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Original paper

The habitat suitability model for the potential distribution of *Ornithodoros tholozani* (Laboulbène et Mégnin, 1882) and *Ornithodoros lahorensis* (Neumann, 1908) (Acari: Argasidae): the main vectors of tick-borne relapsing fever in Iran

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ABSTRACT. Endemic relapsing fever (RF) is one of the most important arthropod-borne diseases caused by various types of *Borrelia* and transmitted by soft tick species. The investigation of the distribution of vectors in a region can help control and prevent the disease. This study aimed to investigate the distribution of *Ornithodoros tholozani* and *Ornithodoros lahorensis* in Iran and to identify the most influential climatic variables affecting their distribution. The ecological niche model was used in Maxent to predict the environmental suitability of the studied species. A review was conducted on the earlier studies carried out in Iran (1977–2018), and the coordinates of collection sites for these two ticks were recorded. Nineteen bioclimatic variables were used for the modelling. The main vectors of RF were reported from 13 provinces, 43 counties and more than 160 villages in Iran. The rate of *Borrelia* spp. infection was higher in *O. tholozani* (36%) than in other soft ticks. The annual mean temperature and precipitation seasonality were the most important factors affecting the distribution of RF vectors. The north-western regions of Iran were found to provide the best environmental needs for these vectors. Therefore, special attention should be paid to control the disease by managing contact with soft ticks in these areas.

Keywords: soft ticks, tick relapsing fever, ecological niche model, Iran

Introduction

Climate and environmental changes in the world are the main causes of various human infectious diseases, including vector-borne and zoonotic ones. These diseases emerge and re-emerge in some parts of the world, and their distribution is dependent on various climate and environmental factors [1–5]. One of the most important vector-borne diseases is the tick-borne relapsing fever (TBRF) that is endemic in some parts of Asia, Africa and America. The agent of TBRF is a spirochete microorganism which is transmitted to humans by some species of *Ornithodoros* soft ticks (Family: Argasidae) [6]. The disease agent is a *Borrelia* species (Family: Borreliaceae) [7,8]. The specific clinical symptom of this disease is a relapsing fever lasting for 2 up to 6 days. The general symptoms of this type of fever include headache, pain, nausea, joint pain and nausea [9,10]. Relapsing fever (RF) is one of the most important endemic diseases in Iran with an annual incidence rate of 140. According to a study conducted between 1996 and 2007 in Iran, 1415 cases of RF were reported from 18 provinces. Among these provinces, Ardabil experienced the highest prevalence of the disease with 625 cases and Isfahan and Sistan and Baluchistan had the lowest [11]. In Iran, four species of *Borrelia* have been

identified in relation to endemic RF, the most important of which is *Borrelia persica* that is transmitted by *Ornithodoros tholozani* across different regions [12–17]. In Iran, *O. tholozani*, *O. tartakovsky* and *O. erraticus* are able to transmit the *Borrelia* species to humans [18]. In recent years, a number of modelling strategies have been developed to predict the potential impacts of climate change on the biodiversity of the *Borrelia* species focusing on identifying a variety of biological species by using their geographical distribution and response to climate change [19–22]. The emergence of GIS and software, such as Maxent, and the production of high-resolution digital maps of the climate and earthy ecology have allowed ecologists to create powerful tools for studying the relationship among bio communities; this, in turn, has led to the expansion of the modelling of the distribution of species. These results can strengthen correlations among the geographical distributions of species and their relationships with climatic and environmental variables [23–25]. Considering the importance of the modelling and distribution of important vectors of the disease, this study set to determine the distribution of two important species of endemic RF in Iran and to determine the suitable habitat locations in the country. In addition, this study aimed to determine the important climatic variables affecting the distribution of these two vectors.

Materials and Methods

Design and study area. All the datasheets (120 articles) of the two vectors of RF in the forms of MSc theses, PhD dissertations and research projects conducted and published from 1977 to 2018 were selected. The inclusion criterion was that their results had to be published as research articles in journals indexed in Cochrane, Medline/PubMed, Google Scholar, Science Direct, Scopus, Web of Science, Veterinary information network, Vet Med Resources, Zoological Record, Abstract Biological and CAB. Besides, the following Iranian databases were also referred to for Persian articles: Iran Medex, Scientific Information Database (SID) and Magiran. Eventually, 18 articles related to the distribution and infection of *O. tholozani* and *O. lahorensis* by *Borrelia* species in Iran were included in the study.

Search methodology. The following words and phrases in all search fields were used to search the articles: soft ticks, Argasidae, vectors of relapsing

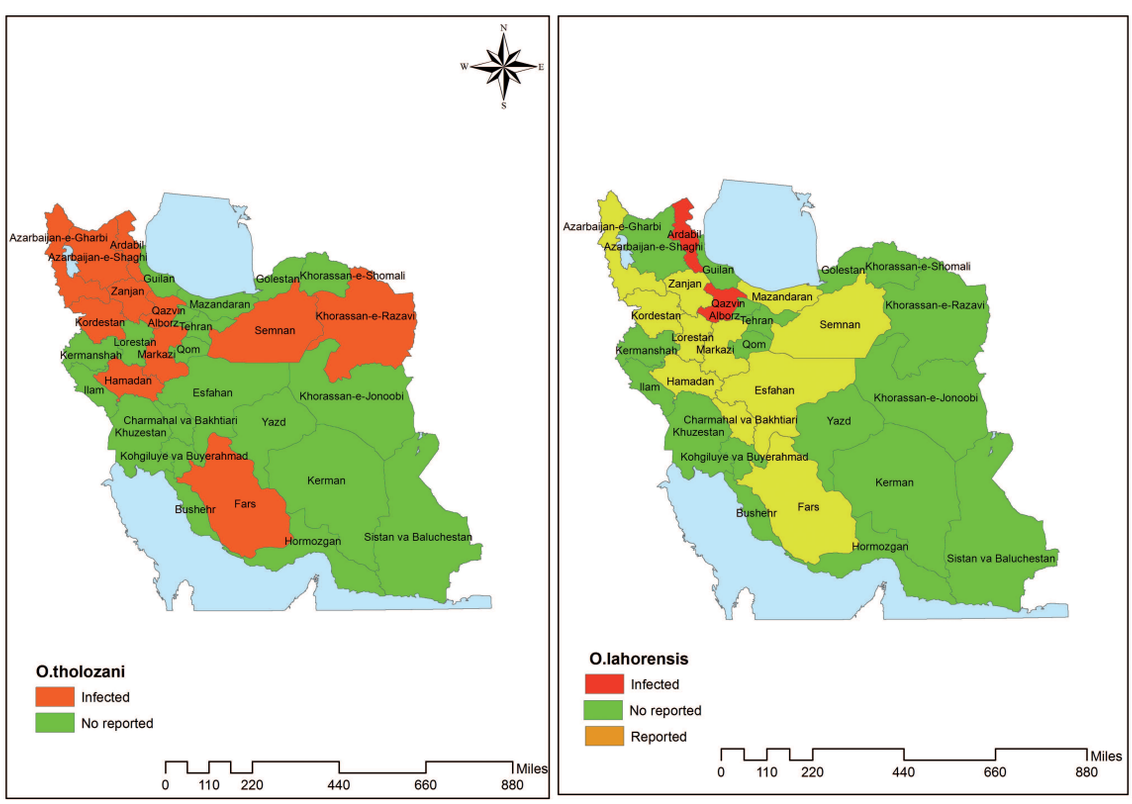

Figure 1. Distribution sites and infection rate of *O. tholozani* and *O. lahorensis* to *Borrelia* spp. in Iran

Table 1. The infection of soft ticks with various *Borrelia* species in Iran

Province	Tick species	*Borrelia* species	Infection rate of tick (%)
Qazvin	*O. tholozani*	*B. persica*	16.60
	O. lahorensis	*Borrelia* sp.	1.30
Hamadan	*O. tholozani*	*B. persica*	3.70
Qazvin	*O. tholozani*	*B. persica*	8.82
	O. erraticus	*B. microti*	50
Markazi	*O. tholozani*	*B. persica*	21.12
Semnan	*O. tholozani*	*B. persica*	36.60
Kurdistan	*O. tholozani*	*B. persica*	19.79
Razavi Khorasan	*O. tartakovsky*	*B. latishevi*	36
Kurdistan	*O. tholozani*	*B. persica*	3
Ardabil	*O. tholozani*	*B. persica*	17.17
Razavi Khorasan	*O. tholozani*	*B. persica*	5.20
Ardabil	*O. tholozani*	*B. persica*	14.33
	O. lahorensis	*Borrelia* sp.	14.33
Zanjan	*O. tholozani*	*B. persica*	12.50
	O. tholozani	*B. persica*	10
Qazvin	*O. tholozani*	*B. persica*	8.80
Hamadan	*O. erraticus*	*B. microti*	8.80
Fars	*O. tholozani*	*B. persica*	8
West Azerbaijan	*O. tholozani*	*B. persica*	19.79
East Azerbaijan	*O. tholozani*	*B. persica*	1
Fars	*O. erraticus*	*B. microti*	No calculate

fever endemic, TBRF, reservoir of *Borrelia*, vectors of *Borrelia*, *Borrelia persica*, *B. latyschevi*, *B. microti*, *B. baltazardi*, *O. tholozani* and *O. lahorensis*.

Modelling. The coordinates of 35 locations for the modelling of *O. tholozani* and 29 locations for the modelling of *O. lahorensis* were extracted and entered into the Excel software. Next, they were saved in CSV format to be used by Maxent 3.3.3 software. There were 19 variables taken from the WorldClim website. To determine the importance of different variables in the model, the Jackknife analysis was employed. The maps presented in the ASCII format in MaxEnt came into Arcmap10.4.1 and were prepared in the form of a raster image. In the end, the distribution maps were prepared.

Results

Evaluation of distribution of vectors and infection rate to *Borrelia* spp.

O. tholozani and *O. lahorensis* were reported in 13 provinces, 43 counties and more than 160 villages in Iran. The rate of *Borrelia* spp. infection was higher in *O. tholozani* than in other soft ticks. The infection rate of *B. persica* was reported to be 1–36% across the country in 11 provinces, including Semnan (36.6%), Qazvin (8.8–16.7%), Hamadan (3.7–8.8%), Markazi (21.21%), Kurdistan (3–19.79%), Razavi Khorassan (5.2 %), Ardabil (14.33%), East Azerbaijan (1%), Zanjan (10–12.5%), Fars(2%) and West Azerbaijan (19.79%). The *Borrelia* infection in *O. lahorensis* was only reported in Qazvin (1.3%) and Ardabil (17.17%) provinces (Fig. 1). Moreover, the infection of other soft tick species was also reported in Iran. The infection of *O. erraticus* with *B. microti* was reported in Qazvin (50%), Hamadan (8.8%) and Fars (1.5%) provinces. In one case, the *O. tartakovsky* infection with *B. latyschevi* was reported in Razavi Khorasan. In terms of *Argas* genus, only *Argas persicus* was reported to be infected with *Borrelia* spp., but *Borrelia* species was not identified (Table 1).

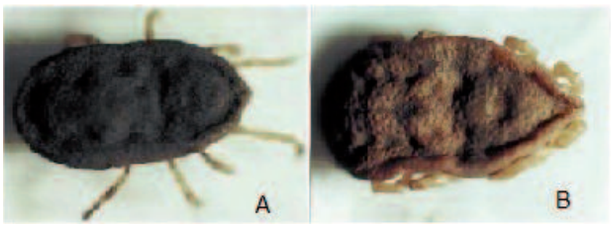

Figure 2. The main vectors of RF in Iran (A: *O. tholozani*; B: *O. lahorensis*)

Modelling results

The modelling results of MaxEnt showed that five factors had the highest impact on the distribution and ecological niche of *O. tholozani* (Bio1, Bio11, Bio10, Bio5 and Bio15) and *O. lahorensis* (Bio11, Bio1, Bio6, Bio10 and Bio5) (Figure 4). As observed in map 2, the most important habitat and presence of *O. tholozani* was in the northwest of Iran and two high-risk areas identified in Iran were Ardabil and Kurdistan provinces. As for *O. lahorensis*, one high-risk area was identified: Ardabil and the East Azerbaijan provinces. Ardabil province was a suitable habitat for two vectors of the TBRF disease, and the probability of the presence of these vectors was more than 90% in these areas (Figs. 2,3). The results of the receiver operating characteristic (ROC) curve (AUC) for two training data and testing data for *O. tholozani* were 0.953 and 0.832, respectively. The ROC curve results for *O. lahorensis* were 0.982 and 0.832, respectively. The results of both testing data were higher than 0.50, showing a favourable test sensitivity (Fig. 4).

Distribution of *Borrelia* species

According to the literature, four species of *Borrelia* have been reported in Iran. Three of these species were isolated from mites, and it has been reported that three species were isolated from ticks. Based on these reports, *B. persica* had a wide distribution in Iran and was isolated from *O. tholozani* in Qazvin, Hamadan, Ardabil, Markazi, Semnan, Kurdistan, Razavi Khorasan, Zanjan, Fars, East Azerbaijan and West Azerbaijan provinces. *Borrelia microti* was isolated from *O. erraticus* in Iran and was reported in Qazvin, Hamadan and Fars provinces. Also, *B. latyschevi* that is transmitted from *O. tartakovsky* in Iran was reported in Razavi Khorasan, and *B. baltazardi* was not isolated from any ticks.

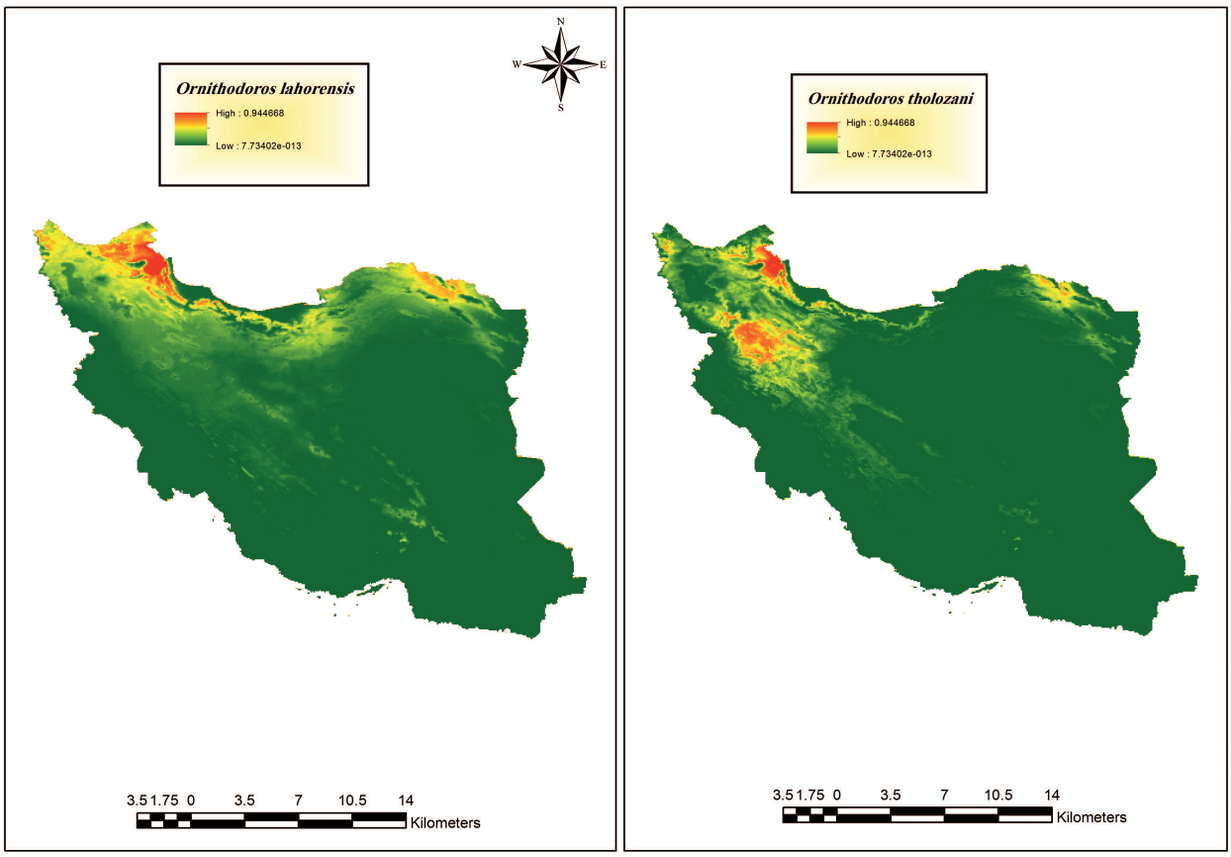

Figure 3. Suitable habitat location for *O. tholozani* and *O. lahorensis* in Iran

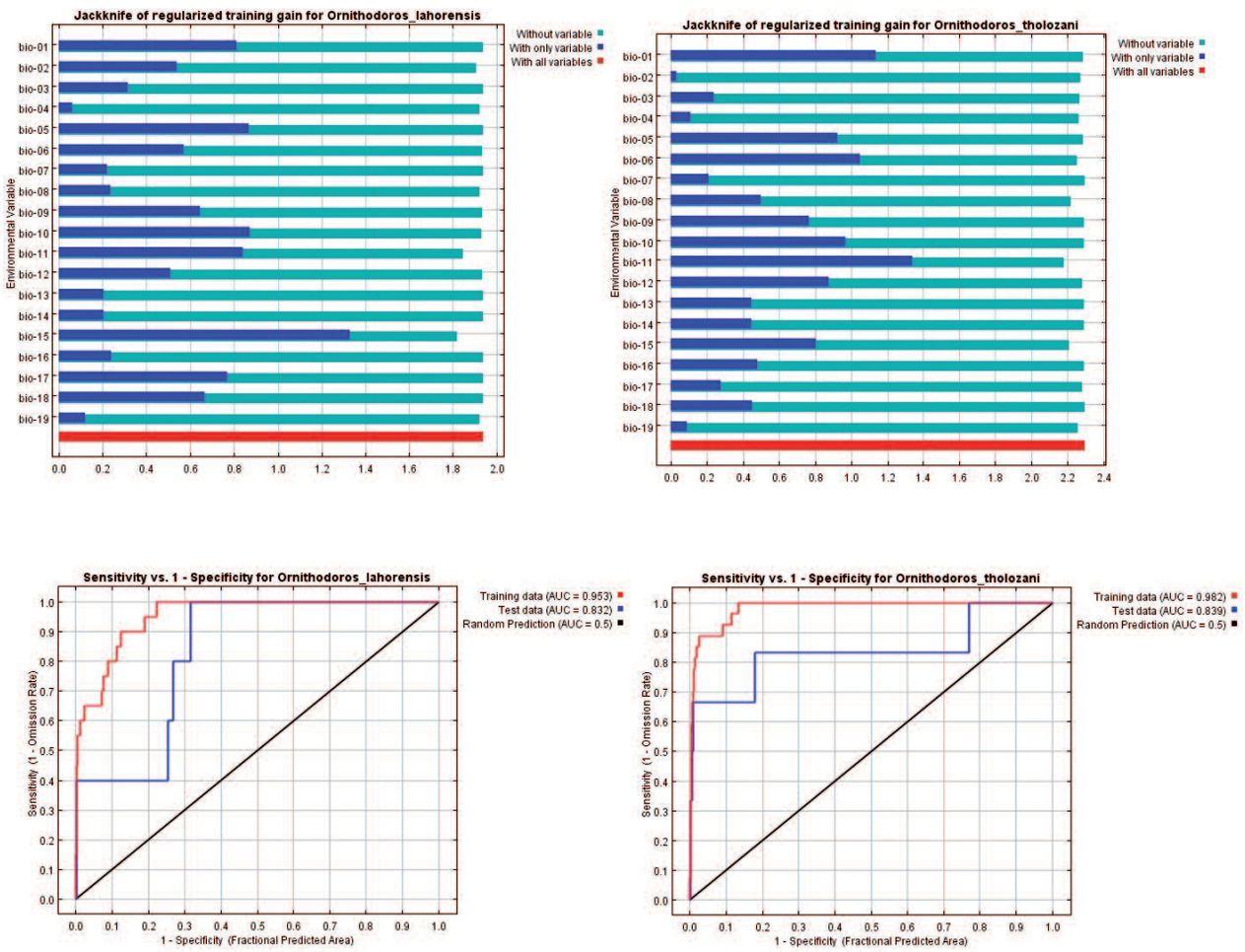

Figure 4. The results of Jackknife and AUC tests for two vectors of RF in Iran

Discussion

Four *Borrelia* species transmitted by four soft ticks were distributed in Iran. The endemic RF was reported in 18 provinces in Iran [11], but three *Borrelia* species (mostly *B. persica* from *O. tholozani*) were isolated from ticks in 11 provinces. These results indicate that the *B. persica* and *O. tholozani* were widely distributed in some parts of the northwest, centre, south and northeast of Iran, and that the infection rate of *O. tholozani* was the highest. The results of this study are in agreement with the results of another study in 2009 [11]. In line with the results of this study, the infection rate of *Borrelia* was reported to be between 2–40% in different parts of the world [28]. Nevertheless, in Europe, the vectors of *Borrelia* species are *Ixodes* genus ticks and are transmitted by *B. burgdorferi*, *B. afzelii*, *B. garinii*, *B. valaisiana* and *B. lusitaniae* [29]. Different software can be employed to determine the ecological niche and suitable habitat for different species of arthropods and investigate the impact of relevant climate and environmental factors [30–31]. Iran has witnessed several modelling studies on important vectors and agents of leishmaniosis complex disease [32–35]. The current study was done for the first time on RF vectors in Iran. The modelling results for two RF vectors showed that the important and suitable habitat for *O. tholozani* and *O. lahorensis* was the north-western region in Iran, and the incidence of RF in provinces of this area was at its highest level [11]. Given that many people in this region work in animal husbandry and farms and that the livestock such as cattle, sheep and goats are the reservoirs of endemic RF [30], the incidence rate of RF in humans and infection rate of reservoirs is very high. The most important climate factors, affecting *O. tholozani* distribution, are the mean temperature of the warmest quarter and annual mean temperature. Regarding the distribution of *O. lahorensis*, these factors are the precipitation seasonality and mean

temperature of the coldest quarter. Since different species of soft ticks in tropical and subtropical regions are widely distributed and more active in the warm seasons, and the temperature has a direct impact on the growth and reproduction of soft ticks [31,32], these results confirm that temperature and precipitation are the two factors affecting the activity and geographical dispersion of *O. tholozani* and *O. lahorensis.* The results of a study on the ecological niche of *O. hermsi*, as the main vector of endemic relapsing fever in the north of America, showed that the three factors of maximum temperature of warmest month, minimum temperature of coldest month and the annual mean temperature had the greatest impact on the dispersion of this species [33]. In another study in the United States, two factors of temperature and rainfall had more effects on the dispersion and ecological niche of *O. turicata* [34]. The distribution of *O. tholozani* and *O. lahorensis* were affected by thermal factors in Iran and the possibility of the presence of these two species in the north-western regions of Iran was estimated to be up to 90%. Thus, the north-western region of Iran is a suitable habitat for these two vectors and a perfect environmental location for the incidence of endemic RF in humans.

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