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Full Length Research Paper

Potential geographic distribution of the cassava green mite *Mononychellus tanajoa* in Hainan, China

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The cassava green mite, *Mononychellus tanajoa*, has been recently recorded as a quarantine pest in Hainan, China. It heavily damaged cassava growth and has caused serious economic losses in some main cassava production areas. In order to effectively monitor and manage this pest, it is necessary to investigate its potential geographical distribution worldwide. In this study, we used the ecological niche models, maximum entropy (Maxent), based on the biological data and known distribution of *M. tanajoa*, and meteorological data from 1950 to 2000 years in WorldClim to predict the potential geographical distribution of *M. tanajoa*. The results suggested that the suitable areas for cassava green mite infestations were mainly restricted to west Hainan (Danzhou, western Changjiang, western Dongfang, and southeast Ledong), north Hainan (Lingao, eastern Chenmai and northern Haikou), east Hainan (northern Lingshui and southern Wanning) and south Hainan (southern Sanya). In addition, some counties of eastern Hainan were predicted to have low suitability or unsuitable areas (e.g. Wenchang and Qionghai). A jackknife test in Maxent showed that the temperature annual range was the most important environmental variable affecting the distribution of *M. tanajoa*. Consequently, the study suggests several reasonable regulations and management strategies for avoiding the introduction or invasion of this high-risk cassava pest to these potentially suitable areas.

Key words: *Mononychellus tanajoa*, potential geographic distribution, maximum entropy (Maxent), ArcGIS, Hainan.

INTRODUCTION

The cassava green mite (*Mononychellus tanajoa* Bonder (Acari: Tetranychidae)), which has been reported in most of the cassava growing regions, is one of the most serious plant mites, which posed a major threat to the production of cassava in subtropics and tropics (Lyon, 1973). In the early 1970s, *M. tanajoa*, an exotic species of Neotropical origin, was discovered attacking cassava in Uganda (Yanjnek and Herren, 1988). *M. tanajoa* soon became one of the most important pests of this crop in Africa causing up to 80% reduction in cassava yield (Night et al., 2011). In many countries and areas, *M. tanajoa* has been identified as a quarantine mite (Elliot et al., 2002; Bellotti and Sehoonhoven, 1978; Delalibera et al., 1992). For instance, it is one of the major quarantine plant mites in China (Chen, 1973).

The risk of *M. tanajoa* entering into China has increased rapidly during the last several decades due to the development of international communication and increasing cassava plating areas. *M. tanajoa* cause > 60% chlorophyll depletion and about 50% leaf area reduction, leading to heavy yield reductions, drastic changes in tuber quality, or even total crop failure (Ayanru and Sharma, 1983). In 2010, *M. tanajoa* was reported in China, since then it has become one of the most dangerous mites in Chinese cassava areas (Chen et al., 2010). *M. tanajoa* continues to constitute a potential threat to Chinese agriculture, especially to Hainan cassava industry. Due to overlapping generations, a high population growth rate and the lack of natural enemies, it is very difficult to control *M. tanajoa* in Hainan. In

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addition, the geographical distribution of *M. tanajoa* depends on many factors, such as temperature, precipitation, and vegetation respectively. As an important part of the risk assessment for the mite, we are concerned to know that if a certain population of *M. tanajoa* accidentally enters China, and which geographical regions are most ecologically suitable for their establishment.

Correlation-based species distribution models, processing ecological information at known species' presence, are a helpful tool for a better understanding and management of invasive alien species (Peterson and Vieglais, 2001; Jeschke and Strayer, 2008; Bomford et al., 2009). They can be used to determine species' potential distribution, possible dispersal routes and overlap with native species, both in geographical and ecological space (Peterson and Vieglais, 2001; Jeschke and Strayer, 2008).Niche-based models have been widely used to predict potential geographic distribution of alien species, and has been applied to the fields of ecology, biogeography, evolution and conservation biology, among others (Ganeshaiah et al., 2003; Peterson, 2003; Levine et al., 2004; Guisan and Thuiller, 2005; Elith et al., 2006; Peterson et al., 2007). The ecological niche of a species, the conjunction of environmental conditions within which a species can maintain populations without immigration, is modeled by a variety of approaches based on occurrence patterns within the species' native distribution to find nonrandom correlations between the presence pattern of a species and the values of the environmental parameters.

The maximum entropy model (Maxent) is a new, general purpose machine learning method which has many advantages making it well-suited for species distribution modeling. Maxent utilizes continuous and categorical data, incorporates interactions between different variables (Phillips et al. 2006), is good at avoiding commission errors (Pearson et al., 2007) and has a better performance than other ecological niche models in predicting the distribution of species, when only a limited number of sample localities are available (Hernandez et al., 2006). It is a machine-learning method for making predictions or inferences from incomplete information. It originates from statistical mechanics, and remains an active area of research that explores applications in diverse areas, such as astronomy, portfolio optimization, image reconstruction, statistical physics, and signal processing.

To assist in developing a strategy for the surveillance, quarantine, and control of *M. tanajoa*, it would be useful to be able to predict areas that could support the establishment in Hainan. In this study, the potential geographical distribution of *M. tanajoa* in Hainan was predicted by Maxent and GIS methodology, and the prediction of the algorithms was tested. Jackknife test was applied to weigh the relative contribution of various ecological factors to overall prediction outcomes.

MATERIALS AND METHODS

Study area

Hainan off the south coast of China, ranging from 18° 10' - 20° 10' N and longitudes 108° 37' - 111° 05' E, contains the only tropical areas in China. It covers 18 counties (cities) and encompasses an area of 34,000 km^2 (Figure 1). The Hainan Island is like a circle island. From the center spread outward, the rugged hills, plains and sea were linked one after another. The plain area covers more than 60 per cent of the total island. The main rivers are Nandu River, Wanquan River and Changhua River.

Under the influence of continental rain shadow, the climate in this region is semi-arid (Zeng and Zeng, 1989; Li et al., 2005), with a mean annual temperature of 24.5 to 25.28°C and a mean annual precipitation of less than 1000 mm (Gao et al., 1988). Precipitation varies greatly, with distinct dry and wet seasons; 90% of the rain falls from May to October, and little rain from November to April. The ratio of potential annual evaporation to average annual precipitation varies between 1.97 and 4.00. The traditional agricultural productions are rubber, cassava, vegetable, and tropical fruits (coconut, banana, mango, pineapple, and litchi) in Hainan.

Occurrence data

The occurrence locations of *M. tanajoa* were mainly based on our extensive field surveys in south China from May to October during 2008 and 2010. We also used some related references (Amusaa and Ojo, 2002; Elliot et al., 2002; Yaninek and Hanna, 2002; Onzo et al., 2003; Zannou et al., 2007; Chen et al., 2010; Night et al., 2011). The longitude and latitude of occurrence locations were obtained by using the geographic names database (GNDB), and the geographical coordinates of collection localities were recorded using a global positioning system receiver.

Using the afore-mentioned sources, the distributional localities of *M. tanajoa* were compiled into a database. For *M. tanajoa*, we obtained 44 distribution records in China (24 records in Hainan) and 296 records in other countries, totaling 320 records in world (Figure 2).

Environmental variables

We considered 19 environmental variables as potential predictors of *M. tanajoa* habitat distribution (Table 1). Nineteen variables were obtained from WorldClim dataset (Hijmans et al., 2005; http://www.worldclim.org/bioclim.htm). All environmental variables were resampled to 1 km spatial resolution. The environment grid layers in American Standard Code for Information Interchange (ASCII) format downloaded from the WorldClim website can be used directly by Maxent.

The Chinese administrative map (1:4000, 000) was downloaded from the National Fundamental Geographic Information System of China (http://nfgis.nsdi.gov.cn/), which included the layers of national boundaries; province boundaries; municipal region boundaries; county boundaries; and the distribution of rivers, roads, and railroads. Some of the layers were included in the final prediction maps to assist the relevant analysis.

Model building and evaluation methods

We used Maxent software (version 3.3.3 e) (Phillips et al. 2006). The occurrence data of *M. tanajoa* was divided into two parts. We randomly selected 75% of the data for model training, and the remaining data (25%) were used for model testing; using the existing parameter settings of Maxent and the 75% occurrence

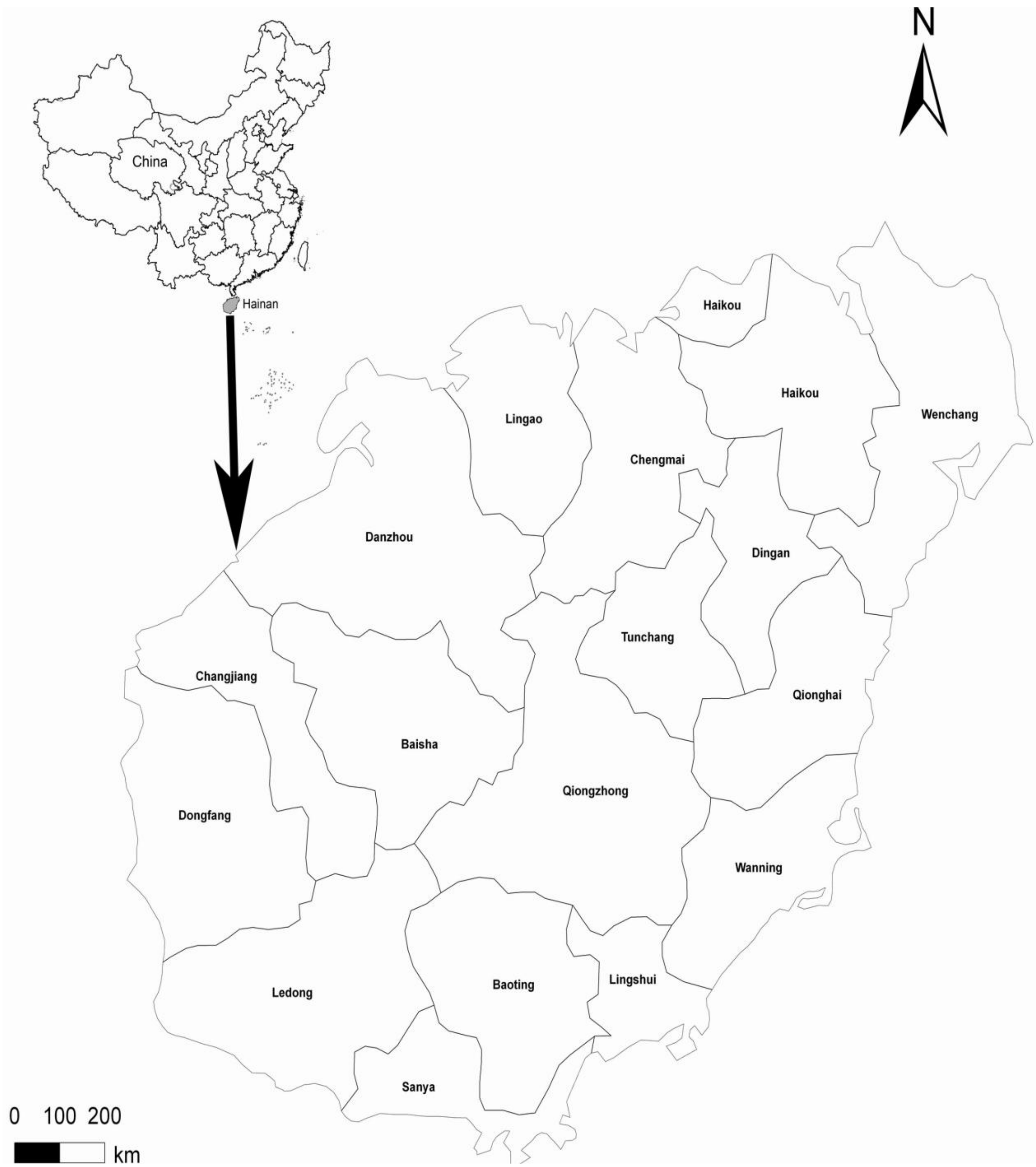

Figure 1. Location of counties (cities) in Hainan.

points to perform the prediction for *M. tanajoa*. A set of four possibilities, such as logistic regression, bioclimatic rules, range rules and negated range rules were employed. The algorithm runs either 1000 iterations of these processes or until convergence. This model produced prediction values ranging from 0 to 1, representing cumulative probabilities of occurrence. Predictions were mapped in ArgGIS 9.3 Desktop (ESRI Inc.). A jackknife test was used to measure variable importance in model development, and receiver operating curve analysis (ROC) was used to assess model quality (Fielding and Bell, 1997). A ROC plot was built by plotting the sensitivity values and the false positive fraction for all available probability thresholds (Manel et al., 2001). The area under the curve (AUC) was a measure of the area under the ROC, ranging from 0.5 to 1.0.

RESULTS

Predicted potential geographic distribution

Figure 3 showed the potential geographic distribution of *M. tanajoa* in Hainan predicted by Maxent. The most

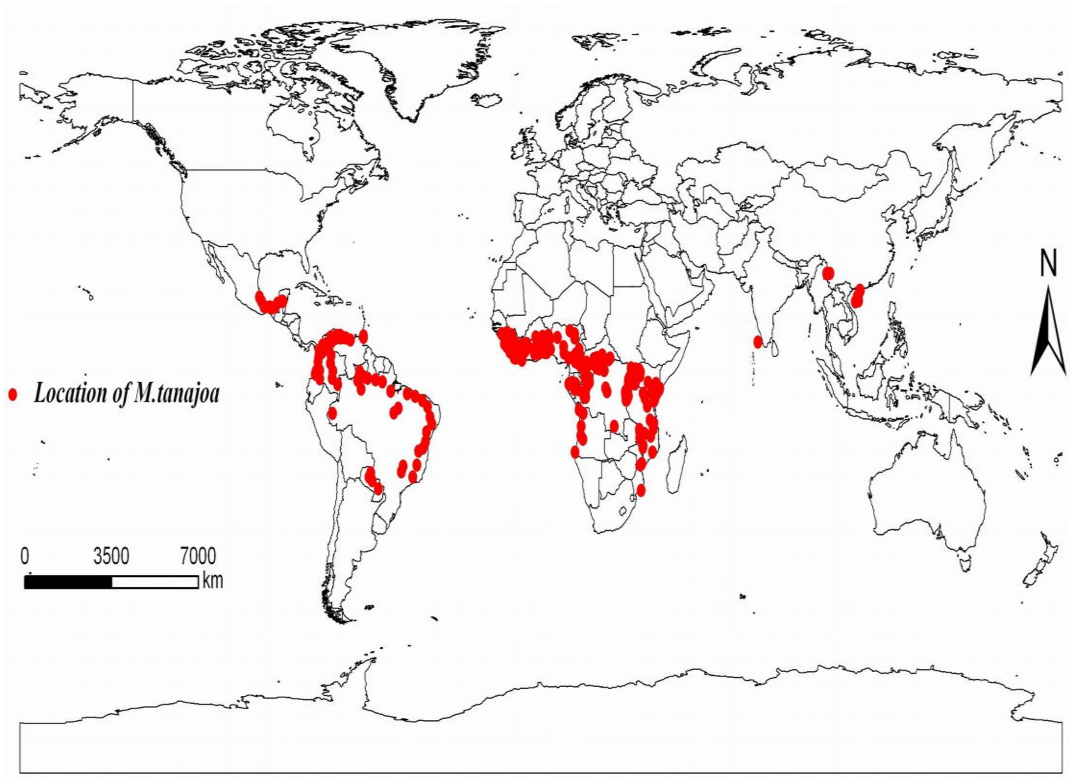

Figure 2. Location map of *M. tanajoa* worldwide.

suitable areas (red areas) were mainly restricted to west Hainan. Secondly, some regions (orange and yellow areas) of Hainan were suitable to the species, too. The remaining cities or counties regions (white areas) had low suitability or were unsuitable regions. The most suitable and unsuitable districts of *M. tanajoa* in Hainan were given in Table 2.

Evaluation of models and the importance of environmental variables

A model with AUC values approaching 1.0 is usually considered a good model, while AUC values close to 0.5 are considered no better than random. In this study, the AUC value for the training data was 0.961 and the AUC value for the test data was 0.942, indicating a high level of accuracy for the Maxent predictions (Figure 4).

In the Jackknife procedure, temperature annual range had the highest gain when used in isolation (Figure 5). This indicated that the temperature annual range was the most important environmental variable influencing the distribution of this species. In addition, some temperature and precipitation variables, such as annual mean temperature, isothermality, temperature seasonality, max temperature of warmest month and min temperature of coldest month, Mean temperature of wettest quarter and driest quarter, mean temperature of coldest quarter, precipitation of wettest month, annual precipitation may also influence this species' distribution to some extent (Figure 5).

DISCUSSION

The ecological niche models developed rapidly in recent years, such as Domain, Garp, Climex and Maxent, etc. Maxent has many advantages compared to other ecological niche models in predicting the potential distribution of species. First, Maxent has better algorithm which is consistent with earlier related studies (Peterson et al., 2007; Phillips and Dudik, 2008; Petchey, 2010; He, 2010; Elith et al., 2011; Gormley et al., 2011). Second, the tendency to variation of predictive accuracy indicates the prediction maps generated by Maxent are generally suitable for processing at a high threshold (high logistic value threshold), which gives a qualitative judgment for each grid as to whether it is suitable or not. In this study, we randomly chose 75% occurrence samples of *M. tanajoa* as the training data and used the remaining 25% as a test subset.

The predictions for the green mite include the current distributions. *M. tanajoa* is the most serious pest worldwide, and has the widest distribution range because of its ability to tolerate harsh environmental conditions. For China, the predictions demonstrate that 1) *M. tanajoa*

Table 1. Environmental variable description.

Variable code	Variable type
Bio 1	Annual mean temperature
Bio 2	Mean diurnal range(mean of monthly(max temp-min temp)
Bio 3	Isothermality (p2/p7) ×100
Bio 4	Temperature seasonality (standard deviation×100)
Bio 5	Max temperature of warmest month
Bio 6	Min temperature of coldest month
Bio 7	Temperature annual range
Bio 8	Mean temperature of wettest quarter
Bio 9	Mean temperature of driest quarter
Bio 10	Mean temperature of warmest quarter
Bio 11	Mean temperature of coldest quarter
Bio 12	Annual precipitation
Bio 13	Precipitation of wettest month
Bio 14	Precipitation of driest month
Bio 15	Precipitation seasonality (coefficient of variation)
Bio 16	Precipitation of wettest quarter
Bio 17	Precipitation of driest quarter
Bio 18	Precipitation of warmest quarter
Bio 19	Precipitation of coldest quarter

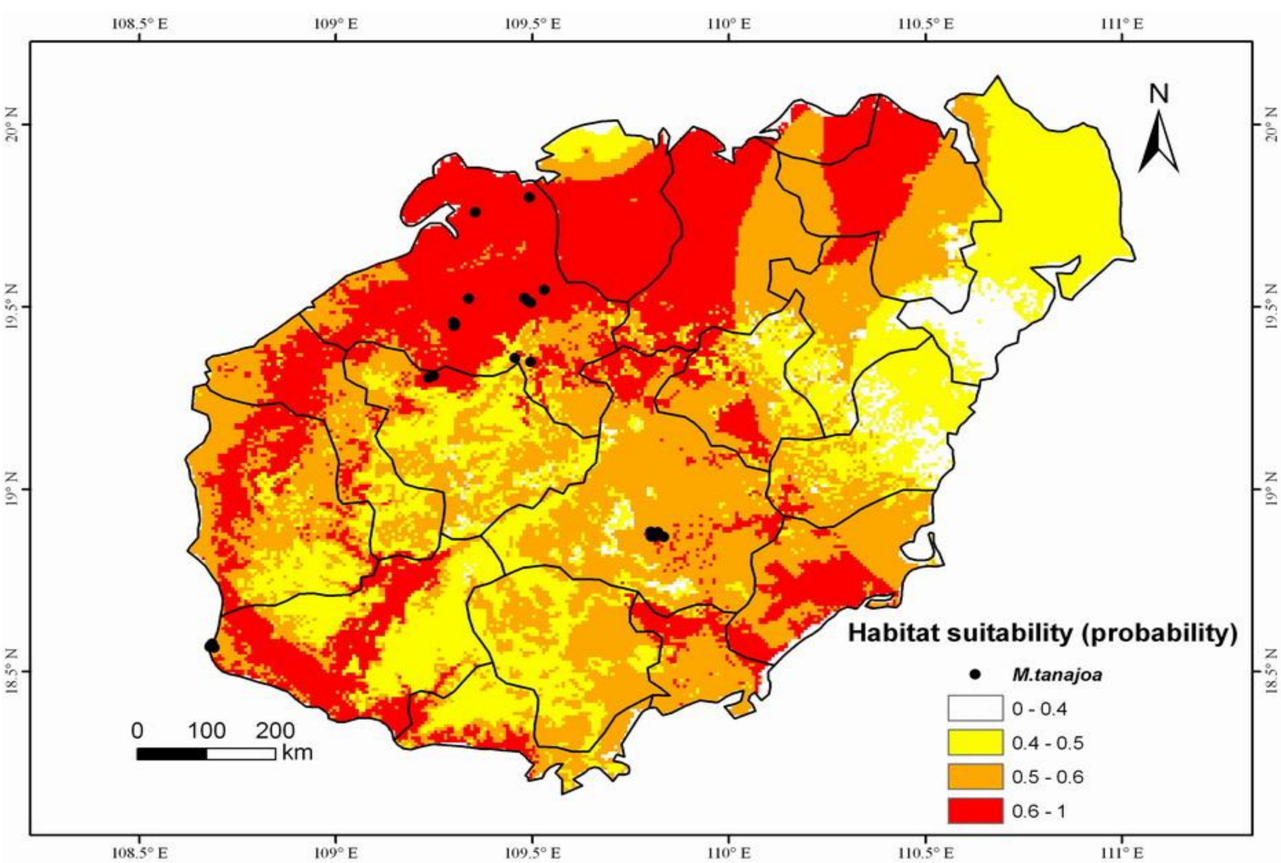

Figure 3. Predicted potential geographic distribution for *M. tanajoa* in Hainan made by all occurrence records and the climatic variables. Results are given in Maxent. Four colors are used to indicate the strength of the prediction for each individual map pixel. The strength of the predictions thus cannot be compared directly.

Table 2. The most suitable and unsuitable districts of M. tanajoa in Hainan.

The most suitable districts				The most unsuitable districts
West	**North**	**East**	**South**	
Danzhou, Western Changjiang, Western Dongfang, Southeastern Ledong	Lingao, Eastern Chenmai, northern Haikou	Northern Lingshui Southern Wanning	Southern Sanya	Southern Wenchang, Central Qionghai, the scattered regions of Ledong, Baisha, Qunzhong, Tunchang and Lingao

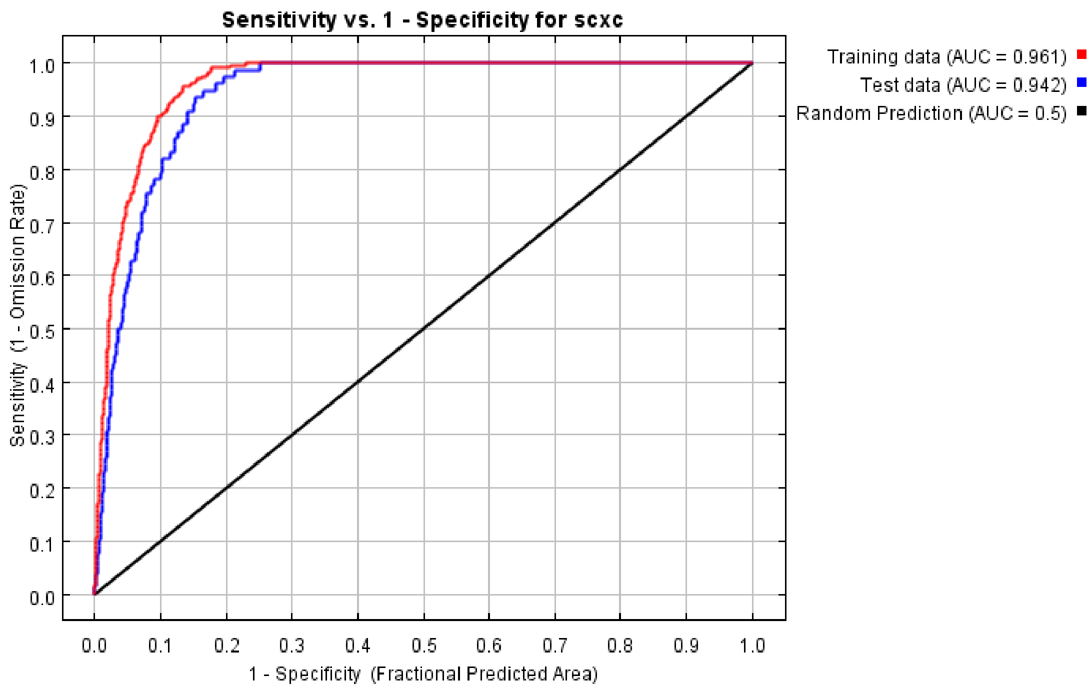

Figure 4. The receiver operating characteristic (ROC) curves for Maxent on one random partition of occurrence records of *M. tanajoa*. Sensitivity equals the proportion of test localities correctly predicted present (1-extrinsic omission rate). The false positive (1-specificity) equals the proportion of all map pixels predicted to have suitable conditions for *M. tanajoa*.

is the main threat to agricultural and cassava plating security. 2) Hainan has the highest risk of being invaded by the mite and therefore deserves special attention. 3); the most likely areas through which *M. tanajoa* could enter China is Hainan, especially coastal areas.

West Hainan has both a subtropical and tropical climates, with a suitable to cassava production. From the prediction study, west Hainan is the main potential distribution areas in Hainan suitable for *M. tanajoa*. Coastal areas (Figure 3) are the main trade routes for imports and exports in and out of Hainan. These are the highest of the interception frequencies of the mite in Hainan. Although to the date there are no records of *M. tanajoa* being captured from nationwide monitoring program each year, the invasive risk of *M. tanajoa* in this region remains high.

Jackknife tests reveal that environmental variables associated with temperature have more influence on potential distributions of *M. tanajoa* than any other variable (Figure 4). According to recent publications, temperature has a significant influence on the physiology of *M. tanajoa* population density (Ysingh, 1981; Manu-Aduening et al., 2007; Zundel et al., 2009).

The import risk of *M. tanajoa* into Hainan increased with the rapid development of cassava planting. In light of the high degree of harm to cassava, the high risk of spread and potential wide distribution of *M. tanajoa*, it is necessary to monitor and manage this pest immediately by appropriate measures and avoid dispersing it to other main cassava production areas:

1. Although this pest has a low dispersive capacity, seedling transportation is one of the main mechanisms of its spread. Therefore, quarantine measures should be

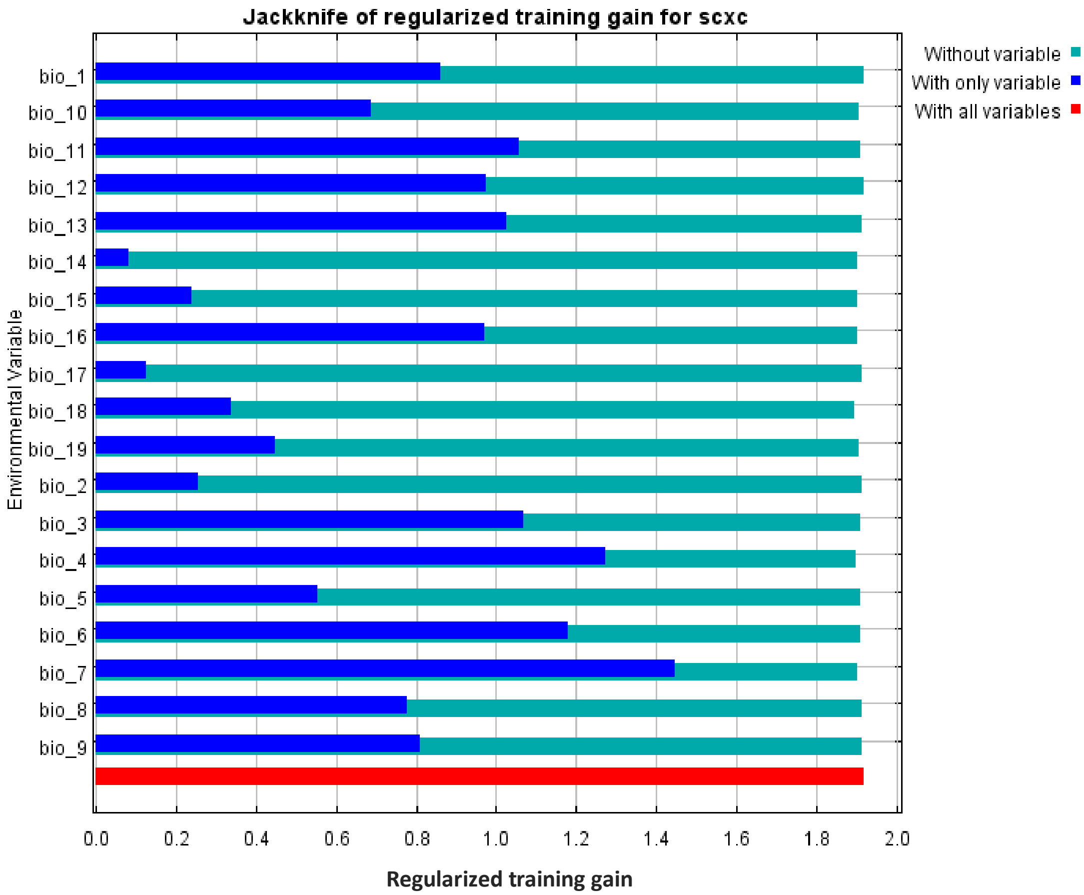

Figure 5. The jackknife test of individual environmental variable importance (blue bars) in the development of the Maxent model relative to all environmental variables (red bar).

strictly applied when cassava varieties are introduced from African or South American, or some areas of China where *M. tanajoa* is known to occur.

2. A general investigation of the distribution of *M. tanajoa* should be conducted, especially in the occurrence locations and the potential geographical distribution areas of *M. tanajoa*.

3. In order to control *M. tanajoa*, effectively, we should investigate its biological characteristics and ecology.

4. We can also use molecular methods to determine levels of genetic diversity, population genetic structure and phylogeography, which will contribute to the elucidation of the population structure and history of this pest.

All these efforts will help to determine appropriate management strategies, and eliminate or reduce its negative impact on cassava production to a certain degree.

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