graham, C.H., Master, L.L., Albert, D.L. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography 29, 773-785.DOI: https://doi.org/10.1111/j.0906-7590.2006.04700.x

ICARDA (2004). ICARDA Annual Report 2004 Communication Team. Aleppo, Syria: International Center for Agricultural Research in the Dry Areas (ICARDA). DOI: https://repo.mel.cgiar.org/handle/20.500.11766/7624

Kemp, W. P., O'Neill, K. M., Cigliano, M. M. & Torrusio, S. 2002. Field-Scale Variation in Plant and Grasshopper Communities. A GIS-based Assessment 6(2): 115-133.DOI: 10.1111/1467-9671.00100

Kiritani, K. 1970. Studies on the adult polymorphism in the southern green stink bug, *Nezara viridula* (Hemiptera: Pentatomidae). Researches on Population Ecology 12(1): 19-34.DOI: BF02511079

Ladle, R.J., Whittaker, R.J. 2011. Conservation Biogeography. John Wiley & Sons Ltd Publication. 301 pp. DOI: 10.1002/9781444390001

Levins, R., Wilson, M. 1979. Ecological theory and pest management. Annual Review of Entomology 25:7-19.DOI: https://doi.org/10.1146/annurev.en.25.010180.001443

Linnavuori, R.E. 1986. Heteroptera of Saudi Arabia. Fauna of Saudi Arabia 8: 31-197.

Linnavuori, R.E. 2008. Studies on the Acanthosomatidae, Scutelleridae and Pentatomidae (Heteroptera) of Gilan and the adjacent provinces in northern Iran. Acta Entomologica Musei Nationalis Pragae 48: 1-21.

Mehrnejad, M. R., Linnavuori, R. E., Alavi, S. H. 2013. Hemipteran bugs associated with pistachio trees and notes on major species. Zoology and Ecology 23(1): 29-40.DOI: 10.1080/21658005.2013.774832

Merriam, G. Lanoue, A. 1990. Corridor use by small mammals: field measurements for three experimental types of *Peromyscus leucopus*. Landscape Ecology 4: 123-131.DOI: https://doi.org/10.1007/BF00132856

Musolin,D. L. 2007. Insects in a warmer world: ecological, physiological and life-history responses of true bugs (Heteroptera) to climate change. Global Change Biology 13: 1565–1585.DOI: 10.1111/j.1365-2486.2007.01395.x

Musolin,D. L., Tougou, D., Fujisaki, K. 2010. Too hot to handle? Phenological and life-history responses to simulated climate change of the southern green stink bug *Nezara viridula* (Heteroptera: Pentatomidae). Global Change Biology 16(1): 73-78.DOI: 10.1111/j.1365-2486.2009.01914.x

Panizzi, A. R. 1997. Wild hosts of pentatomids: Ecological significance and role in their pest status on crops. Annual Review of Entomology 42(1), 99–122.DOI: 10.1146/annurev.ento.42.1.99

Panizzi, A. R., Vivan, L. M., Corrêa-Ferreira, B. S., Foerster, L. A. 1996. Performance of southern green stink bug (Heteroptera: Pentatomidae) nymphs and adults on a novel food plant (Japanese privet) and other hosts. Annals of the Entomological Society of America 89(6): 822–827.DOI: https://doi.org/10.1093/aesa/89.6.822

Parichehreh, S., Tahmasbi, G., Sarafrazi, A., Tajabadi, N., Solhjouy-Fard, S. 2020. Distribution modeling of *Apis florea* Fabricius (Hymenoptera, Apidae) in different climates of Iran. Journal of Apicultural Research.

Parvizi, E., Naderloo, R., Keikhosravi, A. Solhjouy-Fard, S., Schubart, C. D. 2018. Multiple Pleistocene refugia and repeated phylogeographic breaks in the southern Caspian Sea region: Insights from the freshwater crab *Potamon ibericum*. Journal of Biogeography. DOI: https://doi.org/10.1111/jbi.13195

Pearson, R. G., Dawson, T. P. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful?. Global Ecology and Biogeography 12(5): 361-371.DOI:https://doi.org/10.1046/j.1466-822X.2003.00042.x

Phillips, S.J., Anderson, R.P., Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecological modeling 190: 231-256.DOI: https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips, S.J., Dudık, M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31: 161-175.DOI: https://doi.org/10.1111/j.0906-7590.2008.5203.x

Price, P. W. 1975. Insect Ecology. Editions 1-3. Wiley, New York.

Price, P. W., Lewinsohn, T. M., Fernandes, G. W., Benson, W. W. 1991. Plant-Animal Interactions: Evolutionary Ecology in Tropical and Temperate Regions. Wiley, New York.

Roura-Pascual, N., Brotons, L., Peterson, A.T., Thuiller, W. 2008. Consensual predictions of potential distributional areas for invasive species: a case study of Argentine ants in the Iberian Peninsula. biological Invasions. DOI: 10.1007/s10530-008-9313-3

Schaefer, C.W., Panizzi, A.R. 2001. Economic Importance of Heteroptera: A General View. Heteroptera of Economic Importance. CRC Press pp. 3-8.

Schaefer, C.W., Panizzi, A.R., 2000. Heteroptera of Economic Importance. CRC Press, Boca Raton. 828 pp.

Solhjouy-Fard, S., Sarafrazi, A., Minbashi Moeini, M., Ahadiyat, A. 2013. Predicting habitat distribution of five heteropteran pest species in Iran. Journal of Insect Science 13:116.DOI: https://doi.org/10.1673/031.013.11601

Sutherst, R.W., Maywald, G.F., Bourne, A.S. 2007. Including species interactions in risk assessment for global change. Global Change Biology 13 (9): 1843-1859.DOI: 10.1111/j.1365-2486.2007.01396.x

Tavanpour, T., Sarafrazi, A. M., Mehrnejad, M. R., Imani, S. 2016. Distribution scenario of two species of green bugs *Brachynema germarii* and *Nezara viridula* (Hemiptera; Pentatomidae) in Kerman province. Applied Entomology and Phytopatology 84(1): 67-78 [In Persian].DOI: 10.22092/JAEP.2016.106611

Thorn, J.S., Nijman, V., Smith, D., Nekaris, K.A.I. 2009. Ecological niche modelling as a technique for assessing threats and setting conservation priorities for Asian slow lorises (Primates: Nycticebus). Diversity and Distributions 15: 289-298.DOI:https://doi.org/10.1111/j.1472-4642.2008.00535.x

Todd, J. W. 1989. Ecology and behavior of *Nezara viridula*. Annual Review of Entomology 34(1): 273-292.DOI: https://doi.org/10.1146/annurev.en.34.010189.001421

Tougou, D., Musolin, D. L., Fujisaki, K. 2009. Some like it hot! Rapid climate change promotes changes in distribution ranges of *Nezara viridula* and *Nezara antennata* in Japan. Entomologia Experimentalis E Applicata 130(3): 249-258. DOI: https://doi.org/10.1111/j.1570-7458.2008.00818.x

Veres, D., Bazin, L., Landais, A., Lemieux-Dudon, B., Parrenin, F., Martinerie, P., Toye´ Mahamadou Kele, H., Capron, E., Chappellaz, J., Rasmussen, S., Severi, M., Svensson, A., Vinther, B., Wolff, E. 2012. The Antarctic ice core chronology. an optimized multi-parameter and multi-site dating approach for the last 120 thousand years, Climate of the Past, This issue, 2012.DOI: 10.5194/cpd-8-6011-2012

Vivan, L.M., Panizzi, A.R. 2006. Geographical distribution of genetically determined types of *Nezara viridula* (L.) (Heteroptera:Pentatomidae) in Brazil. Neotropical Entomology 35(2):175-181. DOI: 10.1590/s1519-566x2006000200004

Wallace, A.R. 1876. The geographical distribution of animals. Macmillan, London. 910 pp.

Wares, J.P., Goldwater, D.S., Kong, B.Y., Cunningham, C.W. 2002. Refuting a controversial case of human-mediated marine species introduction. Ecology Letters 5: 577-584.DOI: https://doi.org/10.1046/j.1461-0248.2002.00359.x

Williamson, M.H. (1996) Biological Invasions. Chapman and Hall, London.

Yukawa, J., Kiritani, K., Gyoutoku, N., Uechi, N., Yamaguchi, D., Kamitani, S. 2007. Distribution range shift of two allied species, *Nezara viridula* and *N. antennata* (Hemiptera: Pentatomidae), in Japan, possibly due to global warming. Applied Entomology and Zoology. 42(2), 205–215. DOI: https://doi.org/10.1303/aez.2007.205