A GIS based Distribution Modeling of Tortoise Beetles (Cassidinae) in Pakistan

By

Sayyed Kifayatullah

Reg # 189-FBAS/MSES/F13

Department of Environmental Science

Faculty of Basic & Applied Sciences

International Islamic University Islamabad

2017

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A GIS based Distribution Modeling of Tortoise Beetles (Cassidinae) in Pakistan

A thesis submitted to Department of Environmental Sciences, International Islamic University Islamabad, as a partial fulfillment of requirement for the award of the degree of Master of Studies (MS) in Environmental Science.

By

Sayyed Kifayatullah

Reg # 189-FBAS/MSES/F13

Supervised by:

Dr. Zafeer Saqib
(Assistant Professor)

Department of Environmental Science

Faculty of Basic & Applied Sciences

International Islamic University Islamabad

2017

بسم الله الرحمن الرحيم

CERTIFICATE

This thesis entitled "A GIS based Distribution Modeling of Tortoise Beetles (Cassidinae) in Pakistan" submitted by **Sayyed Kifayatullah** in partial fulfilment of MS degree in Environmental Science, has been completed under my guidance and supervision. I am satisfied with the quality of student's research work and allow him to submit this thesis for further process as per rules and regulations of the International Islamic University, Islamabad.

Signature: ______________________

Supervisor's Name: **Dr. Zafeer Saqib**
(Assistant Professor)
Dated: 05-03-2017

FINAL APPROVAL

Thesis Title: A GIS based Distribution Modeling of Tortoise beetles (Cassidinea) in Pakistan

Name of Student: SayyedKifayatullah

Registration No: 189-FBAS/MSES/F13

Accepted by the faculty of Basic and Applied sciences, Department of Environmental Science, International Islamic University, Islamabad in partial fulfilment of the requirements for the degree of Master of Studies (MS) in Environmental Science.

Viva voce Committee

Dean, FBAS
(Prof. Dr. Muhammad Sher) ______________________

Chairman DES
(Prof. Dr. Muhammad Sher) ______________________

Supervisor
(Dr. ZafeerSaqib) ______________________

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Internal Examiner
(Dr. Tariq Rafiq) ______________________

DEDICATION

To my late Father Sayyed Quresh Jan, my loving Mother and elder Brother Syed Inayatullah Jan.

DECLARATION

The material contained in this thesis is my original work, except where acknowledged. No part of this thesis has been previously presented elsewhere for any other degree.

Sayyed Kifayatullah

Date: 05-03-2017

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List of abbreviations and acronyms

SDM – Species Distribution Modeling

ENM – Ecological Niche Modeling

MaxEnt – Maximum Entropy

BioClim – Bio Climatic

GIS – Geographical Information Systems

NARC – National Agriculture Research Center

QAU – Quaid-i-Azam University

IUCN – International Inion for Conservation of Nature

GLMs – Generalized Linear Models

GAMs – Generalized Additive Models

RSFs – Resource Selection Functions

GB – Gilgit Baltistan

AJK – Azad Jammu and Kashmir

RTG – Regularized Training Gain

AUC – Area under Curve

Abstract

Tortoise beetles or Cassidinae is a subfamily of Chrysomelidae or leaf beetles. Due to certain attributes i.e. global distribution and its potential utility as bio control agent they have considerable ecological and economic significance. Being poor flyers tortoise beetles tend to be restricted to their host plants, hence host plants are one of the most important environmental factors that determine its distribution. So far in Pakistan, the only research exclusively focused on Cassidinae species in Rawalpindi/Islamabad along with their host plants is that of Sultan et al. (2008). The current study is the continuity of that research while study area is extended to the whole Pakistan. In the context of Pakistan, due to insufficiency in existing occurrence records of tortoise beetles, approach of insect distribution modeling based on presence data of their reported host plants is adopted. Maximum entropy distribution modeling MaxEnt (3.3.3k version) (Phillips, Anderson et al. 2006) and climate data with spatial resolution of 1 Km2 of WorldClim is used in this study. Based on significance assessment of bioclimatic variables in each model through Jacknife tests, only 10 most informative out of the total 19variablesare selected in final modeling. Results are shown in form of distribution models of 12 Cassidinae beetles which are incorporated categorized calculation of habitat suitability. The resulted maps are with good model fit as AUC values vary between 0.93 and 0.99.

Key Words: Cassidinea, Host plant, Species Distribution Modeling, Ecological Niche Modeling, Bioclimatic variables, Maximum Entropy.

1. INTRODUCTION

1.1 Introduction

Tortoise beetles or Cassidinae is a subfamily of Chrysomelidae or leaf beetles. Due to certain attributes i.e. global distribution, its potential utility as bio control agent for obnoxious weeds and phytophagy on crops and ornamentals, they have considerable ecological and economic significance (Jolivet, Petitpierre et al. 2012; Ghebremariam, Krüger et al. 2014). Like other insect species, for tortoise beetles host plant is one of the most important environmental factor that determine its distribution. As on the basis of its biological and evolutionary history, Cassidinae beetles tend to restricted to their host plants (Barrett and Heil 2012).

Projection of Tortoise beetle's distribution, need deep insight of habitat requirements of their host plant species, predicting their potential habitat and evaluation of habitat. Habitat is the combination of space that an organism inhibits and all eco-factors in that space (Yi, Cheng et al. 2016). With the help of advance Geographical Information Systems (GIS) software and digital environmental layers we can demonstrate the relationship of species with their associated ecological factors in large geographic area (Dallimer, Irvine et al. 2012).

For numerous applications of ecology and conservation, precise modeling of species distribution is essential (Merow, Smith et al. 2013). Predicting the potential distribution of species and evaluation of its habitat can be determined by various modeling techniques (Ashraf, Ali et al. 2016). In this regard positional, topographic and bioclimatic variables are used to model the distribution and potential habitat. In a range of available modeling techniques MaxEnt is an advance and capable of high predictive accuracy technique (Phillips and Dudík 2008).

It is highly desirable to further explain, the research outcomes on Tortoise beetles by scholars of entomology, ecology and taxonomy, from the broad perspectives of Environmental Science. Thus, connecting the natural phenomena with evident economic, social and even political temperaments. In a country like Pakistan where agriculture still is a living source for major portion of population, the environment friendly low cost bio control of unwanted weeds is best available option instead of costly synthetic chemicals and mechanical techniques.

So far in Pakistan researchers of National Agriculture Research Center (NARC) Islamabad i.e. (Sultan, Borowiec et al. 2008) have attempted to record and publish Cassidinae species along with host plants mainly from Islamabad capital territory, adjacent Rawalpindi with few exception like district Thatta in Sindh and Mansehra in KPK provinces. This study aims to map the potential distribution of Cassidinae beetles in Pakistan based on their recorded host plants with the help of Geographical Information System tools i.e. Ecological Niche Modeling through MaxEnt.

1.2 Tortoise beetles (Cassidinea)

1.2.1 Taxonomy of Tortoise beetles

Taxonomically, Cassidinae (tortoise beetles) is subfamily of Chrysomelidae family (leaf beetles) of Coleoptera order (beetles) of insects. The Coleoptera is most diverse order with more than 300,000 described species (Gillott 2005; Agarwala and Bhattacharjee 2012). Within Coleoptera order Chrysomelidae is a large family with almost 37,000 species, 2,000 genera and 19 subfamilies (Seeno and Wilcox 1982; Biondi and D'Alessandro 2012). Cassidinae while comprises 16% of Chrysomelidae species diversity form the second largest sub clade just after Galerucinae (Chaboo 2007). Based on such an outstanding diversity and its global distribution, they have considerable ecological and economic significance. Still there is insufficient work on its intrafamilial relationships at all hierarchic levels, as compared to its importance in global ecosystems (Reid 1995; Bocak, Barton et al. 2014).

1.2.2 Ecologic and Economic attributes of Tortoise beetles

Phytophagy on of cultivated crops, ornamental and medicinal plants, timber and economically valued palms makes tortoise beetles a significant pest group. They have the ability to defoliate plant in larval and adult stages. Their stem mining and leaf chewing can considerably damage plants (Chaboo 2007). Such devastating activities indirectly also enhances the chance of fungal infections which further impose a threat to host plants (BARBOSA, FONSECA et al. 1999; Shonga, Gemu et al. 2013; Ahmed, Majeed et al. 2016).

Apart from the severe impacts on economically significant plants, there is a positive aspect of Tortoise beetles i.e. its potential utility in biological control method for unwanted weedy plant species. Bio control of weed plants is at the same time a cost effective, environmentally safe and ecologically viable method (Dhileepan, Madigan et al. 1996; Fenner 2012).

1.2.3 Host Plant Species of Tortoise beetles

Host plant preferences is one of the most important environmental factors that determine the distribution of insect species (Wisz, Pottier et al. 2013). As they are solely dependent on host plants for food intake and respective ecological relationship with other species. Thereforè, in order to get better insight of the ecological relationship of tortoise beetles, taking its record with their associated host plants is encouraged by (Jolivet and Hawkeswood 1995).

In the context of Pakistan, there are a few records of Cassidinea host plants. In the existing literature for majority of tortoise beetles, obnoxious weeds are host plants. However, some are reported as important pests for cultivated crops and ornamentals. For instance, (Sultan, Borowiec et al. 2008) has reported *Ipomoea batatas* L. (sweet potato) for *Glyphocassis trilineata* Hope and *Celosia cristata* L. for *Cassida exilis* Boh as host plants. The complete list of recorded Tortoise beetles along with their host plants in Rawalpindi and Islamabad is given as Fig. 1: -

Table 1 - Tortoise beetles host plants recorded in Rawalpindi Islamabad (Sultan et al. 2008)

Sr #	Host Plant Family	Host Plant Species	Host for Cassidinea Species
1	Amaranthaceae	*Achyranthes* sp.	*Cassida nigriventris* Boh.
2	-do-	*Alternanthera pungens* kunth	*Cassida nigriventris* Boh.
3	-do-	*Amaranthus viridis* L.	*Cassida exilis* Boh.
4	-do-	*Celosia cristata* L.	*Cassida exilis* Boh.
5	-do-	*Digera muricata* (L.) MArt.	*Cassida exilis* Boh.
6	Betulaceae	*Alnus nitida* (SpAch) endl.	*Notsacantha* cf. *jammuensis*
7	Chenopodiaceae	*Chenopodium* sp.	*Cassida nigriventris* Boh.
8	Convolvulaceae	*Ipomoea nil* (L.) roth.	*Glyphocassis trilineata* hope *L. nepalensis* Boh.
9	-do-	*Ipomoea aquatica* forSSk.	*Cassida circumdata* herBSt *Rhytidocassis indicola* duv.

10	-do-	*Ipomoea cairica* (L.)Sweet	*Cassida circumdata* herBSt
11	-do-	*Ipomoea eriocarpa* R. Br.	*Glyphocassis trilineata* hope
12	-do-	*Ipomoea batatas* (L.) lAM.	*Glyphocassis trilineata* hope
13	-do-	*Ipomoea carnea* jAcQ. ssp. *fistulosa* (MArt. ex choiSy) D. AuStin	*Laccoptera nepalensis* Boh.
14	-do-	*Ipomoea carnea* jAcQ. ssp. *fistulosa* (Mart. ex Choisy) D. AuStin	*Aspidomorpha miliaris* fAB.
15	-do-	*Convolvulus arvensis* L.	*Glyphocassis trilineata* hope
16	Lamiaceae (Labiatae)	*Anisomeles indica* (L.) O.	*Cassida varians* herBSt
17	Rhamnaceae	*Ziziphus nummularia* (BurM. f.) wiGht&Arn.	*Oocassida pudibunda* Boh. *Oocassida cruenta* F.
18	-do-	*Ziziphus jujuba* Mill.	*Cassida exilis* Boh.

Overall host plants are known for 200 genera (63%) of Cassidinae (Borowiec 1999). Individual species reports and list of regional host plants are the primary sources for these records.

1.3 Ecological Niche Modeling (ENM)

The ultimate ecological niche of species is the basis for its geographic distribution. For this study our approached is based on Ecological Niche Modelling (ENM). These models are considered long term stable constrains for potential geographic distribution of species (De Meyer, Robertson et al. 2010; Stigall 2012). Here we combine occurrence data with ecological data in order to obtain correlative models of environmental conditions essential for species existence and predict relative suitability of habitat. According to (Warren and Seifert 2011) ENMs are mostly used following four ways: -

- Estimating habitat suitability known to be occupies by specific species.

- Estimating desired suitability in geographic areas not known to be occupies by the species.
- Estimate the future changes in suitability of habitat for species i.e. due to climate change.
- And to estimate the species niche.

Ecological Niche Modelling is also termed as Species Distribution Modelling. The techniques have emerged in late 1970s at the times of limited computing capacity. The initial focus was on development of such techniques which can efficiently model the response of species to environmental gradients. So far there has been much emphasis on improvement of statistical basis of SMDs including but not limited to the introduction of new statistical methods, its implementation and comparison, assessment of sampling size and design in terms of model performance and overall evaluation of models itself (Zimmermann, Edwards et al. 2010; Peterson and Soberón 2012). In Ecological Niche Modelling, environmental parameters are compared within geographic space. ENM is based on methods of statistics like GAMs and GLMs or generalized additive models and generalized linear models (Ashraf, Ali et al. 2016).

1.4 Maximum Entropy Density Estimation (MaxEnt)

Maximum Entropy Density Estimation (MaxEnt) uses presence only or occurrence data to create distributional models. Capable of producing precise and useful models with small sample sizes, it is specifically appreciated for exploratory research (P Anderson, Dudík et al. 2006; Phillips, Anderson et al. 2006). The values of environmental variables at occurrence sites impose constrains on the unknown distribution in a way that empirical values of occurrence data and mean and variance of environmental variables in the model prediction are close to each other. Further, through known occurrences and background points it approximates the unknown distribution. The result is shown in a map where every grid has a value 0-100 which represent relative suitability of species occurrence (Phillips, Anderson et al. 2006; Tinoco, Astudillo et al. 2009).

In other words, according to (Phillips and Dudík 2008) from occurrence data a set of constrains are derived and are considered in model of probability distribution. These constrains are simple functions of environmental variables and expressed as features. Specifically, the mean of each environmental variable or feature is required to be close to empirical average over the occurrence site. Here the constrains characteristically under-specifies the model, while probability distributions on the other hand satisfying the constrains, therefore, we select the maximum entropy i.e. the most unconstrained one.

1.5 Problem Statement

Primarily there are very limited occurrence records of Tortoise beetles and their host plants in the context of Pakistan. Further, the existing records or occurrence data has not been utilized so far for mapping the potential distribution of Tortoise beetles in the whole country. Moreover, rather than deliberate focus on distribution of Tortoise beetles, research outcomes in studies of (Chaudhry 1966; Alam, Beg et al. 1969; Chaudhry, Chaudhry et al. 1970) originate from their work on faunistic surveys, aimed to document (a range of) insect species associated with forests and weed species. However, in available published literature the work of (Sultan, Borowiec et al. 2008) is the only attempt solely based on Tortoise beetles and their host plants in Rawalpindi Islamabad.

1.6 Objectives of the Study

The main objectives of this study are: -

- To predict the potential distribution of Tortoise beetles (Cassidinea) in Pakistan based on its host plants species with the help of Geographic Information Systems (GIS) tools.
- To incorporate the recent bioclimatic and topographic data in mapping and distribution modeling of Tortoise beetles in Pakistan.
- To analyze the relation of Tortoise beetle's host plants in reference to bioclimatic layers using Maximum Entropy Density Estimation (MaxEnt).
- To make use of recorded of host plats species specimens of Tortoise beetles laying at national herbarium of NARC, herbarium of QAU and independent surveys.

1.7 Significance of the Study

Explorative research on relationship of species distribution and physical environment has remained an area of keen interest in ecological and environmental studies. This study is an initial attempt to focus on Cassidinae beetles which are at the same time considered a valuable bio control agent for unwanted weeds and a serious pest to certain cultivated crops and ornamentals. The numerical models can be used for describing patterns and making predictions. The approach adopted for this study is insect pest distribution based on host plant species occurrence. This will also provide insight regarding distribution of host species.

2. REVIEW OF LITERATURE

2.1 Taxonomy of Tortoise beetles (Cassidinea)

Taxonomically, Cassidinae (tortoise beetles) is subfamily of Chrysomelidae family (leaf beetles) of Coleoptera order (beetles) of insects. The Coleoptera is most diverse order with more than 300,000 described species (Gillott 2005). Within Coleoptera order, Chrysomelidae is a large family while having more than 37,000 species. These species are further arranged in almost 2,000 genera and 19 subfamilies (Seeno and Wilcox 1982).

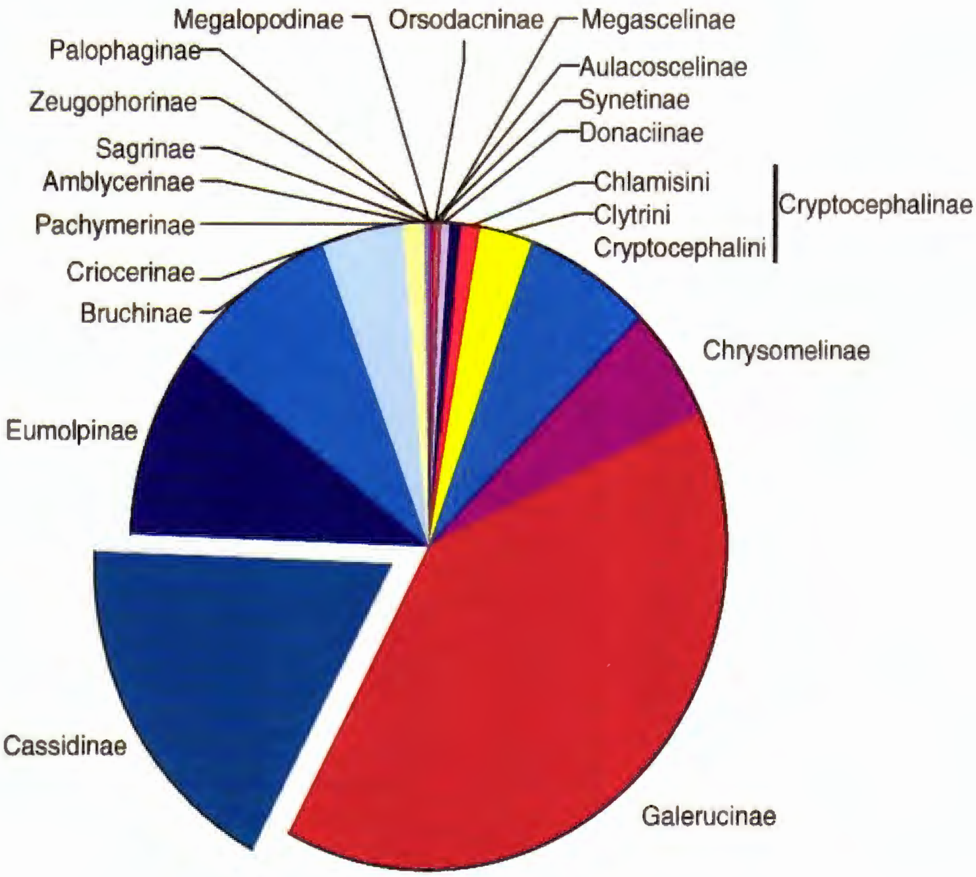


Figure 1. Subfamilies of Chrysomelidae (Chaboo 2007)

Cassidinae while comprises 16% of Chrysomelidae species diversity form the second largest sub clade just after Galerucinae (Chaboo 2007). On the basis of such an outstanding diversity and its global distribution, they have considerable ecological and economic significance.

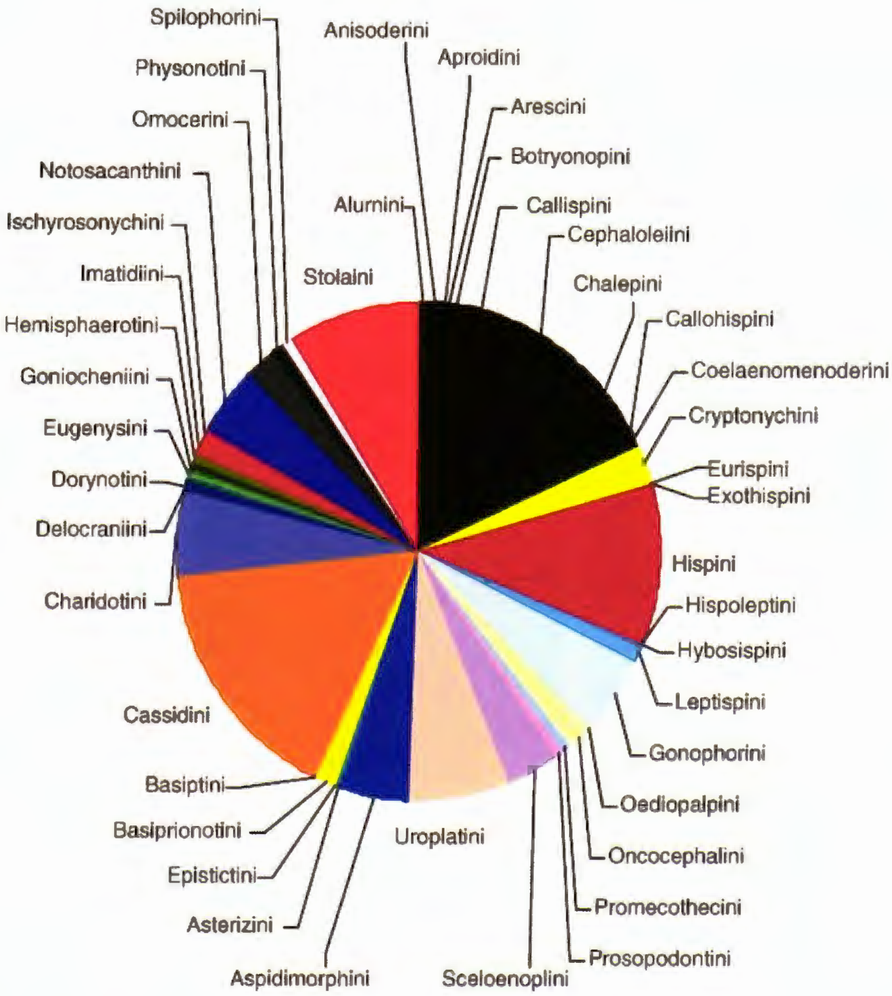


Figure 2 - Species diversity of various tribes within Subfamily Cassidinae (Chaboo 2007)

This remarkable diversity, coupled with a worldwide distribution and phytophagous diet, gives chrysomelids considerable ecological and economic significance. Despite their important role in global ecosystems, knowledge of intrafamilial relationships is surprisingly imprecise at all hierarchic levels (Reid 1995).

2.2 Ecologically and economically important attributes of Tortoise Beetles

Phytophagy on of cultivated crops, ornamental and medicinal plants, timber, and economically valued palms makes tortoise beetles a significant pest group. They can defoliate plant in larval and adult stages. Their stem mining and leaf chewing can considerably damage plants (Chaboo 2007). Such devastation activities indirectly also enhance the chance of fungal infections which further impose a threat to host plants (BARBOSA, FONSECA et al. 1999).

Apart from the severe impacts on economically significant plants, there is a positive aspect of Tortoise beetles i.e. its potential utility in biological control method for unwanted weedy plant species. Biocontrol of weed plants is at the same time a cost effective, environmentally safe and ecologically viable method (Dhileepan, Madigan et al. 1996; Klein 2011). Several species of Cassidinea beetles accidentally introduced in beginning of previous century to North America from Europe turned into amazing defoliator of agricultural weeds (Tipping 1993; Martinez and Plata-Rueda 2014). There are certain other examples of intentional introduction specifically for biocontrol with varied range of success (KLEINJAN and SCOTT 1996; Diaz, Manrique et al. 2014).

2.3 Insect pests host plant preferences

2.3.1 Host Specificity

Host specificity is encountered in many phytophagous insects, plant-parasitic fungi and flowering parasitic plants. For example, many leaf beetles (family Chrysomelidea) are known to specialize on a single host plant species (Rane, Ranade et al. 2000; Borowiec, Sultan et al. 2008). As the distribution of such specialist is dependent on host availability and abundance, the range of these species can be quite restricted. Host specialists may be evolved to utilize a particular host species and may be successful in homogenous community but do not have the advantage of being capable of utilizing a wider range in mixed communities. Thus specialist are limited by the distribution and abundance of their hosts, generalist will not be disadvantageous by lack of particular host. Conversely host specialization can advantageous as it minimized the competition from other parasitic species particularly when successful utilization involves overcoming the defense mechanism of a particular hos species. Danaus butterflies for example, are capable of utilizing milkweeds as larval food plants and their digestive proteases can digest the defensive proteins found in the latex of these plants (Pereira, Ramos et al. 2010). Among the phytopathogenic fungi "sepecial forms" or *formae specialis* of rust fungus *Puccinia graminis* f. sp. secalis on rye (Alexopoulos, Mims et al. 1996). Each *formae specialis* has different physiological races; *P. graminis* f. sp. *tritici* for example has about 350 races and different wheat cultivars show varying levels of susceptibility to these (Alexopoulos, Mims et al. 1996).

2.3.2 Host Range

Parasites can be generalists parasitizing a wide range of unrelated hosts or can be specialist exhibiting high level of host specificity sometimes utilizing a single host species. Even in generalists sometimes only a component of available host range is preferentially utilized. Intrinsic biological properties of host-parasite associations and emergent properties of their ecological and evolutionary relationships determined pattern of host specificity (Dick and Patterson 2007).

2.4 Description of the reported Host Plants of Tortoise beetles

So far there are a few records of Tortoise beetles host plants in the context of Pakistan. Earlier studies were not aimed to report Cassidinea and their host associations. However, the work of (Sultan, Borowiec et al. 2008) is a deliberate attempt to record and report the Cassidinea with Host Plants in Rawalpindi Islamabad. Brief description of reported host pants is hereby given one by one.

2.4.1 *Achyranthes aspera* L.

Achyranthes aspera L. belongs to Amaranthaceae family is found as weed and is the reported host plant of *Cassida nigriventris* Boh. (Srivastav, Singh et al. 2011) has reported for the use of its seeds, roots and shoots in traditional system of medicines in India. A wide range of its phytochemical constituents possess properties like antiperiodic, diuretic, purgative, laxative, anti-asthmatic, hepatoprotective and anti-allergic. According to (Qureshi and Bhatti 2009) in Nara desert of Pakistan people traditionally use the paste its root to stop bleeding after abortion, to facilitate delivery and to stimulate labor pain. Further the powder of its root mixed with honey is used to cure asthma, cough, cold and joint pain.

2.4.2 *Alternanthera pungens* Kunth

Alternanthera pungens Kunth also called Khakiweed is member of Amaranthaceae family and is one of the fastest growing weed in many arid and semiarid regions of the world. On the basis of its morphological characteristics it has the ability to resist herbicides and adopt a wide range of environmental factors thus most of the times outcompete other species especially grass turf (Kopec, Gilbert et al. 2004; Hephner 2011). A beetle *Cassida nigriventris* Boh. for which *Alternanthera pungens* Kunth has been reported as host plant can be utilized as biocontrol agent.

2.4.3 *Amaranthus viridis* L.

Amaranthus viridis L. is an annual herb from Amaranthaceae family and is reported as host plant for *Cassida exilis* Boh. The plant has certain medicinal uses. It is antidiabetic, antioxidant and antifungal. The root juice is used treatment of inflammation in urination (Kumar, Lakshman et al. 2012). It also improves digestion and used in calcium and vitamin A deficiency. Traditionally, the paste of its root is applied on scorpion sting and is also used for removing kidney and gallbladder stones (Qureshi and Bhatti 2009).

2.4.4 *Celosia cristata* L.

Celosia cristata L. is reported host plant of *Cassida exilis* Boh. The *Celosia* species is a small genus of edible and ornamental plants belonging to Amaranthacea. *Celosia cristata* L. is a nonwoody plant, 2 to 5 feet in height and common in Africa, Asia and South America (Surse, Shrivastava et al.). It is a traditional medicinal herb used as anti-inflammatory agent, disinfectant, removing liver-heat, improving eye sight and treatment of nose bleeding. It has high nutritional value and is also used as ornamental plant. It is well known for its traditional uses in China, India and East African highlands (Ramesh, Mahalakshmi et al. 2013).

2.4.5 *Digera muricata* (L.) MArt.

Digera muricata (L.) Mart., is another reported host plant of *Cassida exilis* Boh. It is an annual herb, having 20 to 70 cm height, belongs to the Amaranthaceae family and found as a weed. The plant is native to Africa, and tropical and temperate regions of Asia. It is commonly found on disturbed and waste ground but occur in a rage of habitats. It also appears in agriculture fields as a weed in a worrying number. On the other hand, almost all its parts are used in traditional system of medicines and is considered as a versatile medicinal plant (Sharma and Vijayvergia 2013).

2.4.6 *Alnus nitida* (SpAch) endl.

Alnus nitida (SpAch) endl belongs to Betulaceae family and is reported host plant of *Notsacantha* cf. *jammuensis*. The specie is on the IUCN red list of threatened species. It occurs as a large tree i.e. 20 m or more in height and is common in temperate part of Himalayas i.e. Pakistan, Afghanistan India and Nepal. Its wood is of fine quality used making of furniture and construction. It also has medicinal uses as mixture of its bark is applied to treat body pain and swelling (IUCN 2014). Alnus nitida (SpAch) endl known for its high-profile antioxidant and hepato-protective contents and is also used for inflammatory disorders (Sajid, Khan et al. 2016).

2.4.7 *Ipomoea nil* (L.) roth.

Ipomoea nil (L) roth belongs family Convolvulaceae and is the reported host plant for two species of Tortoise beetles (Cassidinae) i.e. *Glyphocassis trilineata* hope and *Laccoptera nepalensis* Boh. Ipomoea nil is climbing annual herb, known as morning glory, native to topics and is introduced widely being an attractive ornamental plant. In folk medicine, it is used for treatment of liver disorder. It is also anticarcinogenic, antimalarial, antimicrobial, antidiabetic and anti-inflammatory (Babu, Divya et al. 2013). Ethanol extract of its root has the quality to cure human gastric cancer (Meira, Silva et al. 2012).

2.4.8 *Ipomoea aquatica* forSSk.

Ipomoea aquatica forSSk. belongs family Convolvulaceae and is the reported host plant for*Cassida circumdata* herBSt. It is also known as water morning glory or water convolvulus. The plant grows well in most soil, side-lines of fresh water, lakes ponds and wet rice fields. Generally, it grows I the wild while also cultivated as vegetable in all over South East Asia. It is an effective natural herb used for treatment of various diseases with a range of health benefits as possess vital minerals, vitamins, alkaloids and secondary metabolites (Chen, Yang et al. 1991; Prasad, Shivamurthy et al. 2008; MALAKAR and Choudhury 2015).

2.4.9 *Ipomoea cairica*(L.) Sweet

Ipomoea cairica (L) Sweet belongs to Convolvulaceae family and the reported host plant of *Cassida circumdata* herBSt. The plant is also termed as Cairo morning glory and coastal morning glory. The specie is found as a weed in disturbed habitats, waste areas, gardens and vegetation near water passages. There is uncertainty in terms of exact native range however tropical Africa and Asia is assumed to be region of its origin (Austin and Huáman 1996) and currently found in tropical areas worldwide. Due to certain attributes i.e. rapid growth and capable to creep along round without supporting plants it is emerged as significant environmental weed (Srivastava and Shukla 2015). According to (Sykes and Campbell 1977) *Ipomoea cairica* is among the top 30 environmental weeds in south-eastern Queensland Australia. The plant has antioxidant and anti-inflammatory properties (Srivastava and Shukla 2015).

2.4.10 *Ipomoea eriocarpa* R. Br.

Ipomoea eriocarpa R. Br. belongs to Convolvulaceae family which is the reported host plant of *Glyphocassis trilineata* hope. The plant is primarily cultivated for ornamental purposes but can become tough weed. It has been described as a challenging weed to agriculture in California along with certain other species of Ipomoea. Seeds of *Ipomoea eriocarpa* contain several alkaloids, some of them are neurotoxins to humans and animals (Babu, Divya et al. 2013). On the other hand, the plant is also used for treatment of ulcer and fever in traditional medicine (Madhava 2005).

2.4.11 *Ipomoea batatas* (L.) IAM.

Ipomoea batatas (L.) Lam. is commonly known as sweet potato. It belongs to Convolvulaceae family and is reported host plant of *Glyphocassis trilineata* hope. It is native to South America and now extensively cultivated in tropical subtropical and temperate regions (Milind 2015). It is extremely versatile and delicious vegetable with high nutritional value. The plant has extraordinary medicinal significance with anticancer, anti-diabetic and inti-inflammatory properties (Mohanraj and Sivasankar 2014). Traditionally sweet potato is use for treatment of tumor in mouth and throat while its leaves are used as antibacterial and antifungal agents. It is also eaten raw to cure anemia and diabetes (Milind 2015). Extracts sweet potato have the potential to prevent cancer (Meira, Silva et al. 2012).

2.4.12 *Ipomoea carnea* Jacq.

Ipomoea carnea Jacq. belongs to Convolvulaceae family and is reported host plant of *Laccoptera nepalensis* Boh. It is a following plant with heart shaped rich green leaves. On terrestrial habitat, it grows up to 6 m while remain shorter in water (Sharma and Bachheti 2013). The plant has diversified usage i.e. stem is used for making paper and as firewood, leaves are used as fertilizer, the plänt as whole for fencing and its flowers for ornamental purposes (Chand and Rohatgi 1987). *Ipomoea carnea* has sufficient content of methane hence having the potential of biogas production (Srivastava and Shukla 2015). The plant also has a range of medicinal properties (Sharma and Bachheti 2013).

2.4.13 *Convolvulus arvensis* L.

Convolvulus arvensis L. commonly known as field bindweed belongs to family Convolvulaceae and is reported host plant of *Glyphocassis trilineata* hope. The plant is perennial vine of 2 m in height and week stem and occurs all over the temperate regions of the world (Weaver and Riley 1982). Due to specialized root system, it can survive even in long droughts periods. According to the findings of Washington state university *Convolvulus arvensis* L. is reported as one among top 10 weeds of the world and is a potential threat to 34 crops in 54 countries. The plant is classified as prohibited weed in 35 states of USA and several provinces of Canada (Austin 2000). From the perspective of its medicinal usage the plant is used for reducing wounds, inflammation and swelling, treatment of skin ulcers. It is also used to cure abdominal pain and worms in children (Weaver and Riley 1982).

2.4.14 *Anisomeles indica* (L.) O.

The reported host plant of *Cassida varians* herBSt*Anisomeles indica* (L.) O. belongs to Lamiaceae (Labiatae). It is a scrubby perennial plant with 1 to 2 m in height, aromatic leaves 2.5 to 7.5 cm long and purple flowers in dense whorls. The plant is native to Southeast Asia and distributed in India, China, Japan and from Malaysia to Australia (Baranwal, Irchhaiya et al. 2012). The plant is known for its medicinal utility as having anti-inflammatory antibacterial and herbicidal properties (Dharmasiri, Thabrew et al. 2000). According to (Huang, Lien et al. 2012) the methanol extracts of the plant has a reportedly antioxidative characteristic. In Chinese and Indian medicine system *Anisomeles indica* is traditionally used for treatment of hypertension, gastric dysfunction and inflammatory dysfunction (Baranwal, Irchhaiya et al. 2012).

2.4.15 *Ziziphus nummularia* (BurM. f.) wiGht&Arn.

Ziziphus nummularia (BurM. f.) wiGht&Arn. belongs to Rhamnaceae family and is reported host plant for two species of tortoise beetles *Oocassida pudibunda* Boh. And *Oocassida cruenta* F. It is commonly known as wild jujube and Jharberi. It is a scrub plant with up to 2 m in height which grow will in warm and dry climate. Its fruit is edible, leaves are used as forage, braches for fencing coupled with its medicinal usage (Verma 2016). The leaves of *Ziziphus nummularia* is used to cure fever and reduce weight. The fruit is digestible having cooling effect and used for treatment of burning sensation, thirst and vomiting (Chopra et al. 1986). The also is a good source of vitamin C and sugar coupled with essential nutrients. Furthermore, the fruit is anticancer, used for treatment of anemia and to purify blood (Verma 2016).

2.4.16 *Ziziphus jujuba* Mill.

Ziziphus jujuba Mill belongs to Rhamnaceae family and is reported host plant for *Cassida exilis* Boh. The plant is commonly known as ber and jujube and is widely cultivated. The plant has various morphologies i.e. shrubs to medium size trees. The height ranges from 3 to 15 m. The plant is of medicinal significance i.e. its leaves are antidiabetic, blood purifier, anticancer and enhance hair growth (Tripathi 2014). The fruit of *Ziziphus jujuba* has antioxidant, hepatoprotective and anticancer properties (Mahajan and Chopda 2009). In chemical composition, the plant there are rich content of vitamins and minerals include vitamin A, B, C, sugar, flavonoids calcium phosphate and iron (Tripathi 2014).

2.5 Species Distribution Modeling

Species distribution models (SDMs) are numerical tools that combine observations of species occurrence or abundance with environmental estimates. They are used to gain ecological and evolutionary insights and to predict distributions across landscapes and time. For centuries humans have observed and recorded consistent relationships between species distributions and the physical environment. The initial scientific writings in this regard were mostly qualitative, though numerical models such as Species Distribution Models (SDMs) are now widely used for both describing patterns and making predictions. These numerical techniques support wide range of applications, with varying degrees of success. Published examples indicate that Species Distribution Models (SDMs) can perform well in characterizing the natural distributions of species. With certain prerequisites like reliable primary data, functionally relevant predictors and appropriately specified model an SMD can provide useful ecological insight and strong predictive capability (Elith and Leathwick 2009).

SDMs combine concepts from ecological and natural history traditions with more recent developments in statistics and information technology. The ecological roots of SDMs belong in early studies i.e. those of (Grinnell 1904) and (SCHIMPER, BALFOUR et al. 1903) that described biological patterns in terms of their relationships with geographical or environmental gradients. Moreover, research that highlighted the individualistic responses of species to their environment provided the strong conceptual argument for modeling individual species rather than communities.

Modern quantitative modeling and mapping of species distributions emerged when two parallel streams of research activity converged. On the one hand, field-based ecological studies of species-habitat associations, which was primarily dependent on linear multiple regression and discriminant function analyses, later on benefitted from new regression methods that provided coherent treatments for the error distributions of presence-absence and abundance data. Subsequently, Generalized Linear Models (GLMs) enabled pioneering regression-based SDMs that had much more sophistication and realism than was possible earlier. The key structural features of GLMs continue to be useful and are part of many current methods including RSFs (Manly, McDonald et al. 2007) and maximum entropy models MaxEnt (Phillips, Anderson et al. 2006).

In parallel, rapid methodological advances in physical geography provided new data and information systems. New methods allowed robust and detailed preparation of digital models of the Earth's surface elevation, interpolation of climate parameters, and remote sensing of surface conditions in both marine and terrestrial environments. These greatly enhanced SDM capabilities by providing estimates of environmental conditions across entire landscapes, including retrospectively at surveyed locations. Alongside these advances, the development of geographic information systems (GIS) provided important tools for storing and manipulating both species records and environmental data (Foody 2008; Swenson 2008). The gains are easily taken for granted, but stand in stark contrast to the resources available to early ecologists who usually only had simple measurements of location e.g. latitude, longitude, elevation or depth, and sometimes of local site conditions e.g. slope, drainage and geology.

2.6 Predicting Species Geographic Distribution based on Ecological Niche Modeling

The ultimate ecological niche of species is the basis for its geographic distribution. Ecological niche is defined by various scholars with varying point of views. (Grinnell 1904) has defined it as the combination of ecological conditions where species can maintain their populations without immigration for survival. Others have indicated the difference between fundamental and realized niche. The range of theoretical possibilities in terms of species ecological prerequisites and space actually occupied by species with given interactions respectively. According to (Peterson, Soberón et al. 1999) for the sake of argument it is true that only the realized niche is observable in nature but the range of distributional possibilities can be observed in diverse community backgrounds thus the interpretation of fundamental ecological niche can be assembled.

In this regard, certain approaches have been applied to model fundamental ecological niches of species. BIOCLIM is the most common among them. It involves the totaling of species presence in categories for respective environmental dimension while winsorizing the extreme 5% along with each ecological dimension. According to (Stockwell 1999) the common disadvantage of BIOCLIM is over-prediction or commission error. Others scholars i.e. (Austin 2002) have applied the approach of logistic regression in response of the challenge of combining environmental variables into predictions.

In efforts for ecological niche modeling and species geographic distribution modeling, generally there two types of errors. Those include omission error or exclusion or of areas where species actually occur. It signifies the failure of modeling techniques to cover all ecological conditions where the species can survive and establish. Furthermore, the commission error that is including the areas where the specie doesn't occur. Such error further has two types i.e. real commission error that is addition of ecological factors irrelevant to species niche and apparent commission error in response of species absence owing to interspecific interaction as well as historical factors i.e. limited colonization ability, speciation patterns, and local extinction. In this sense, apparent commission error represents a real feature of species' distributional ecology: not all habitable areas are inhabited (Peterson, Soberón et al. 1999).

3. MATERIAL AND METHODS

3.1 Study Area

For the purpose of this study, Pakistan is our focused study area. The country as a whole is not a single natural geoecological entity. The reflection of its varied topographic and bioclimatic conditions can be observed in multiplicity of its flora, fauna, soil, habitats and climates (Khan 1999). Pakistan is also termed as "the land of many lands" as the world major bioclimates are found here. Basically, the country is subtropical, stretching all the way from Arabian Sea in south to Hindukush Himalayan ranges in North. The total area is 796,096 square kilometers which lies between 23.45 to 34.75 degree north and from 61 to 75.5 degree east. The altitudinal variation ranges from sea level to 8,611 m (Murtaza 1991; Mufti, Woods et al. 1997).

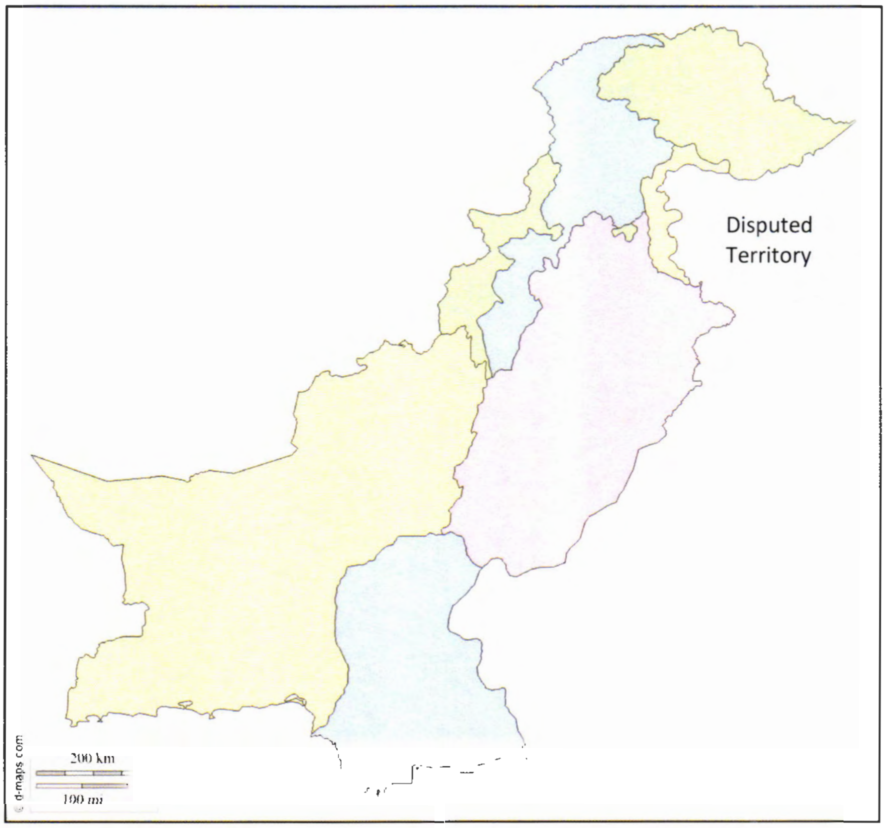
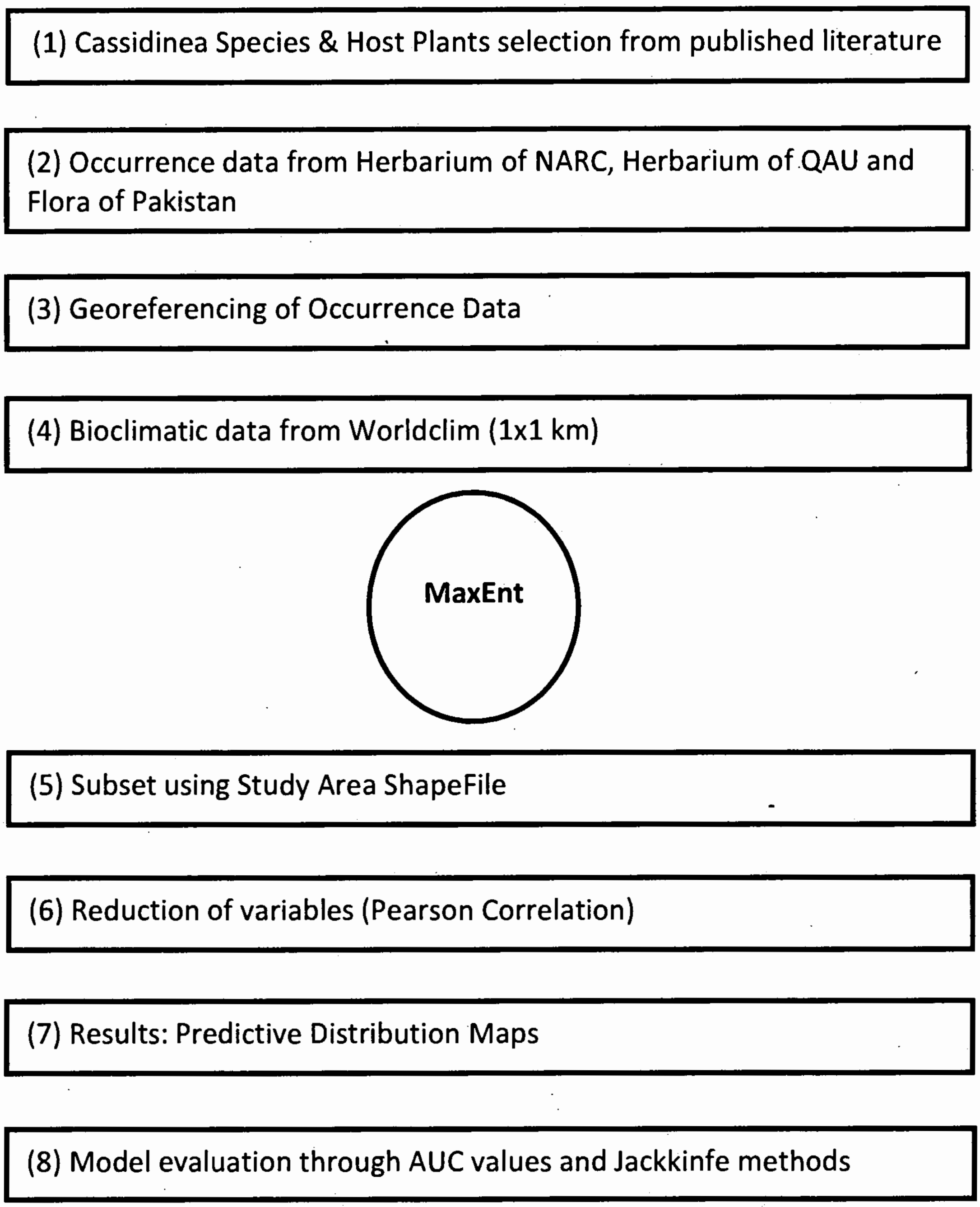


Figure 3 - Study Area for current study; Pakistan


(1) Cassidinea Species & Host Plants selection from published literature
(2) Occurrence data from Herbarium of NARC, Herbarium of QAU and Flora of Pakistan
(3) Georeferencing of Occurrence Data
(4) Bioclimatic data from Worldclim (1x1 km)
MaxEnt
(5) Subset using Study Area ShapeFile
(6) Reduction of variables (Pearson Correlation)
(7) Results: Predictive Distribution Maps
(8) Model evaluation through AUC values and Jackkinfe methods

3.2 Predicting Distribution on the basis of Host Plants

For insect species like Tottoise beetles (Cassidinea) host plant is an important environmental factor that determines their distribution. As on the basis of its biological and evolutionary history, Cassidinae beetles tend to restricted to their host plants (Chaboo 2007). For getting batter insight of ecological relationships of Tortoise beetles (Jolivet and Hawkeswood 1995) have encouraged taking their records with associated host plants. Furthermore, there are insufficient occurrences records of Tortoise beetles itself in context of Pakistan. Therefore, approach of predicting distribution on the basis of host plant species has been adopted for this study. (Sultan, Borowiec et al. 2008) have precisely studied and published the Cassidinea species occurrences along with their host plants in Rawalpindi and Islamabad. In current study effort has been made to explore the niche of reported Cassidinea species from their described host plants while expanding study area to the whole country.

3.3 Occurrence Data Collection

A total of 497specimen records of 16 host plants of 6 different families for 12 species of Cassidinea noted by (Sultan, Borowiec et al. 2008) were collected from National Herbarium, National Agricultural Research Council (NARC) Islamabad, Herbarium of Quaid-e-Azam University Islamabad, online data resource tropics.org/project/pakistan and other filed surveys. Furthermore, 67 occurrence records of 9 Cassidinea species are obtained from Insect Museum of NARC. However, there were no presence/occurrence data for the remaining 3 species. The herbarium specimen records of host plants cover a wide range within the study area while records taken from Insect Museum primary cover Rawalpindi/Islamabad and few from Mansehran and Thatta districts. Google Earth was used for geo-referencing of herbarium records.

3.4 Climate Data

Climate data is obtained from the online database (http://www.worldclim.org/) of WorldClim having spatial resolution of 1 Km2(Hijmans, Cameron et al. 2005). WorldClim climatic variables are widely used in Species Distribution Modeling(Kumar and Stohlgren 2009). It is an impressive display of various climatic conditions for the period 1950 to 2000 (Khanum, Mumtaz et al. 2013). According to (Hijmans, Cameron et al. 2005) the variables poses annual ranges, seasonality and limiting factors i.e. monthly and quarterly temperature and precipitation extremes. Separate models have been run for each insect species and their respective host plats. Description of each bioclimatic variable and its display over the study area is given as follows:-

3.4.1 Bio 01 – Annual Mean Temperature

The unit of Bio 01 or annul mean temperature is degree Celsius. Bio 01 is the average climate response of entire year. It is calculated by results of average monthly temperature over 12 months. This variable gives insight of approximated total energy inputs of an ecosystem.

$$Bio\ 1 = \frac{\sum_{i=1}^{i=12} Tavg_i}{12}$$

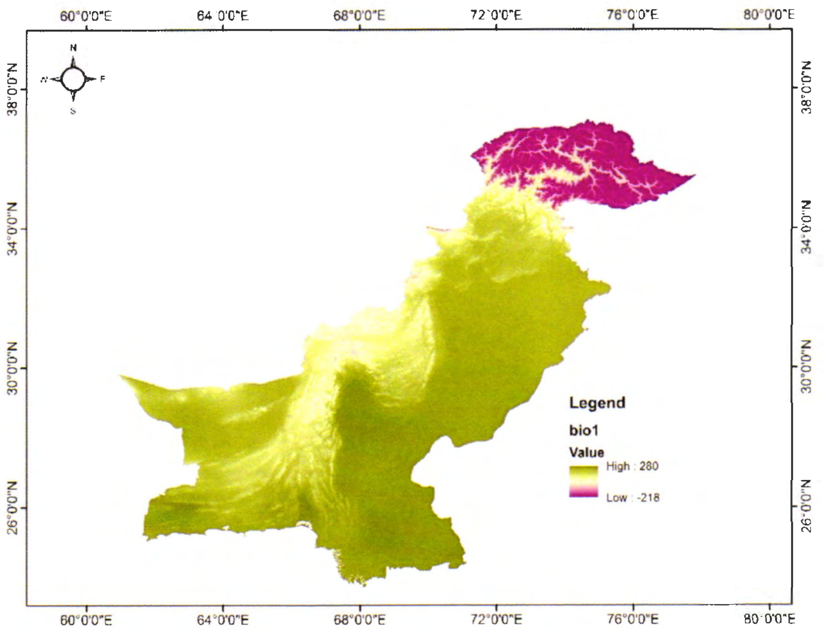


Figure 4 - Bio 01- Annual Mean Temperature of study area

3.4.2 Bio 02 – Annual Mean Diurnal Range Temperature

Bio 02 or annual mean diurnal range temperature is obtained from inputs of monthly maximum and minimum temperatures differences. The difference of each month is then averaged in twelve months of the year. It is presented in degree Celsius. It provides evidence of temperatures fluctuation effects on species.

$$Bio\ 2 = \frac{\sum_{i=1}^{i=12}\left(Tmax_i - Tmin_i\right)}{12}$$

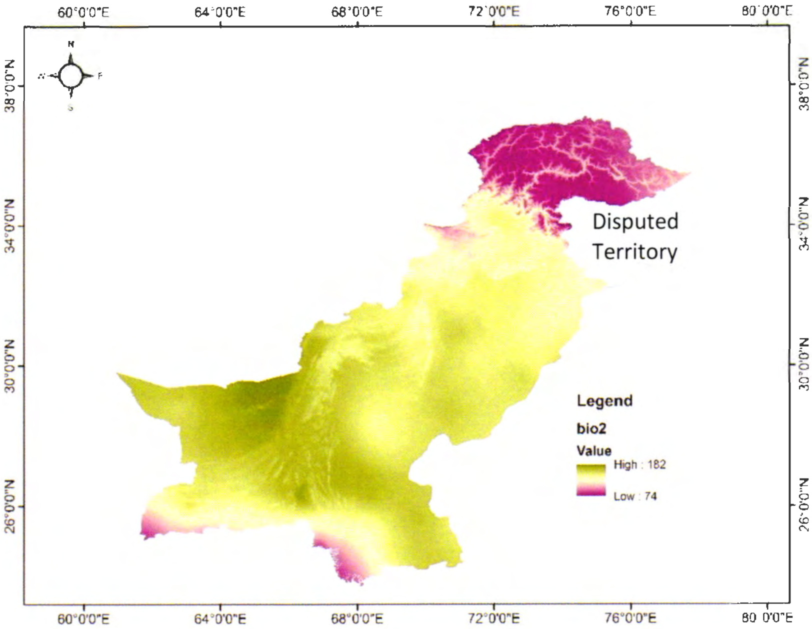


Figure 5- Bio 02 - Annual Mean Diurnal Range Temperature of study area

3.4.3 Bio 03 – Isothermality

Bio 03 or Isothermality appraise magnitude of day to night temperature oscillation in relevance to annual or winter to summer oscillations. It is presented in percent and is achieved from the inputs of Bio 02 and Bio 07 and then with multiplication with 100.

$$Bio\ 3 = \frac{Bio\ 2}{Bio\ 7} x100$$

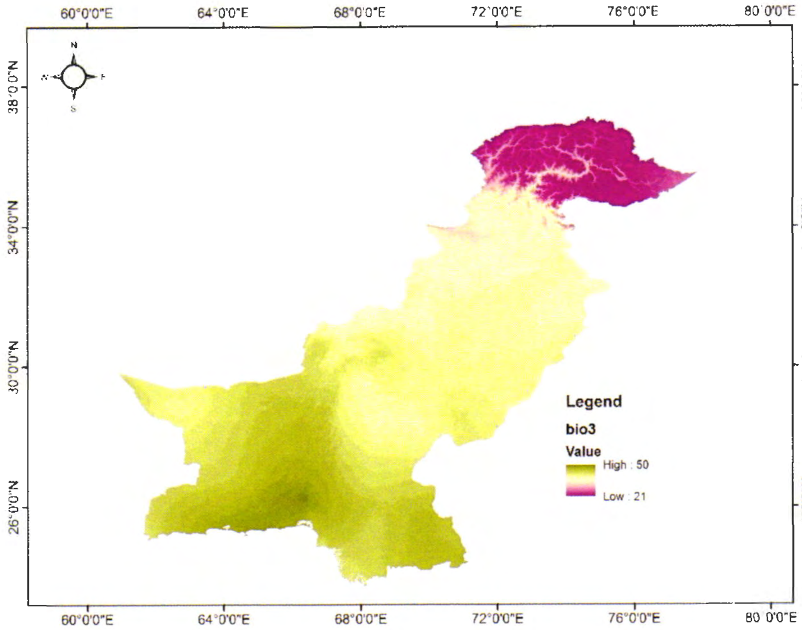


Figure 6 - Bio 03 - Isothermality of study area

3.4.4 Bio 04 – Temperature Seasonality, Slandered Deviation

This variable consider/explore the extent of temperature variation in a year based on standard deviation of the average of monthly temperatures. It is presented in degree Celsius. The greater the resulted value of standard deviation the greater will be the range of temperature variability. Its formula is:-

$$Bio\ 4 = SD\{Tavg_1, ..., Tavg_{12}\}$$

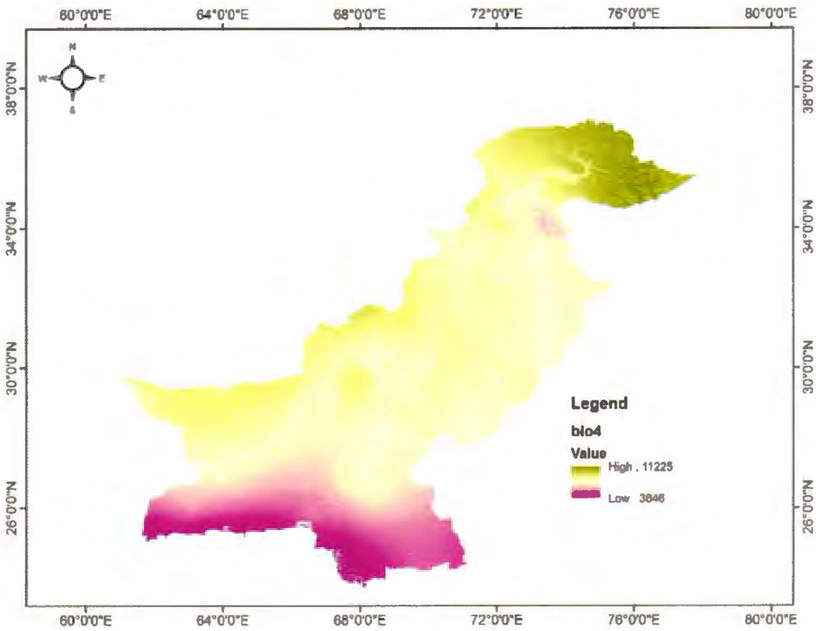


Figure 7 - Bio 04 - Temperature Seasonality, Slandered Deviation of study area

3.4.5 Bio 05 - Maximum Temperature of the Warmest Month

Bio 05 measures the uppermost monthly temperature occurrences in a year. This variable helps in exploring the effects of high temperature on species distributions. It is presented in degree Celsius and its formula is:-

$$Bio\ 5 = \max(\{Tmax_1, \ldots, Tmax_{12}\})$$

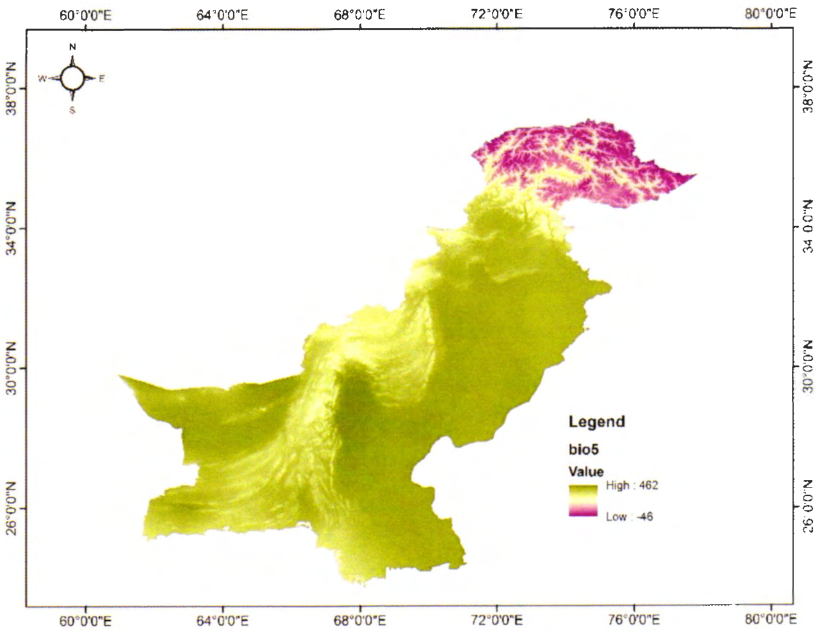


Figure 8 - Bio 05 - Maximum Temperature of the Warmest Month of study area

3.4.6 Bio 06 – Minimum Temperature of the Coldest Month

Bio 06 measures the lowermost monthly temperature occurrences in a year. This variable helps in exploring the effects of lower temperature on species distributions. It is presented in degree Celsius and its formula is:-

$$Bio\ 6 = \min(\{Tmin_1, \ldots, Tmin_{12}\})$$

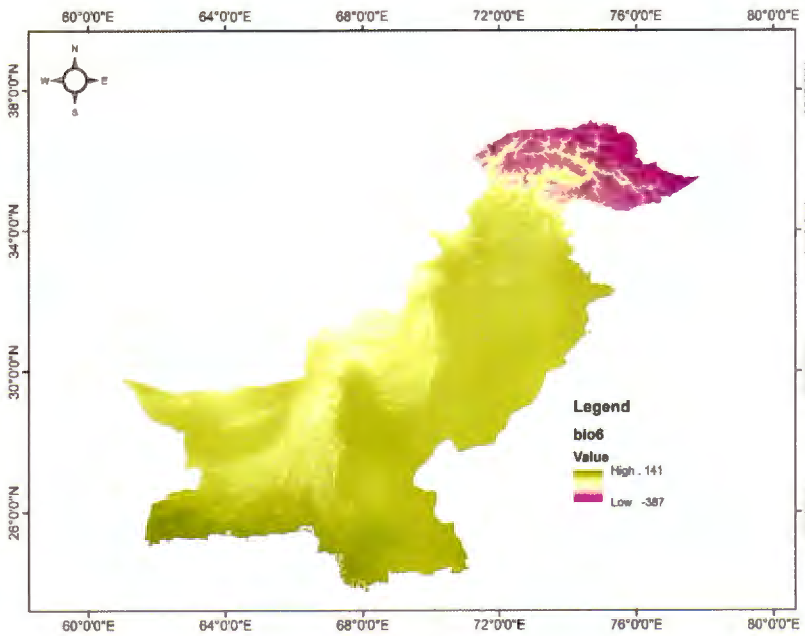


Figure 9 - Bio 06 – Minimum Temperature of the Coldest Month of study area

3.4.7 Bio 07 – Annual Temperature Range

This variable measures the difference between the highest and the lowest temperature in a year. The resulted values of Bio 05 and Bio 06 are used as input values. It is presented in degree Celsius.

$$Bio\ 7 = Bio\ 5 - Bio\ 6$$

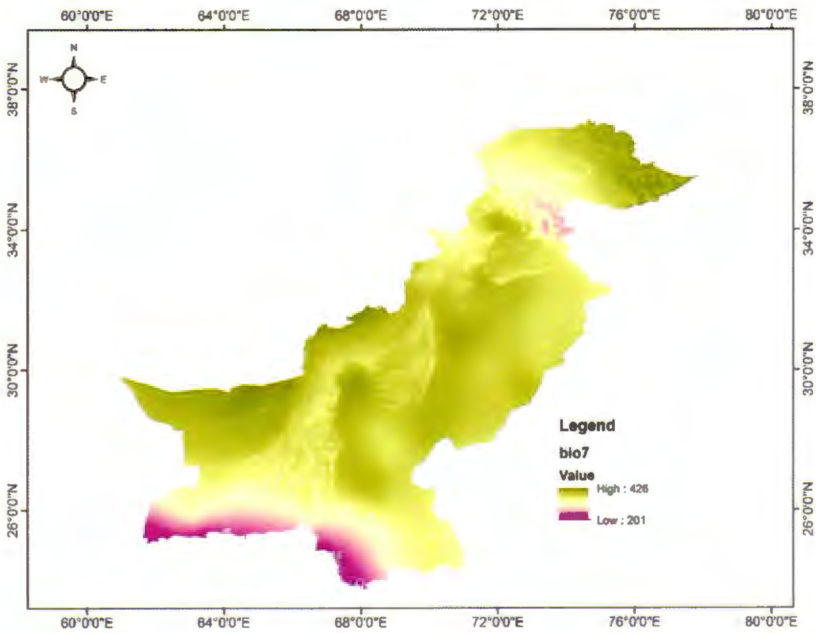


Figure 10 - Bio 07 – Annual Temperature Range of study area

TH-16888

3.4.8 Bio 08 – Mean Temperature of Wettest Quarter

This variable estimates the average temperature during the wettest quarter or season of the year. The values of monthly precipitation and mean temperature are used as input for calculating Boi 08. It is presented in degree Celsius.

$$Bio\ 8 = \frac{\sum_{i=1}^{i=3} Tavg_i}{3}$$

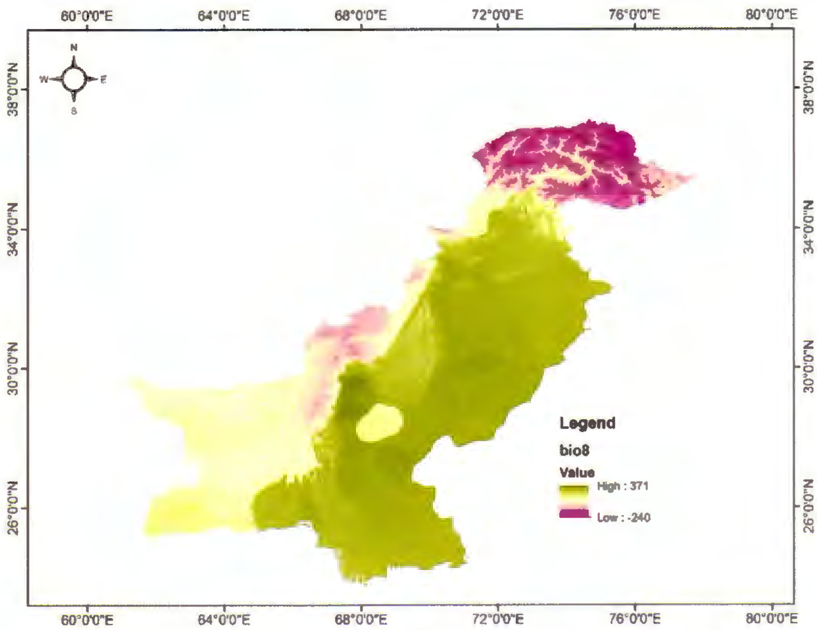


Figure 11 - Bio 08 – Mean Temperature of Wettest Quarter of study area

3.4.9 Bio 09 – Mean Temperature of Driest Quarter

This variable estimates the average temperature during the driest quarter or season of the year. Just like Bio 08 the values of monthly precipitation and mean temperature are used as input for calculating Boi 09. It is also presented in degree Celsius.

$$Bio\ 9 = \frac{\sum_{i=1}^{i=3} Tavg_i}{3}.$$

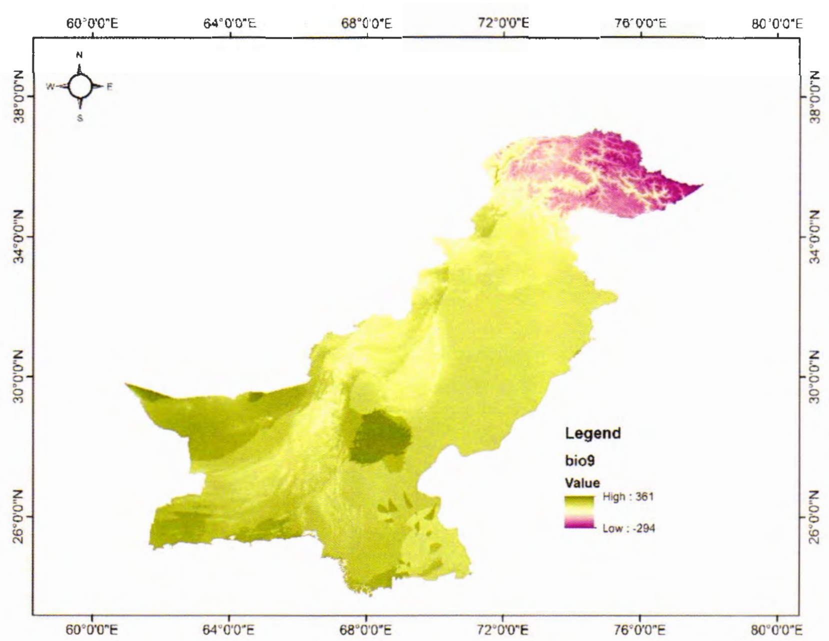


Figure 12 - Bio 09 – Mean Temperature of Driest Quarter of study area

3.4.10 Bio 10 – Mean Temperature of Warmest Quarter

This variable estimates the average temperature during the warmest quarter or season of the year. The values of monthly precipitation and mean temperature are used as input for calculating Boi 10. It is also presented in degree Celsius.

$$Bio\ 10 = \frac{\sum_{i=1}^{i=3} Tavg_i}{3}$$

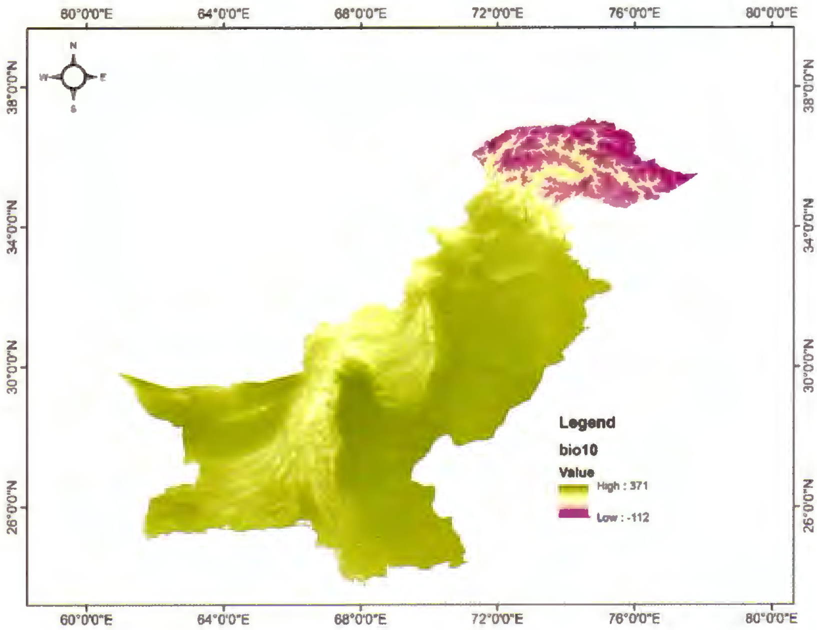


Figure 13 - Bio 10 – Mean Temperature of Warmest Quarter of study area

3.4.11 Bio 11 – Mean Temperature of Coldest Quarter

This variable estimates the average temperature during the coldest quarter or season of the year. The values of monthly precipitation and mean temperature are used as input for calculating Boi 11. It is also presented in degree Celsius.

$$Bio\ 11 = \frac{\sum_{i=1}^{i=3} Tavg_i}{3}$$

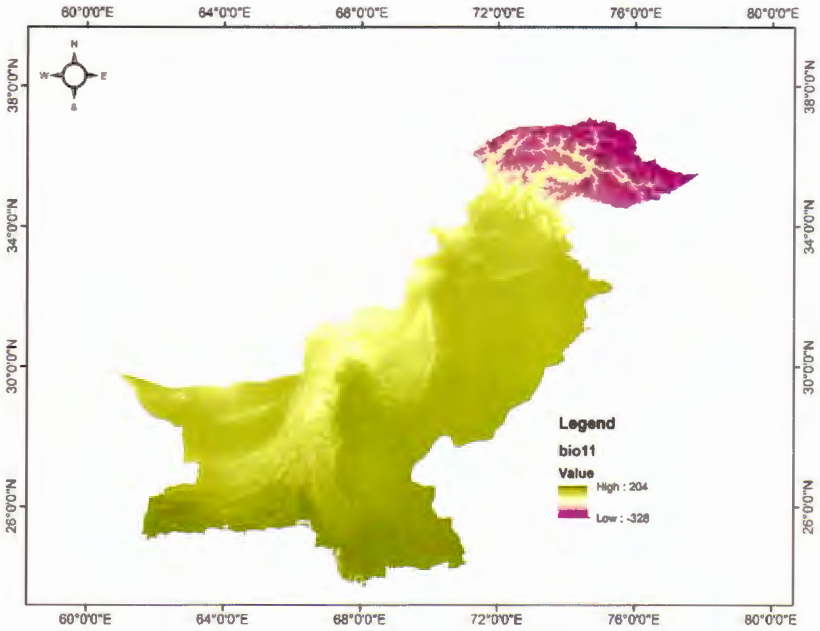


Figure 14 - Bio 11 – Mean Temperature of Coldest Quarter of study area

3.4.12 Bio 12 – Annual Precipitation

This variable approximates the total precipitation of all months of the year. It is presented in Millimeters. Bio 12 is significant for examining the importance of water obtainability for species distribution.

$$Bio\ 12 = \sum_{i=1}^{i=12} PPT_i$$

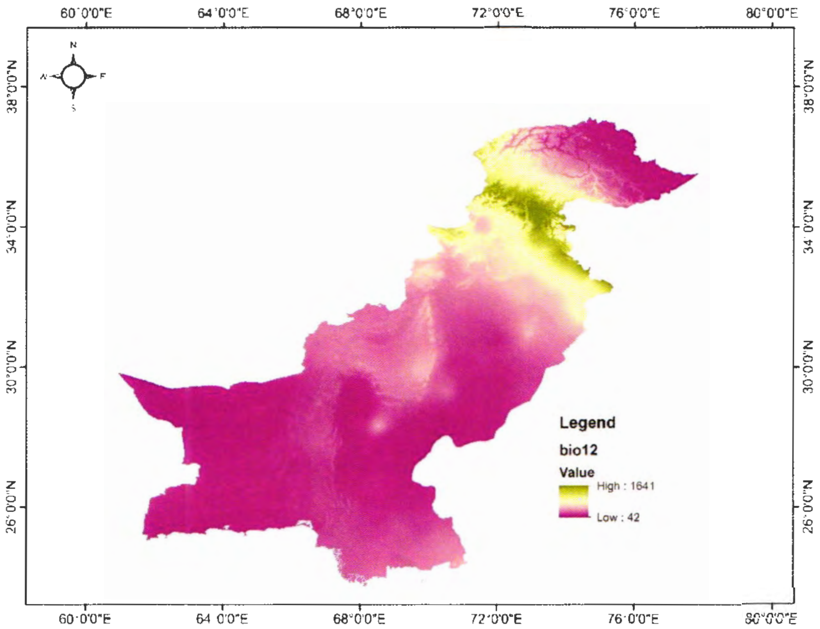


Figure 15 - Bio 12 – Annual Precipitation of study area

3.4.13 Bio 13 – Precipitation of Wettest Month

This variable approximates the total precipitation during the wettest month of the year. It is presented in Millimeters. The precipitation of every month is used as input for calculation this variable.

$$Bio\ 13 = \max([PPT_1, \ldots, PPT_{12}])$$

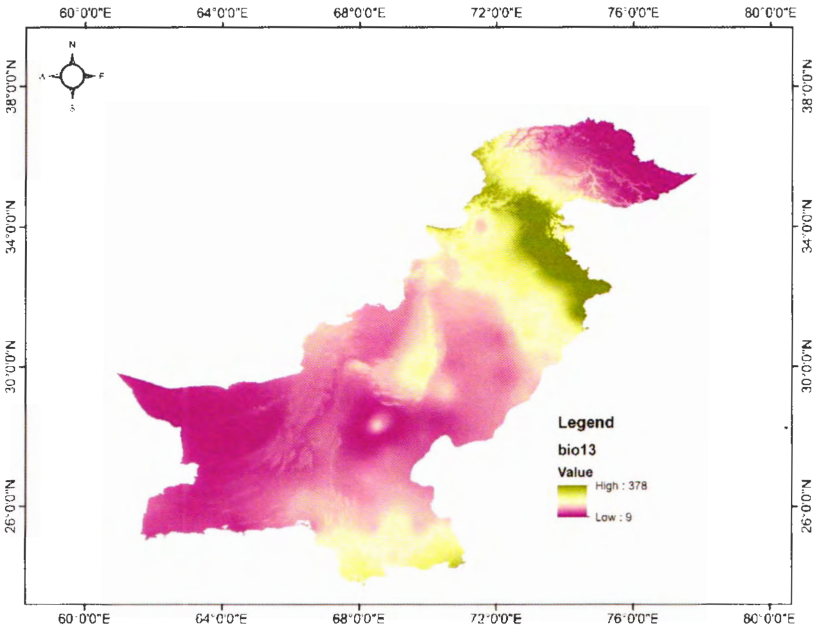


Figure 16 - Bio 13 – Precipitation of Wettest Month of study area

3.4.14 Bio 14 – Precipitation of Driest Month

This variable approximates the total precipitation during the driest month of the year. It is presented in Millimeters. The precipitation of every month is used as input for calculation this variable.

$$Bio\ 14 = \min([PPT_i, \ldots, PPT_{12}])$$

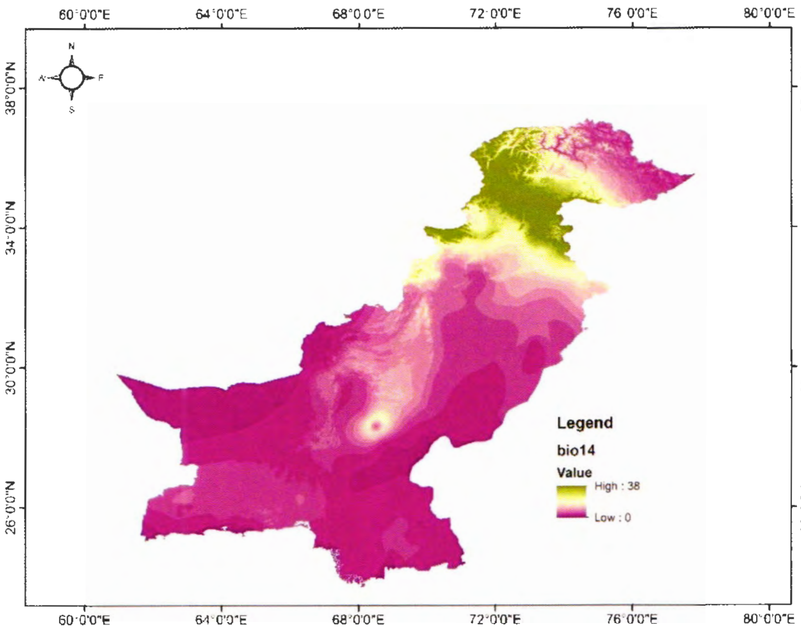


Figure 17 - Bio 14 – Precipitation of Driest Month of study area

3.4.15 Bio 15 – Precipitation Seasonality

This variable measures the variation in total monthly precipitation in a given year. It is the ratio of standard deviation of the total monthly precipitation to the mean of total precipitation or we may call it coefficient of variation. It is presented in percentage.

$$Bio\ 15 = \frac{SD\left\{PPT_1.....PPT_{12}\right\}}{1+(Bio\ 12/12)} \times 100$$

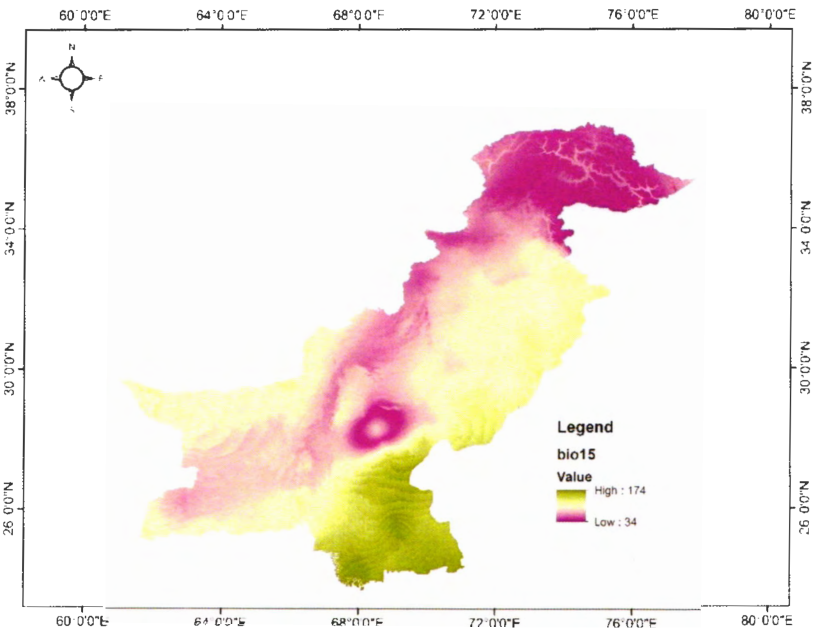


Figure 18 - Bio 15 – Precipitation Seasonality of study area

3.4.16 Bio 16 – Precipitation of Wettest Quarter

This variable approximates the total precipitation during the wettest quarter of the year. It is presented in Millimeters. The precipitation of every month is used as input for calculation this variable.

$$Bio\ 16 = \max\left(\begin{vmatrix} \sum_{i=1}^{i=3} PPT_i, \\ \sum_{i=2}^{i=4} PPT_i, \\ \cdots \\ \sum_{i=10}^{i=12} PPT_i \\ \sum_{i=11}^{i=1} PPT_i, \\ \sum_{i=12}^{i=2} PPT_i \end{vmatrix}\right).$$

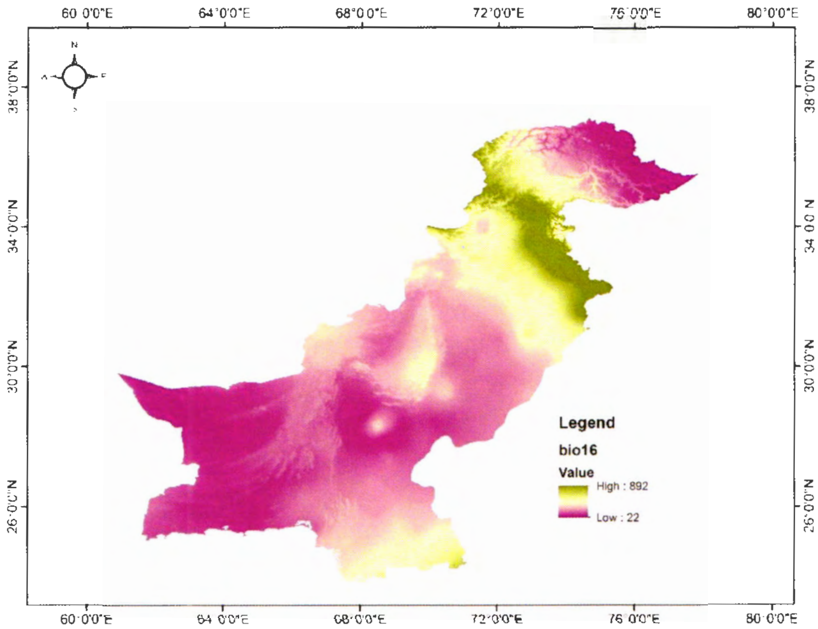


Figure 19 - Bio 16 – Precipitation of Wettest Quarter of study area

3.4.17 Bio 17 – Precipitation of Wettest Quarter

This variable estimates the total precipitation during the driest quarter of the year. It is presented in Millimeters. The precipitation of every month is used as input for calculation this variable.

$$Bio\ 17 = \min\left(\left|\begin{array}{l}\sum_{i=1}^{i=3} PPT_i, \\ \sum_{i=2}^{i=4} PPT_i, \\ \quad \ldots, \\ \sum_{i=10}^{i=12} PPT_i \\ \sum_{i=11}^{i=1} PPT_i, \\ \sum_{i=12}^{i=2} PPT_i\end{array}\right|\right)$$

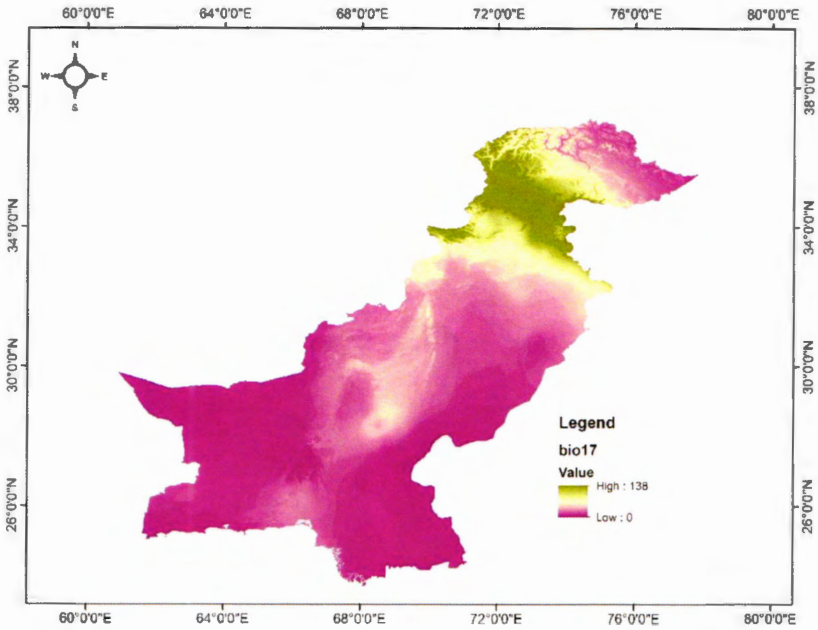


Figure 20 - Bio 17 – Precipitation of Wettest Quarter of study area

3.4.18 Bio 18 – Precipitation of Warmest Quarter

This variable estimates the total precipitation during the warmest quarter of the year. It is presented in Millimeters. The overall precipitation and temperature of every month is used as input for calculation this variable.

$$Bio\ 18 = \sum_{i=1}^{i=3} PPT_i$$

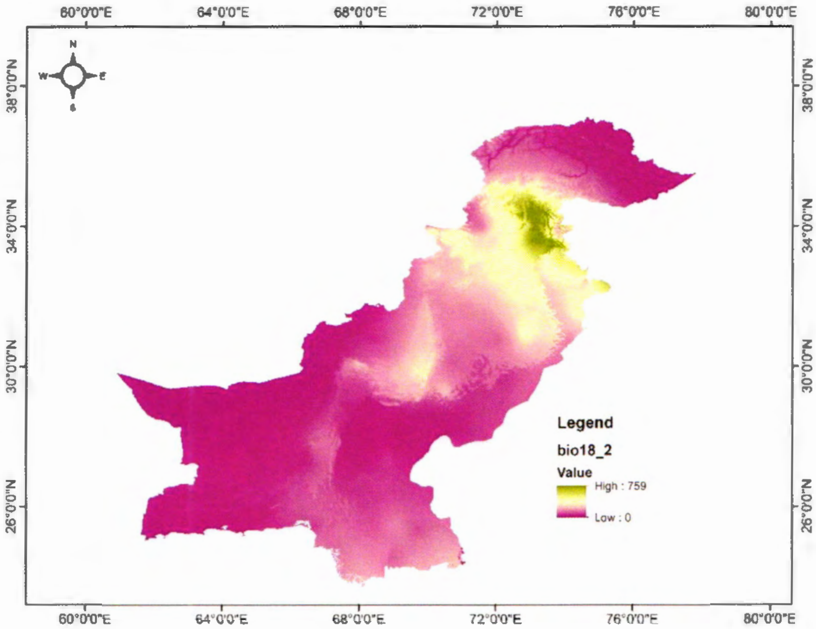


Figure 21 - Bio 18 – Precipitation of Warmest Quarter of study area

3.4.19 Bio 19 – Precipitation of Coldest Quarter

This variable estimates the total precipitation during the coldest quarter of the year. It is presented in Millimeters. The mean temperature and overall precipitation temperature of every month is used as input for calculation this variable.

$$Bio\ 19 = \sum_{i=1}^{i=3} PPT_i$$

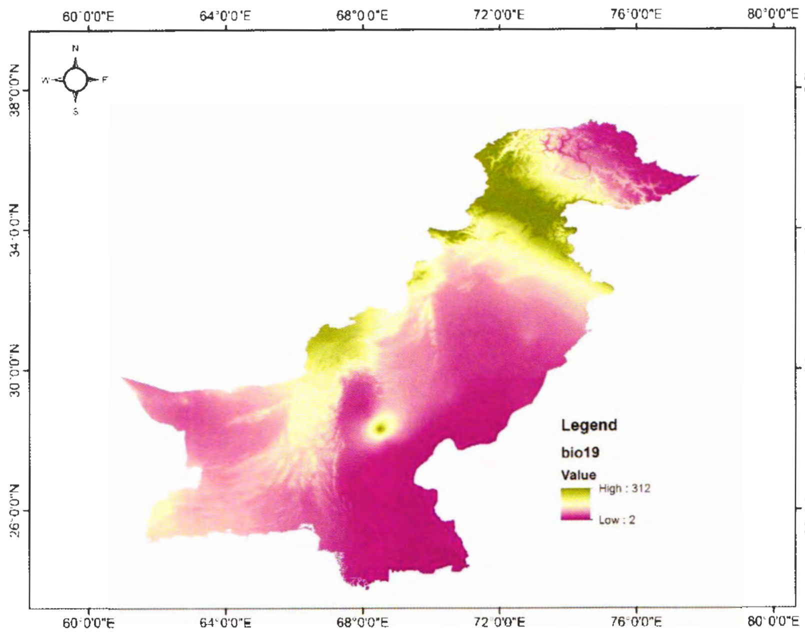


Figure 22 - Bio 19 – Precipitation of Coldest Quarter of study area

3.5 Modeling

MaxEnt (3.3.3k version) or Maximum entropy distribution modeling (Phillips, Anderson et al. 2006) is used in this study. Principally MaxEnt operates on statistical mechanics in order to make predictions from incomplete information (Esmer 2005). We only need species occurrence data and environmental variable layers of study area in this technique. On the basis of its performance MaxEnt is preferred by several scholars i.e.(P Anderson, Dudík et al. 2006; Ortega-Huerta and Peterson 2008). In case of small sample sizes MaxEnt is an ideal modeling method (Esmer 2005).

Modeling of each insect species is carried out on occurrence points of their respective reported host plants. Initially, all the nineteen bioclimatic variables and along with elevation were tested in modeling of insects species. For significance assessment of bioclimatic variables in each model, Jacknife test was implemented. Based on their importance in each model, only 10 most informative variables are selected in final modeling.

4. RESULTS AND DISCUSSION

Results are initially presented in maps of predicted suitable habitat for twelve selected Cassidinae species based on occurrences of their reported host plants. Habitat suitability of study area is categorized in four classes i.e. high suitability, moderate suitability, low suitability and unsuitable habitat based on threshold values i.e. greater than 0.6, 0.4 to 0.6, 0.2 to 0.4 and less than 0.2 respectively. The resulted maps are further described in tabular form, showing predicted habitat suitability of study area for each species in square kilometer and respective percentage. Subsequently, it is followed by compression of predictor bioclimatic variables in terms of their significance for geographic distribution of each Cassidinea species. Comparison of bioclimatic variables is carried out through Jakknife tests from MaxEnt.

4.1 *Aspidimorpha indica* Boh

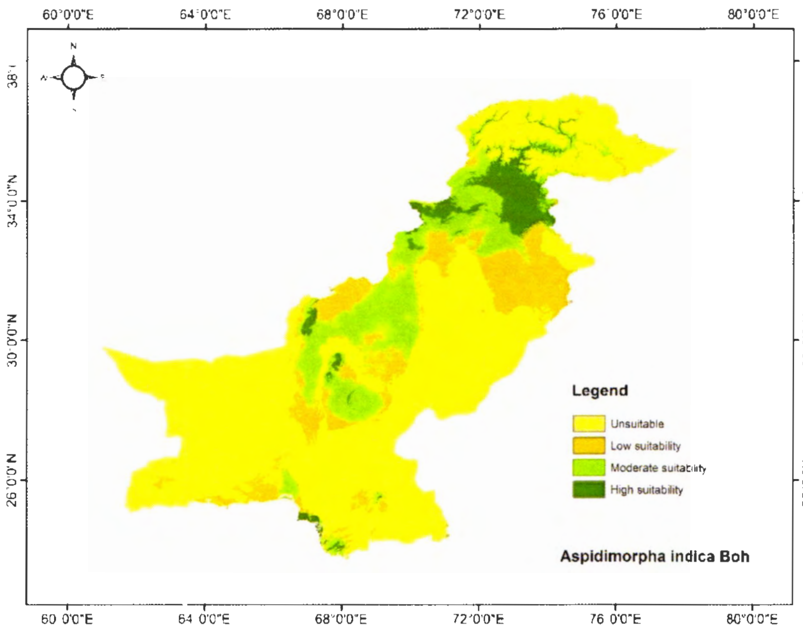


Figure 23 - Predicted geographic distribution map of Aspidimorpha indica Boh in Pakistan

As per MaxEnt results, highly suitable habitat for *Aspidimorpha indica* includes areas of Buner, Shagla and Swat in Malakand Division. Mansehra, Batagram, Haripur and Abbottabad districts in Hazara Division. Major part of Kurram and Awrakzai while certain areas in Khyber and North Wazirstan Agencies of FATA. Muzaffarabad and Kotli of AJK and Islamabad and

Rawalpindi in Potohar region. Pashin, Quetta and Bolan of Baluchistan province and Karachi east and some parts of thatta in Sindh. Moderately suitable habitat for *Aspidimorpha indica* includes Bajawar, Mohmand and South Waziristan of FATA. Peashwar valley i.e. Peshawar, Charsadda, Mardan and Swabi districts. Southeren districs of KPK i.e. Kohat and Karak. Chakwal and Attok in Potohar. Zhob, Musakhail, Loralai, Qilla Saifullah, Mastung, Lasbela and Jafarabad of Bluchistan province. Jazakabad, Shikarpur and Thatta of Sindh. Furthermore, major portion of North Punjab and some districts of North western Baluchistan is low suitable habitat for *Aspidimorpha indica*.

Table 2 - Habitat suitability comparison of *Aspidimorpha indica* Boh in Pakistan

Suitability	**Threshold**	**Prediction (Km^2)**	**Prediction (%)**
Unsuitability	< 0.2	386367.05	43.79%
Low Suitability	0.2 - 0.4	328193.55	37.19%
Moderate Suitability	0.4 – 0.6	119179.61	13.51%
High Suitability	> 0.6	48622.79	5.51%

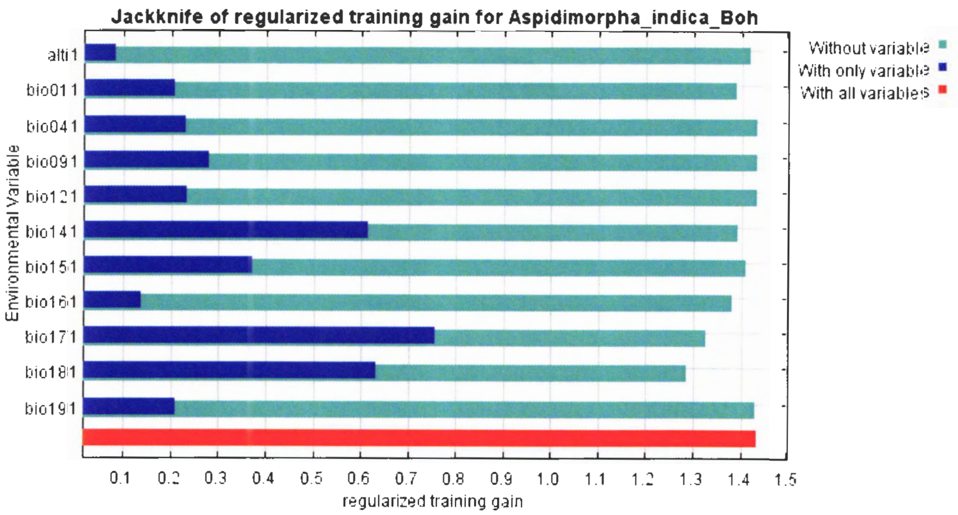


Figure 24 - Jackknife test of regularized training gain for Aspidimorpha indica Boh

Jackknife test through MaxEnt show relative influence of selected bioclimatic variable for *Aspidimorpha indica* Boh in Pakistan. As shown in Fig. xx bio 17 (precipitation of driest quarter), bio 18 (precipitation of warmest quarter), bio 14 (precipitation of driest month), and bio 15 (precipitation seasonality) are more significant or having more contribution as compared to reaming variables. Within the selected variables altitude and bio 16 (precipitation of wettest quarter) have least contribution in distribution of *Aspidimorpha indica* Boh in Pakistan.

4.2 *Oocassida pudibunda* Boh

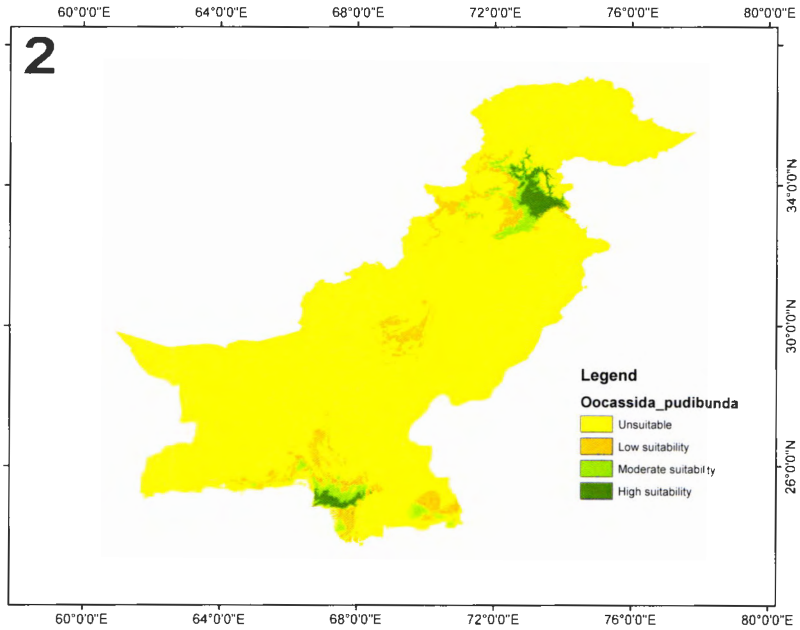


Figure 25 -Predicted geographic distribution map of Oocassida pudibunda Boh in Pakistan

The resulted distributional map shows that highly suitable habitat of *Oocassida pudibunda* in Pakistan includes some part of district Buner in Mlakand Division. Islamabad and Rawalpindi in Potohar. Haripur and Abbottabad in Hazara and Kotli in AJK. Karachi west, Malir and Karachi South in Sindh. Moderately suitable habitat of *Oocassida pudibunda* includes certain parts of Peshawar Valley and Southern districts of KPK. Jehlum and Attock in Potohar. A small portion of Gawadar and Lasbela of Blucjistan and Thtta and Mithi in Sindh Province. Some parts of FATA and Malakand Division, North western and South western Baluchistan and western as well as southern Sindh are shown as habitat with low suitability for *Oocassida pudibunda* in Pakistan.

Table 3 - Habitat suitability comparison of *Oocassida pudibunda* Boh in Pakistan

Suitability	**Threshold**	**Prediction (Km²)**	**Prediction (%)**
Unsuitability	< 0.2	684023.07	77.52%
Low Suitability	0.2 - 0.4	162727.68	18.44%
Moderate Suitability	0.4 – 0.6	20337.87	2.30%
High Suitability	> 0.6	15274.38	1.73%

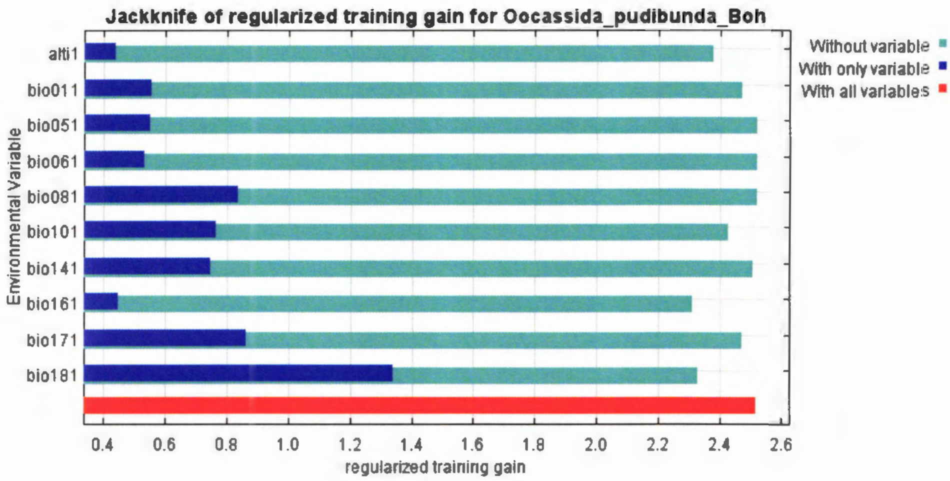


Figure 26 - Jackknife test of regularized training gain for Oocassida pudibunda Boh

The relative contribution of bioclimatic variable for distribution of *Oocassida pudibunda* Boh through Jackknife test show that bio 18 (precipitation of warmest quarter), bio 17 (precipitation of driest quarter), bio 8 (mean temperature of wettest quarter) and bio 10 (mean temperature of warmest quarter) are more significant than other variables. While altitude and bio 16 (precipitation of wettest quarter) have least contribution.

4.3 *Oocassida cruenta* F

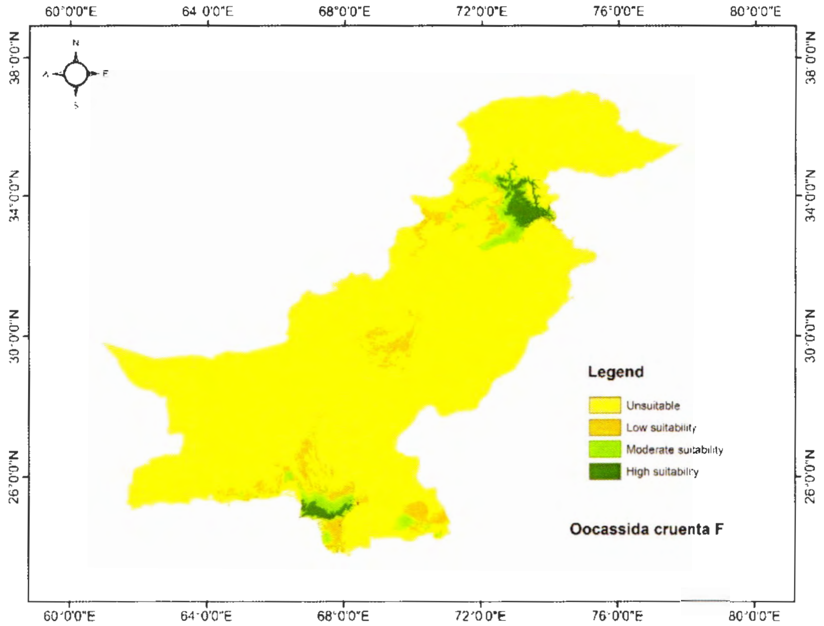


Figure 27 - Predicted geographic distribution map of Oocassida cruenta F in Pakistan

Highly suitable habitat for *Oocassida cruenta* F in Pakistan are some areas in Malakand agency in Fata, district Mardan, Nowshehra and Buner in KPK. Batagram, Mansehra, Haripur and Abbottabad in Hazara along with Muzaffarabad, Punch and Kotli in AJK. Islamabad, Rawalpindi and Attock in Potohar. Hyderabad, Karachi west and Malir in Sindh province. Moderately suitable habitat includes Orakzai and Khyber and Bajawar agencies of FATA. Swat and Dir of Malakand Division, Hungu and Karak of Southern KPK, Chakwal in Potohar and Bhimbar in AJK. Gawadar and Lasbela in Baluchistan while Mithi and Thatta in Sindh. Furthermore, districts of Kohlu, Lorali, Dera Bugti, Khuzdar and Bakran of Baluchistan, Dera Ghazi Khan and Jehlum of Punjab, Swabi and Charsadda of KPK, Mohmand, South and North Waziristan of FATA are areas of low suitability for distribution of *Oocassida cruenta* F in Pakistan.

Table 4 - Habitat suitability comparison of *Oocassida cruenta* F in Pakistan

Suitability	**Threshold**	**Prediction (Km²)**	**Prediction (%)**
Unsuitability	< 0.2	675377.60	76.54%
Low Suitability	0.2 - 0.4	161826.19	18.34%
Moderate Suitability	0.4 – 0.6	27130.90	3.07%
High Suitability	> 0.6	18028.31	2.04%

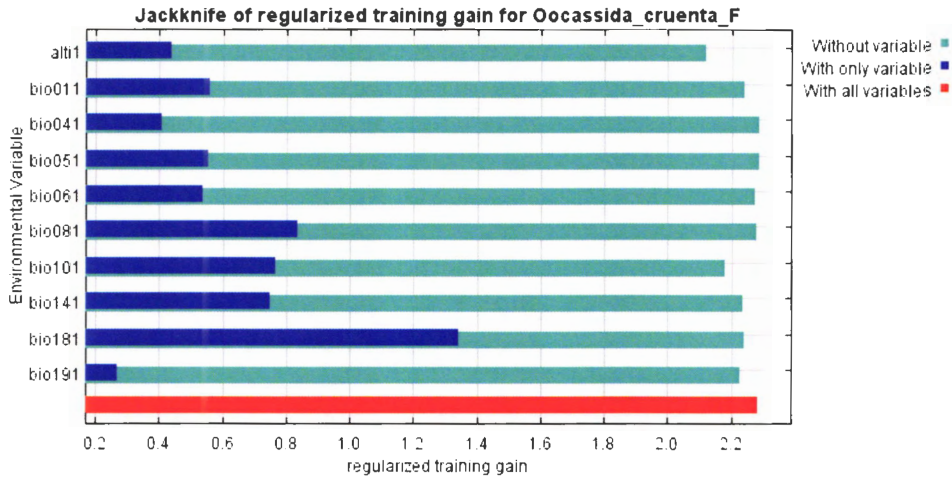


Figure 28 - Jackknife test of regularized training gain for Oocassida cruenta F

Jackknife test result shows that bio 18 (precipitation of warmest quarter), bio 8 (mean temperature of wettest quarter), bio 10 (mean temperature of warmest quarter) and bio 14 (precipitation of driest month) are more significant or having more contribution as compared to reaming variables. Within the selected variables bio 19 (precipitation of the coldest quarter) and bio 4 (temperature seasonality) have least contribution in distribution of *Oocassida cruenta* F in Pakistan.

4.4 *Notsacantha jammuensis*

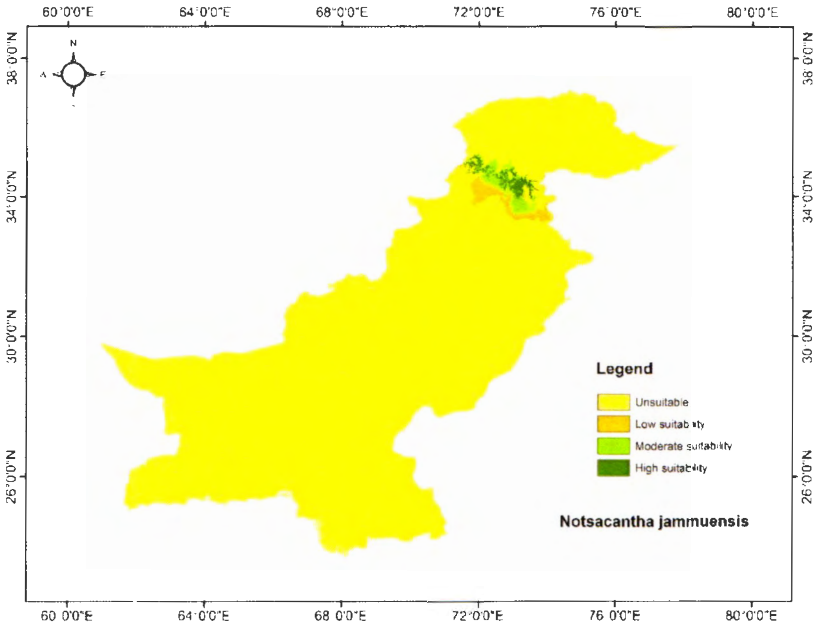


Figure 29 - Predicted geographic distribution map of Notsacantha jammuensis

In study area Pakistan, the areas which are shown as highly suitable habitat for *Notsacantha jammuensis* are district Dir upper and lower, Swat, Shangla and Buner of Malakand division. Abbottabad of Hazara division and Muzaffarabad in AJK. Moderate suitable habitat areas are Islamabad, small portion of Malakand agency, Haripur and Sudhnati. Low suitable areas for *Notsacantha jammuensis* are some parts in District Chitral, of Malakand division, Bajawar agency in FATA, Mardan, Charsadda and Swabi in Peshawar Valley, Kohistan and Haripur in Hazara and Kotli in AKJ.

Table 5 - Habitat suitability comparison of *Notsacantha jammuensis* in Pakistan

Suitability	**Threshold**	**Prediction (Km²)**	**Prediction (%)**
Unsuitability	< 0.2	838480.71	95.03%
Low Suitability	0.2 - 0.4	30701.64	3.48%
Moderate Suitability	0.4 – 0.6	7481.70	0.85%
High Suitability	> 0.6	5698.95	0.65%

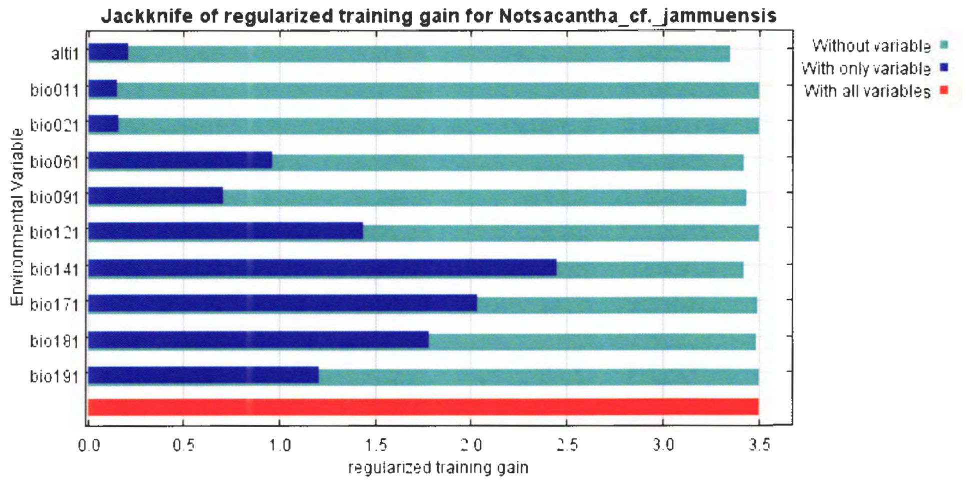


Figure 30 - Jackknife test of regularized training gain for Notsacantha jammuensis

Result of Jackknife of regularized training gain for *Notsacantha jammuensis* shows that bio 14 (precipitation of driest month), bio 17 (precipitation of driest quarter), bio 18 (precipitation of warmest quarter) and bio 12 (annual precipitation) are more significant variables. While variables such as bio 01 (annual mean precipitation) and 02 (mean diurnal range) along with altitude are least contributing.

4.5 *Laccoptera nepalensis* Boh

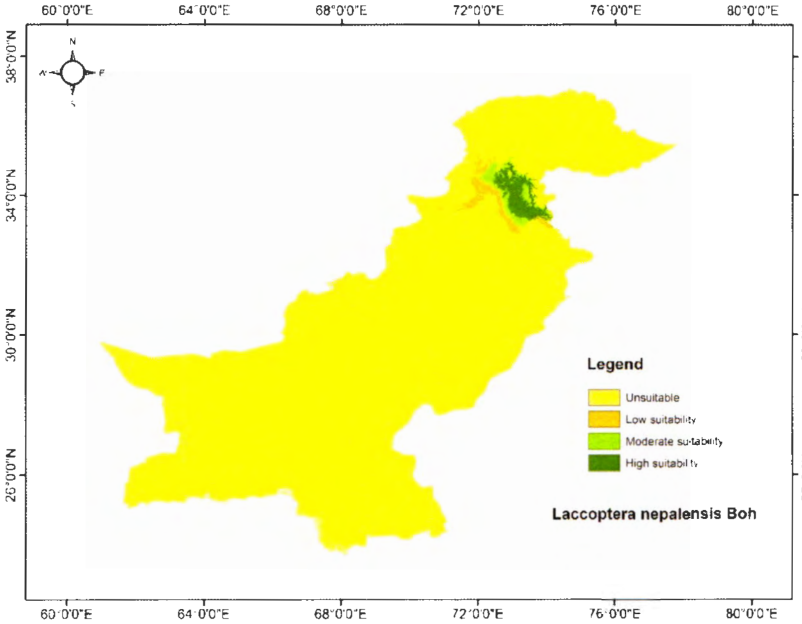


Figure 31 - Predicted geographic distribution map of Laccoptera nepalensis Boh in Pakistan

As per resulted distributional map, highly suitable habitat of *Laccoptera nepalensis* in Pakistan are areas of Kotli, Punch, Bagh and Muzaffarabad in AJK. Shangla and Buner in Malakand division, Batagram, Haripur and Abbottabad in Hazara and Islamabad and Rawalpindi in Potohar region. The moderate and low suitable habitat for *Laccoptera nepalensis* are just adjacent with areas of high suitability.

Table 6 - Habitat suitability comparison of *Laccoptera nepalensis* Boh in Pakistan

Suitability	**Threshold**	**Prediction (Km^2)**	**Prediction (%)**
Unsuitability	< 0.2	825424.46	93.55%
Low Suitability	0.2 - 0.4	38715.39	4.39%
Moderate Suitability	0.4 – 0.6	6763.05	0.77%
High Suitability	> 0.6	11460.10	1.30%

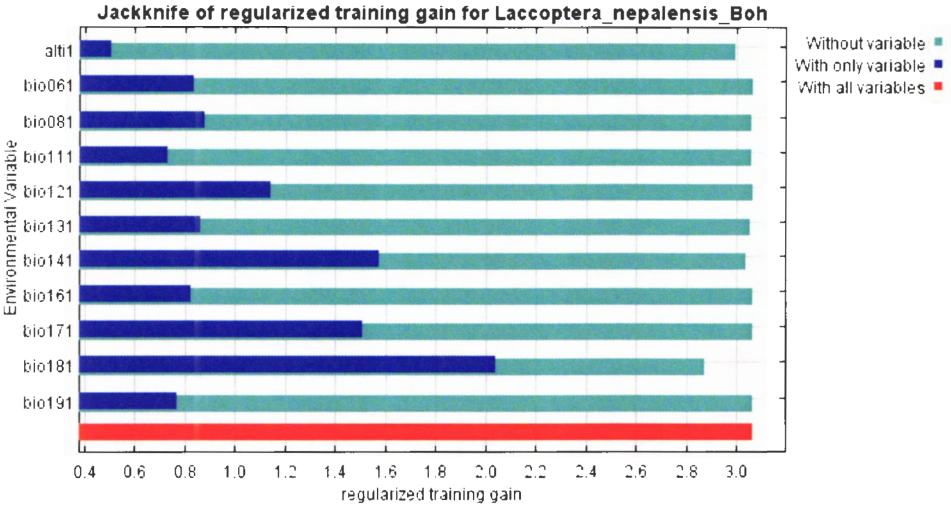


Figure 32 - Jackknife test of regularized training gain for Laccoptera nepalensis Boh

Jackknife test result shows that bio 18 (precipitation of warmest quarter), bio 17 (precipitation of driest quarter), bio 14 (precipitation of driest month) and bio 12 (annual precipitation) are more significant variables for distribution of *Laccoptera nepalensis* Boh in Pakistan. On the other hand, variables with least contribution include altitude, bio 11 (mean temperature of coldest quarter) and 13bio (precipitation of wettest month).

4.6 *Glyphocassis trilineata* Hope

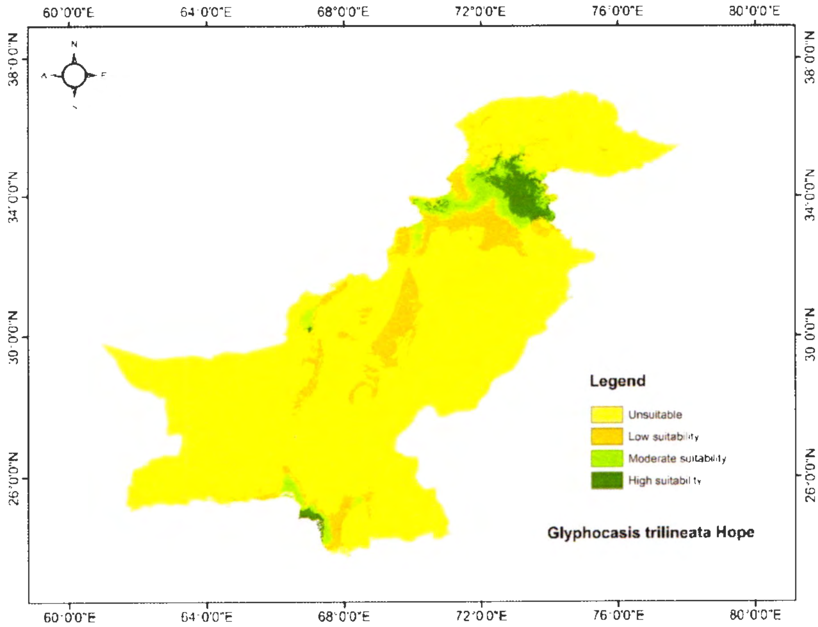


Figure 33 - Predicted geographic distribution map of Glyphocasis trilineata Hope in Pakistan

Highly suitable habitat for *Glyphocassis trilineata* Hope in Pakistan is a narrow line ranges from Swat to Malakand agency, major portion of district Shangala and Buner in Malakand division. A small portion of Kohistan with almost half of Batagram as well as Mansehra and major portion of Abbottabad and Haripur in Hazara division. Some parts of Kurram and Orakzai agencies in FATA, entire Islamabad, range from Muzaffarabad to Kotli in AJK, Quetta in Baluchistan and Karachi in Sindh. Moderate suitable habitat is several districts in Peshawar Valley i.e. Charsadda, Nowshehra, Mardan and Swabi. Khyber agency in FATA, Hangu in Southern KPK, Rawalpindi in Potohar and Punch and Bagh in AJK. Pashin, Lasbela and Gawadar in Baluchistan and Hyderabad and Thatta in Sindh. Low suitable habitat is certain parts of Northern Pakistan i.e. Chitral, Gilgit and Chillas. Bajawar and Mohmand agencies in FATA and district Peshawar. Karak and Kohat in Southern KPK, Attock and Chakwal in Potohar, Khushab in Punjab and Mirpur and Bhimber in AJK. Mussakhil, Bakran Kohlu, Dera Bugti and Jaffarabad in Baluchistan. Thatta, Jamshoro, Thando Allah Yar and Badin in Sindh province.

Table 7 - Habitat suitability comparison of *Glyphocassis trilineata* Hope in Pakistan

Suitability	**Threshold**	**Prediction (Km²)**	**Prediction (%)**
Unsuitability	< 0.2	533064.23	60.41%
Low Suitability	0.2 - 0.4	298747.10	33.86%
Moderate Suitability	0.4 – 0.6	28781.01	3.26%
High Suitability	> 0.6	21770.66	2.47%

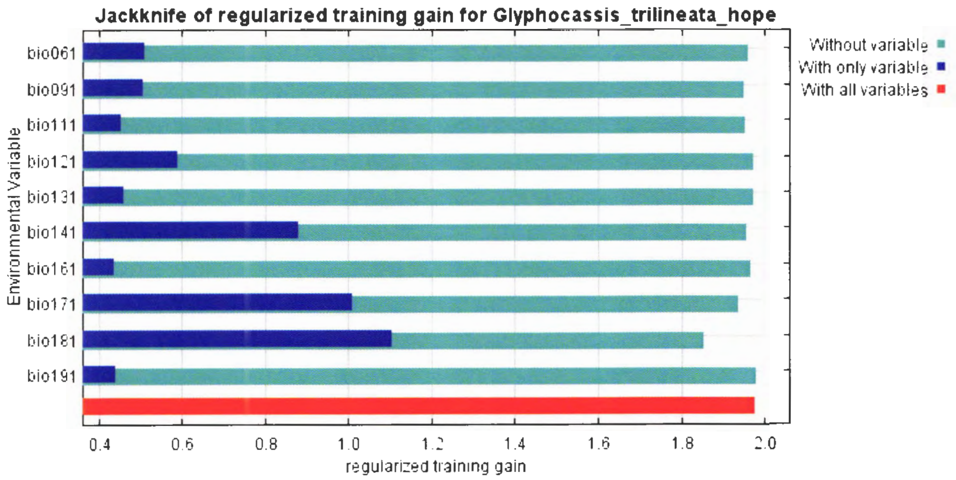


Figure 34 - Jackknife test of regularized training gain for Glyphocassis trilineata Hope

The relative contribution of bioclimatic variable for distribution of *Glyphocassis trilineata* Hope through Jackknife test show that bio 18 (precipitation of warmest quarter), bio 17 (precipitation of driest quarter), bio 14 (precipitation of driest month) and bio 12 (annual precipitation) are more significant variables. While bio 16 (precipitation of wettest quarter), bio 19 (precipitation of the coldest quarter) and 13 bio (precipitation of wettest month) have least contribution.

4.7 *Cassida varians* herBSt

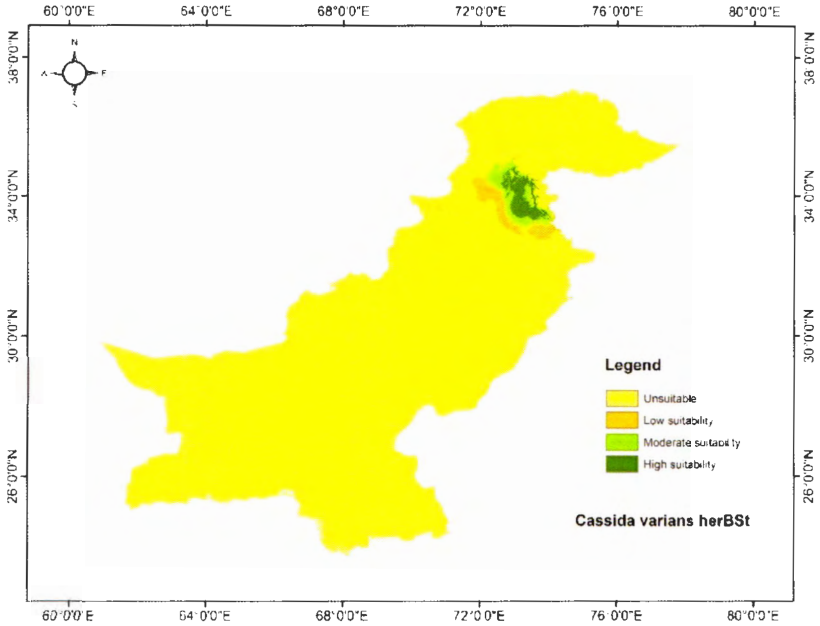


Figure 35 - Predicted geographic distribution map of Cassida varians herBSt in Pakistan

The resulted distributional map of *Cassida varians* shows that highly suitable habitat in Pakistan is Islamabad as a whole, Rawalpindi partially, major portion of Abbottabad and Mansehra and small portion of Batagram in in Hazara along with Muzaffarabad, Sudhnati and Kotli partially in AJK. Moderately suitable habitat comprises of Shangla, Swat and Buner in Malakand division. Some parts of Haripur and Abbottabad in Hazara division and Mirpur in AJK. Low suitable habitat for *Cassida varians* in Pakistan ranges from district Kohistan of Hazara towards Shangla and Swat in Malakand division. Furthermore, range of low suitable habitat stretch from Mardan, Nowshehra and Swabi of Peshawar Valley, cross Attock, Chakwal and Jehlum of Potohar, fairly touch district Gujrat of Northern Punjab and reach Bhimbar of AJK.

Table 8 - Habitat suitability comparison of *Cassida varians* herBSt Hope in Pakistan

Suitability	**Threshold**	**Prediction (Km²)**	**Prediction (%)**
Unsuitability	< 0.2	825817.88	93.59%
Low Suitability	0.2 - 0.4	38827.04	4.40%
Moderate Suitability	0.4 – 0.6	8450.63	0.96%
High Suitability	> 0.6	9267.44	1.05%

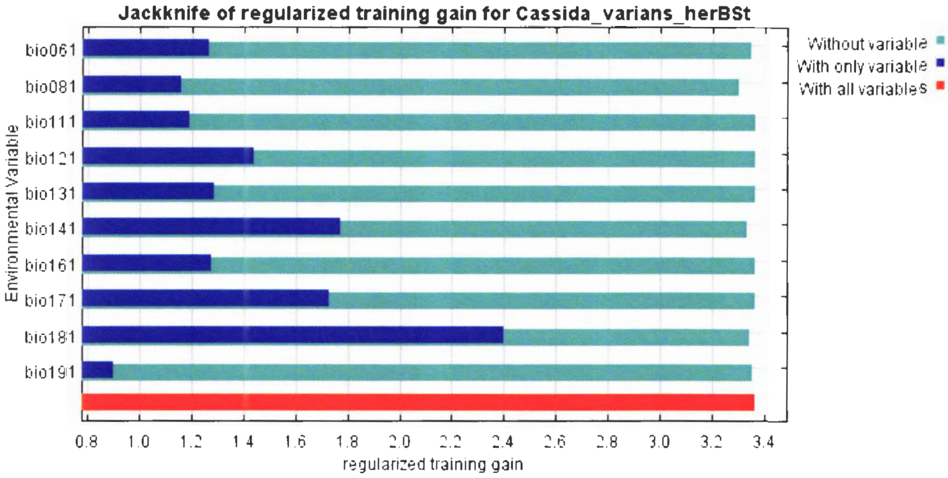


Figure 36 - Jackknife test of regularized training gain for Cassida varians herBSt

As shown in Fig. 4.14, Jackknife test result shows that bio 18 (precipitation of warmest quarter), bio 17 (precipitation of driest quarter), bio 14 (precipitation of driest month) and bio 12 (annual precipitation) are more significant or more contribution variables. Whereas bio 19 (precipitation of the coldest quarter) and bio 8 (mean temperature of wettest quarter) have least contribution in distribution of *Cassida varians* herBSt in Pakistan.

4.8 *Cassida nigriventris* Boh

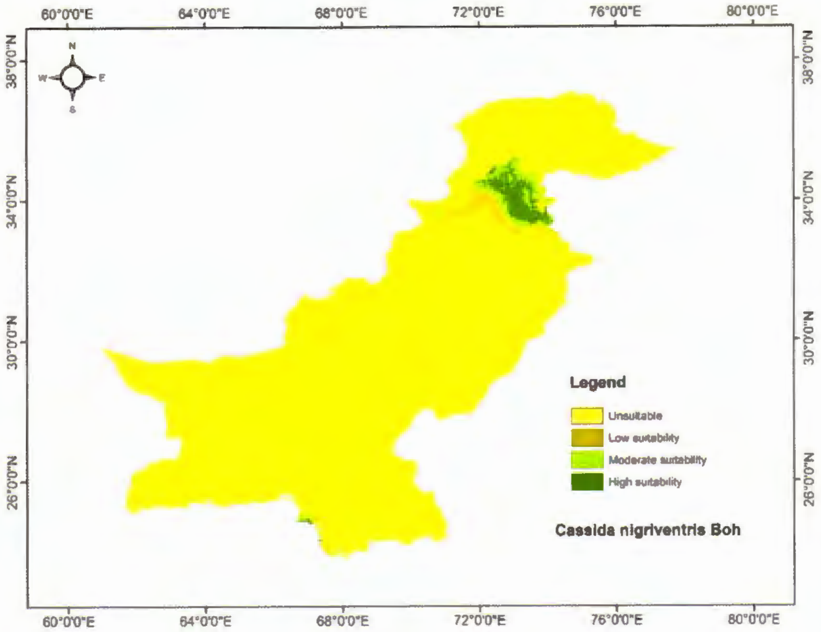


Figure 37 - Predicted geographic distribution map of Cassida nigriventris Boh in Pakistan

The resulted distributional map of *Cassida nigriventris* shows that highly suitable habitat in Pakistan is some parts of district Swat, Shangla and Malakand agency and considerable fragment of Buner in Malakand division. Substantial area of Haripur and Abbottabad, while gradually decreasing towards Mansehra and Batagram in Hazara division. Absolute range from Islamabad towards Kotli in AJK and some parts of Karachi south in Sindh. Moderately suitable habitat of *Cassida nigriventris* includes certain parts of Swat and Shangla in Malakand, Kohistan, Batagram, Mansehra, Abbottabad in Hazara, Muzaffarabad and Bagh in AJK. A narrow range line streatches from Kurram agency towards Dra Adamkhail of Khyber agency in FATA. Low suitable habitat ranges from Southern KPK towards Peshawar Valley, Potohar to the vicinity of Mirpur and Bhimber of AJK.

Table 9 - Habitat suitability comparison of *Cassida nigriventris* Boh

Suitability	**Threshold**	**Prediction (Km²)**	**Prediction (%)**
Unsuitability	< 0.2	814431.97	92.30%
Low Suitability	0.2 - 0.4	40861.58	4.63%
Moderate Suitability	0.4 – 0.6	12362.34	1.40%
High Suitability	> 0.6	14707.11	1.67%

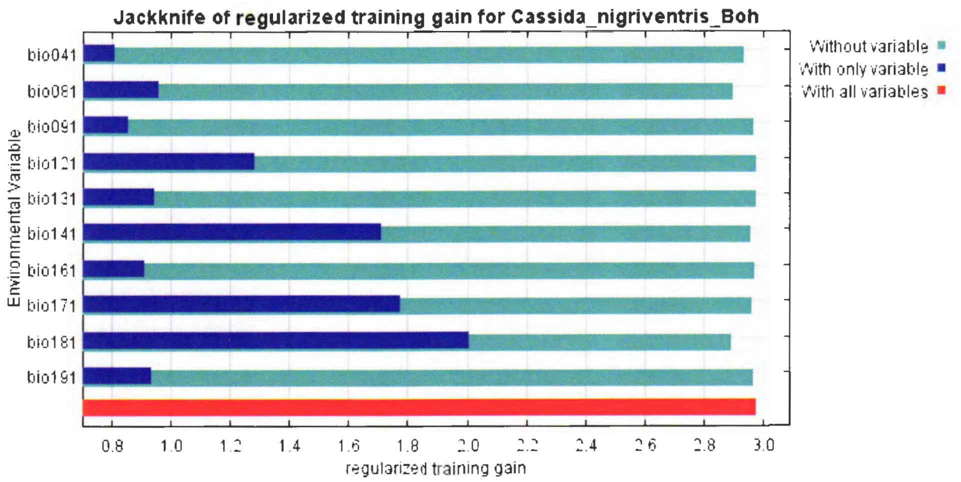


Figure 38 - Jackknife test of regularized training gain for Cassida nigriventris Boh

The relative contribution of bioclimatic variable for distribution of *Cassida nigriventris* Boh through Jackknife test show that bio 18 (precipitation of warmest quarter), bio 17 (precipitation of driest quarter), bio 14 (precipitation of driest month) and bio 12 (annual precipitation) are more significant variables. On the other hand bio 4 (temperature seasonality) and bio 9 (mean temperature of direst quarter have least contribution.

4.9 *Cassida exilis* Boh

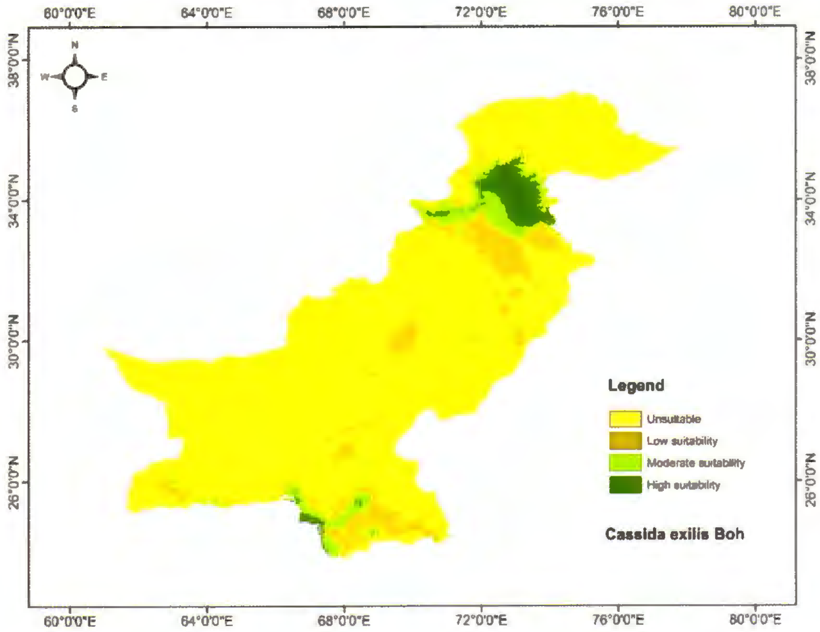


Figure 39 - Predicted geographic distribution map of Cassida exilis Boh in Pakistan

Highly suitable habitat for *Cassida exilis* in Pakistan is Malakand agency, Shangala and Buner in Malakand division. Kurram and Orakzai agencies in FTA. A tiny portion in Nowshehra and considerable part of Mardan in Peshawar Valley. Batagram, Mansehra, Haripur and Abbottabad in Hazara. Islamabad and Rawalpindi in Potohar while Muzaffarabad, Sudhnati and Kotli in Azad Kashmir. Karachi West, South and Malir along with border of area of Baluchistan and Sindh. Tando Muhhamad Khan, Hyderabad and Badin of Sindh province. Moderately suitable habitat includes Gawadar and Lesbela districts of Baluchistan. From Runn of Kutch towards the upper edge of Karachi and from Thatta towads Tandu Muhammad Khan and some parts of Badin district of Sindh. Furthermore, several areas of FATA and Dir of Malakand division, Southern districts of KPK, Peshawar Valley and from Attock towards Rawalpindi. Low suitable habitat of *Cassida exilis* includes Bajawar, Mohmand, Kurram and South Waziristan agencies of FATA, Dir in Malakand division and Kohistan of Hazara division. From Southeren districts of KPK i.e. Karak na dKohat toward Mianwali of Punjab. Chakwal and Jehlum of Potohar. District Sargodha and Gujrat of Northern Punjab. Hafizabad, Nankana Sahb, Faisalabad, Jhang and Toba Tek Singh and Pak Patan of Central Punjab. Barkhan and Dera Bugti of Baluchistan. Naushwhro Feroz, Dadu and Sukkar of Sindh Province as well.

Table 10 - Habitat suitability comparison of *Cassida exilis* Boh in Pakistan

Suitability	Threshold	Prediction (Km^2)	Prediction (%)
Unsuitability	< 0.2	486043.59	55.08%
Low Suitability	0.2 - 0.4	336253.76	38.11%
Moderate Suitability	0.4 – 0.6	32395.96	3.67%
High Suitability	> 0.6	27669.69	3.14%

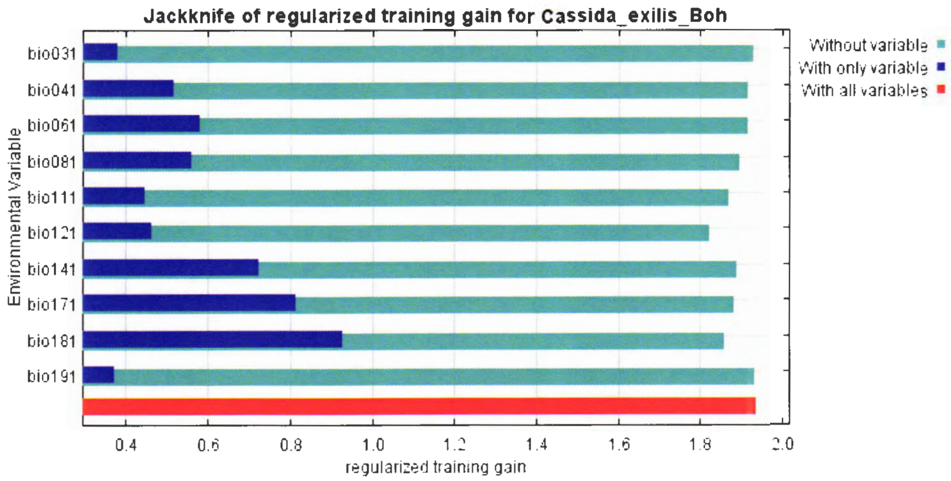


Figure 40 - Jackknife test of regularized training gain for Cassida exilis Boh

As shown in Fig. 4.18, Jackknife test result shows that for distribution of *Cassida exilis* Boh bio 18 (precipitation of warmest quarter), bio 17 (precipitation of driest quarter), bio 14 (precipitation of driest month) and bio 6 (mean temperature of coldest month) are more significant or more contribution variables. Whereas bio 19 (precipitation of the coldest quarter) and bio 3 (isothermally) and bio 11 (mean temperature of coldest quarter) have least contribution in distribution of *Cassida exilis* Boh in Pakistan.

4.10 *Cassida circumdata* herBSt

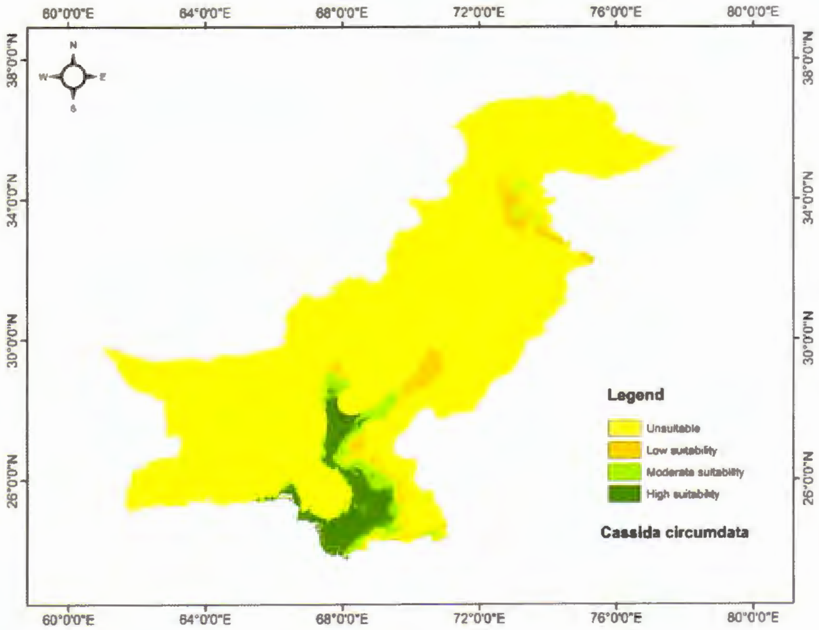


Figure 41 - Predicted geographic distribution map of Cassida circumdata herBSt in Pakistan

As per resulted map of *Cassida circumdata*, highly suitable habitat in Pakistan is mainly in Sindh province with exception of small portions of Lesbela, Jal Magsi and Nasirabad of Baluchistan. In Sindh it ranges from Larkana towards Shikarpur on west and Dadu and Neushahro Feroz on south. It turns towards south west i.e. Nawab Shah, Matriari, Tandu Muhammad Khan, Hyderbad, Mirpurkhas, Tando Allahyar and Badin. The range turn the direction towards east i.e. Thatta and Karachi. Moderately suitable habitat occurs alongside suitable habitat zones in Baluchistan and Sindh. However it reaches to Bolan in Baluchistan and Kashmore in Sindh. Islamabad, Mansehra and Kotli are partially the moderate suitable habitat. Low suitable habitat are areas in Hazara, Potohar, AJK and southern Punjab.

Table 11 – Habitat Suitability Comperision of *Cassida circumdata* in Pakistan

Suitability	**Threshold**	**Prediction (Km²)**	**Prediction (%)**
Unsuitability	< 0.2	579519.10	65.68%
Low Suitability	0.2 - 0.4	228328.92	25.88%
Moderate Suitability	0.4 – 0.6	28563.69	3.24%
High Suitability	> 0.6	45951.29	5.21%

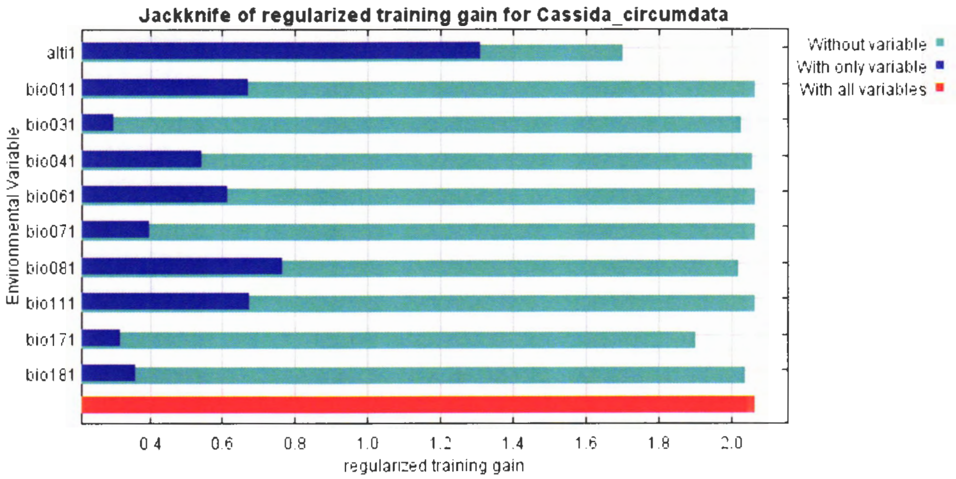


Figure 42 - Jackknife test of regularized training gain for Cassida circumdata

Jackknife test result shows that for distribution of *Cassida circumdata* Altitude, bio 8 (mean temperature of wettest quarter), bio 1 (annual mean temperature), bio 11 (mean temperature of coldest quarter) and bio 6 (minimum temperature of coldest month) are more significant or more contribution variables. Whereas bio 3 (isothermally), bio 17 (precipitation of driest quarter) and 18 (precipitation of warmest quarter) have least contribution in distribution of *Cassida exilis* Boh in Pakistan.

4.11 *Aspidomorpha miliaris* fAB

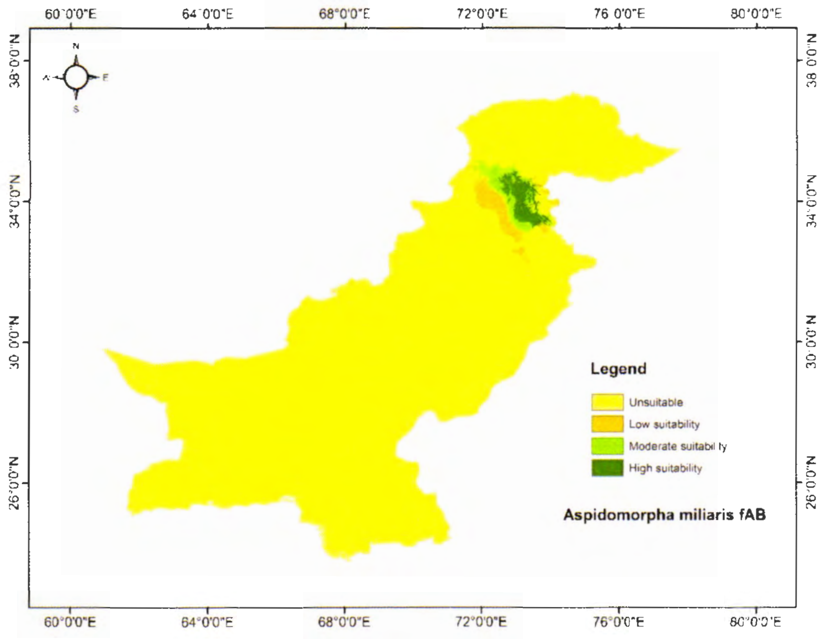


Figure 43 - Predicted geographic distribution map of Aspidomorpha miliaris fAB in Pakistan

Highly suitable habitat for *Aspidomorpha miliaris* in Pakistan is primarily Islamabad and Hazara while partially Malakand division and AJK. The range covers parts of Shangla and Buner, it reach to Batagram and then from Mansehra to Abbottabad in Hazara. It covers some parts of Rawalpindi and expands toward Kotli and then to Muzaffarabad in North. Moderately suitable habitat is Dir and Swat in Malakand division, Haripur in Hazara and somewhat Rawalpindi. Low suitable habitat is from Mardan, Nowshehra and Swabi in Peshawar Valley to some parts of Attock, Rawalpindi and Mirpur in AKJ.

Table 12 - Habitat suitability comparison of *Aspidomorpha miliaris* fAB

Suitability	**Threshold**	**Prediction (Km^2)**	**Prediction (%)**
Unsuitability	< 0.2	778843.70	88.27%
Low Suitability	0.2 - 0.4	84671.18	9.60%
Moderate Suitability	0.4 – 0.6	8745.88	0.99%
High Suitability	> 0.6	10102.24	1.14%

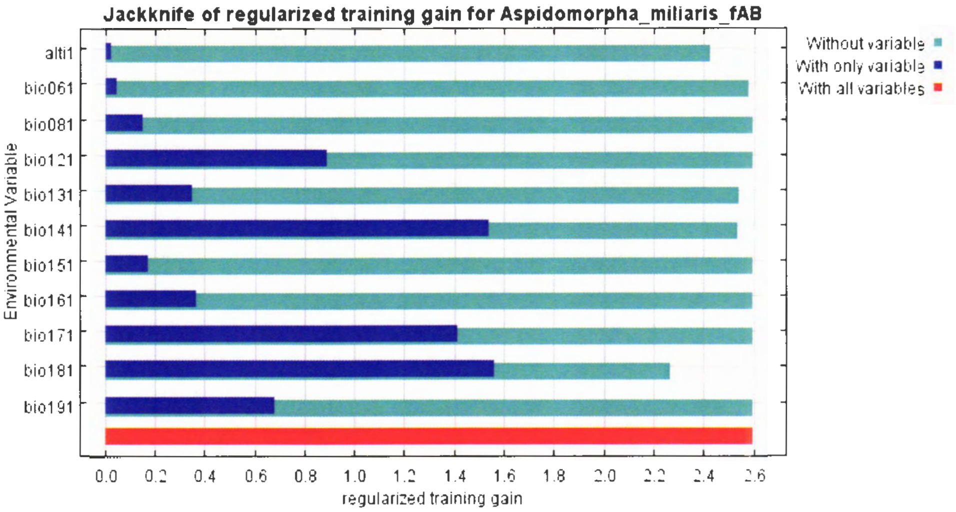


Figure 44 - Jackknife test of regularized training gain for Aspidomorpha miliaris fAB

The relative contribution of bioclimatic variable for distribution of *Aspidomorpha miliaris* fAB through Jackknife test show that 18 (precipitation of warmest quarter), bio 14 (precipitation of driest month), bio 17 (precipitation of driest quarter) and bio 12 (annual precipitation) are more significant variables. Whereas Altitude, bio 6 (minimum temperature of coldest month) and bio 8 (mean temperature of wettest quarter) have least contribution in distribution of *Aspidomorpha miliaris* fAB in Pakistan.

4.12 *Rhytidocassis indicola* duv

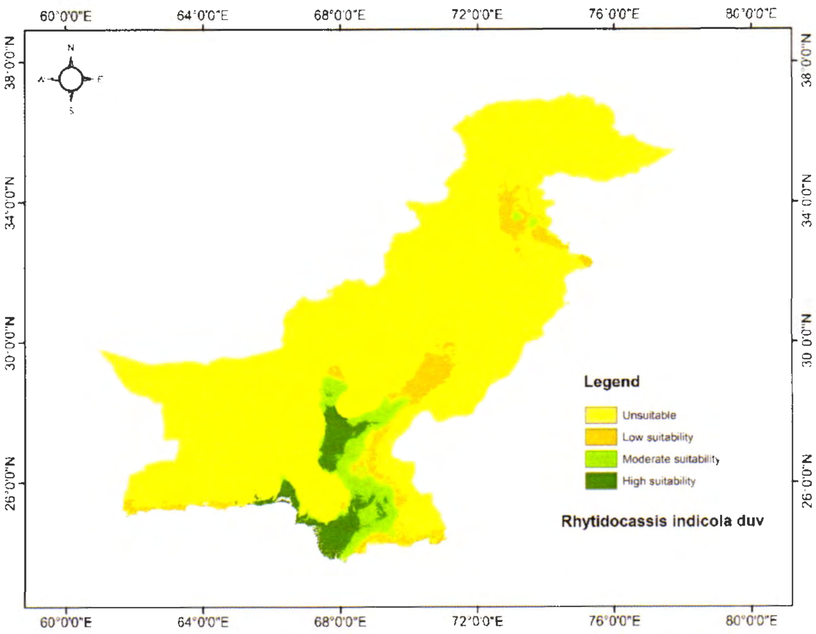


Figure 45 - Predicted geographic distribution map of Rhytidocassis indicola duv *in Pakistan*

As per resulted map of *Rhytidocassis indicola*, highly suitable habitat in Pakistan is mainly in Sindh province. It also includes some parts of Lesbela, Jal Magsi, Nasirabad and Gawadar of Baluchistan. Several districts of Sindh i.e. Larkana Dadu, Neushahro Feroz, Tandu Muhammad Khan, Hyderbad, Mirpurkhas, Thatta and Karachi. Moderately suitable habitat is certain parts of Jalmagsi and Nasirabad in Baluchistan. Shikarpur, Gutki, Kashmore, Nawab Shah, Matriari, Sangar and Badin of Sindh province along with Islamabad and Kotli in AJK. Low suitable habitat is Haripur, Rawalpindi, Mirpur, Bhimbar and Norowal. District of Southern Punjab i.e. Muzaffargarh, Rajanpur and Rahimyar Khan. Khairpur, Umarkot and Mithi of Sindh along with Gawadar of Baluchistan.

Table 13 - Habitat suitability comparison of *Rhytidocassis indicola* duv in Pakistan

Suitability	**Threshold**	**Prediction (Km^2)**	**Prediction (%)**
Unsuitability	< 0.2	528616.72	59.91%
Low Suitability	0.2 - 0.4	278754.69	31.59%
Moderate Suitability	0.4 – 0.6	39687.32	4.50%
High Suitability	> 0.6	35304.26	4.00%

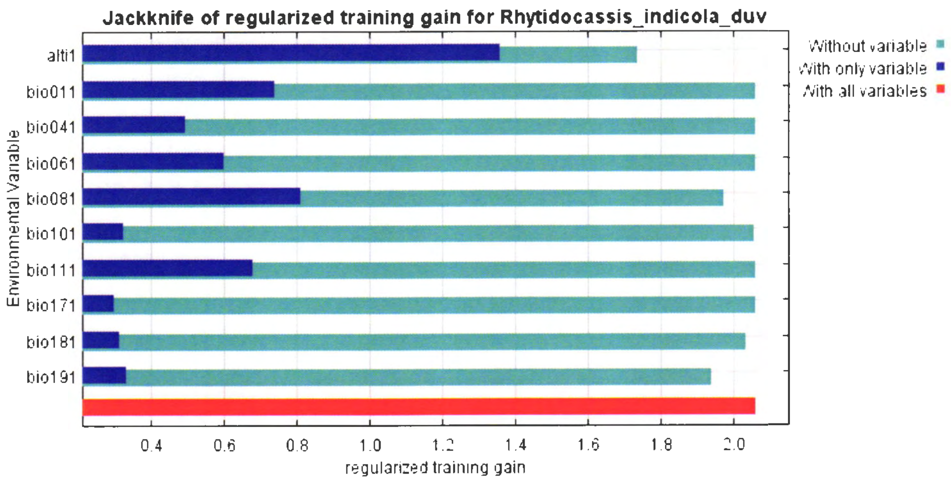


Figure 46 - Jackknife test of regularized training gain for Rhytidocassis indicola duv

The relative contribution of bioclimatic variable for distribution of *Rhytidocassis indicola* duv through Jackknife test show that Altitude, bio 8 (mean temperature of wettest quarter), bio 1 (annual mean temperature), bio 11 (mean temperature of coldest quarter) and bio 6 (minimum temperature of coldest month) are more significant variables. Whereas bio 17 (precipitation of driest quarter), 18 (precipitation of warmest quarter) and bio 19 (precipitation of the coldest quarter) have least contribution in distribution of *Rhytidocassis indicola* duv in Pakistan.

DISCUSSION

The output

By incorporating the occurrence data of reported host plants of Cassidinea beetles from herbarium specimens and online catalogues with bioclimatic data of study area, the resulted maps are with good model fit. The AUC values vary between 0.93 and 0.99. Such models are impressive display of species distribution under current climatic conditions(Elith and Leathwick 2009). The comparisons of various environmental variables through Jacknife tests of MaxEnt give better insight of significantly contributing factors for each individual species. In this regard temperature variation is more significant in distribution of *Cassida circumdata* herBSt. Temperature variations along with altitude are major factors for *Rhytidocassis indicola* duv. Subsequently, precipitation patterns coupled with temperature variations influence the distribution of *Oocassida pudibunda* Boh, *Oocassida cruenta* F and *Cassida exilis* Boh. Furthermore, water availably or precipitation are contributing more in distribution of *Aspidimorpha indica* Boh, *Notsacantha jammuensis*, *Laccoptera nepalensis* Boh, *Glyphocasis trilineata* Hope, *Cassida varians* herBSt, *Cassida nigriventris* Boh and *Aspidomorpha miliaris* fAB.

Uncertainties in Modeling

There always remain chances of commission errors in Ecological Niche Modeling because of not integrating variables like biological interactions i.e. competition and invasion. Such interactions can potentially impose limitations on species distribution (Welk 2004; Loo, Nally et al. 2007). According to (Kadmon, Farber et al. 2003) Ecological Niche Modeling and Species Distribution Modeling result in potential niche/distribution of species while traditional ecological evaluation datasets appraise the realized niche/distribution. Over prediction might also be observed in some cases due to the modeling algorithm upon which our study is based on. As a role of thumb, MaxEnt predicts the distribution of species at unknown locations where environmental conditions are closest to uniform or maximum entropy to the known habitat of species.

Considerations for Future Studies

In current study we relied on occurrence records of reported host plants of Tortoise battles due its sufficient availability in herbarium specimens. An effort for collection of enough occurrence records of Tortoise beetles is recommended for even more precise distribution modeling. The resulted models of this study is based on climate data of WorldClimfor the period 1950 to 2000 and present the current predicted distribution of targeted species. By incorporating the data for the period 2000 to 2050 the future distribution is also desired which will demonstrate the possible changes in distribution due to climate change.

Conclusion

Findings of this study in the form of species distribution models (SMDs) for prediction of ecological niche of 12 selected species is probably the first attempt focused on Cassidinea which is a significant subfamily of leaf beetles. Such models are helpful in identifying areas of concern i.e. their potential utility as biocontrol agents for weeds and adequate management upon their appearance as agricultural pests.

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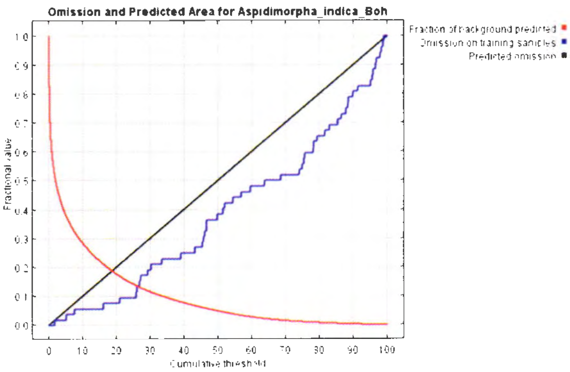
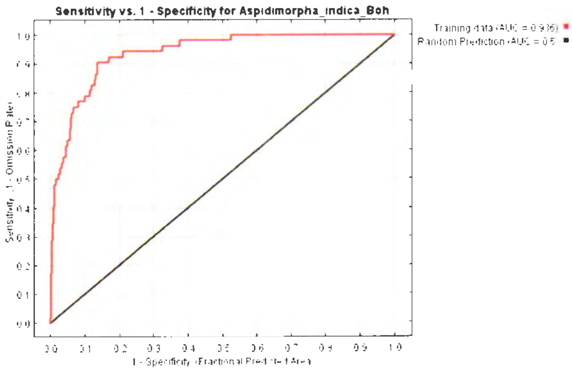
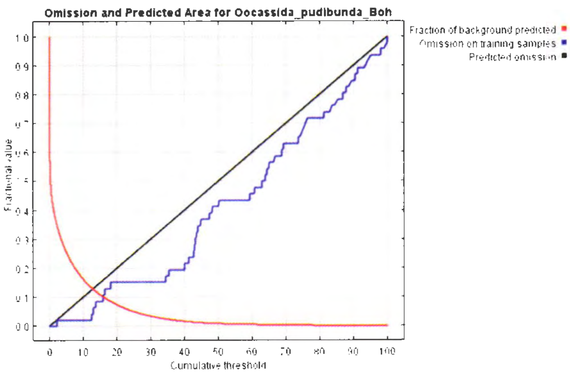
Appendix

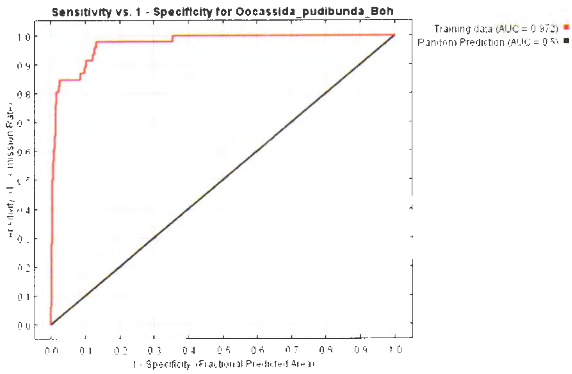




Appendix A. Omission and predicted area for *Aspidimorpha indica* Boh

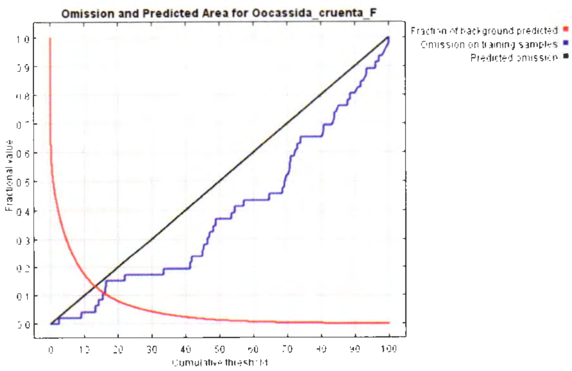
Appendix B. Sensitivity vs. Specificity for *Aspidimorpha indica* Boh

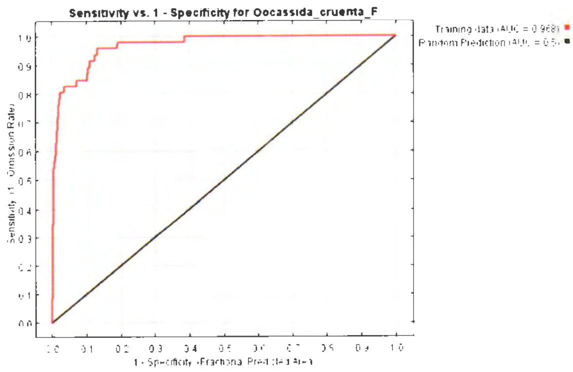




Appendix C. Omission and predicted area for *Oocassida pudibunda* Boh

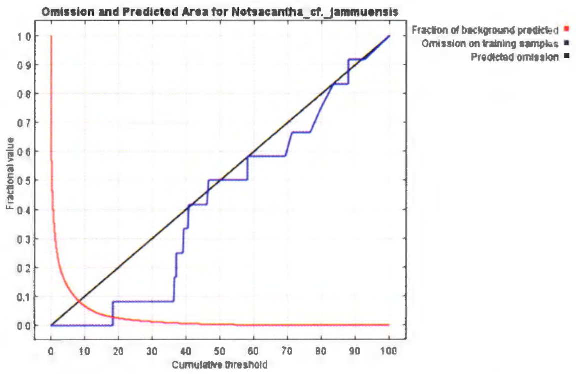
Appendix D. Sensitivity vs. Specificity for *Oocassida pudibunda* Boh



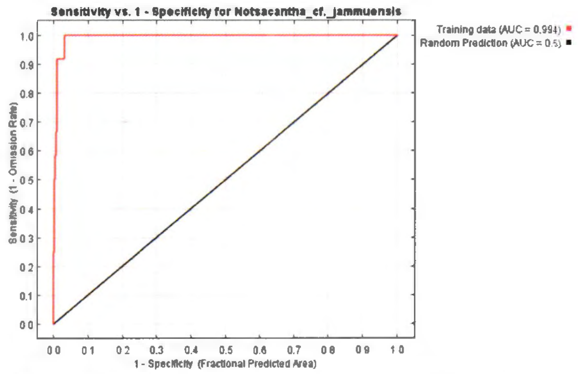


Appendix E. Omission and predicted area for *Oocassida cruenta* F

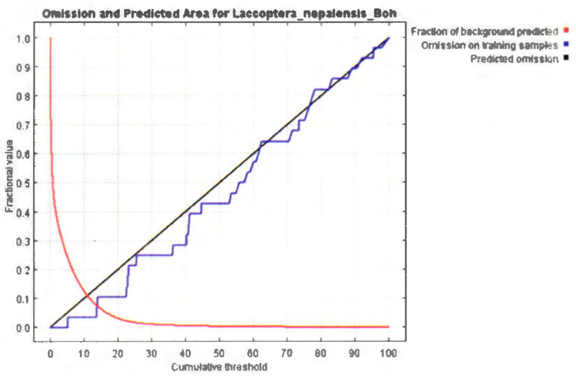
Appendix F. Sensitivity vs. Specificity for *Oocassida cruenta* F



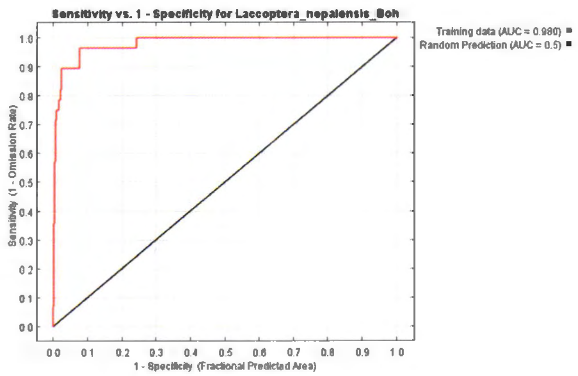
Appendix G. Omission and predicted area for *Notsacantha* cf. *jammuensis*



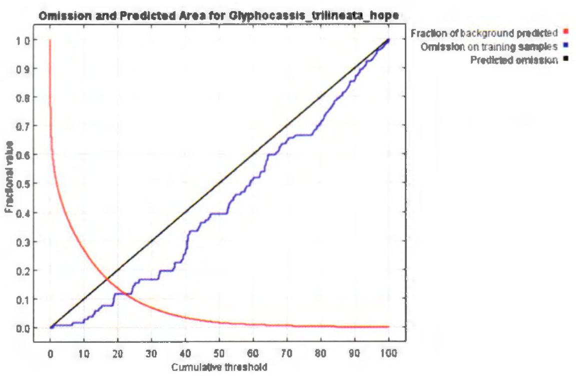
Appendix H. Sensitivity vs. Specificity for *Notsacantha* cf. *jammuensis*



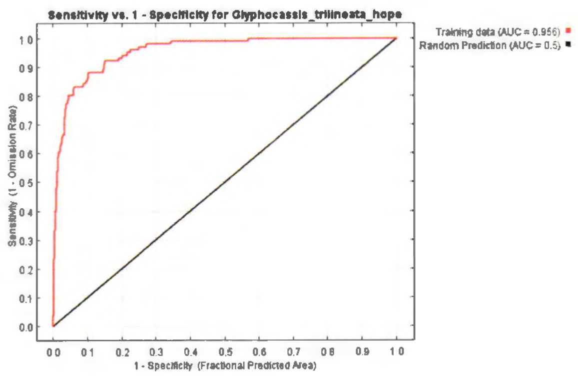
Appendix I. Omission and predicted area for *Laccoptera nepalensis* Boh



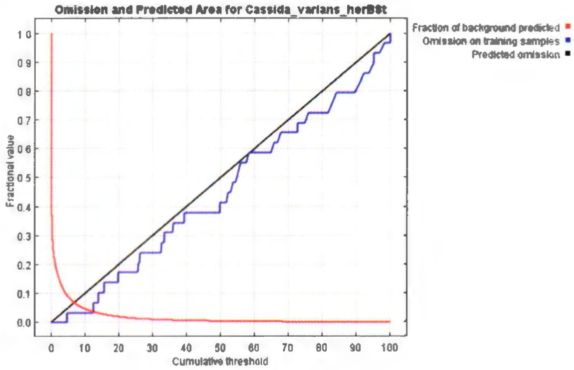
Appendix J. Sensitivity vs. Specificity for *Laccoptera nepalensis* Boh



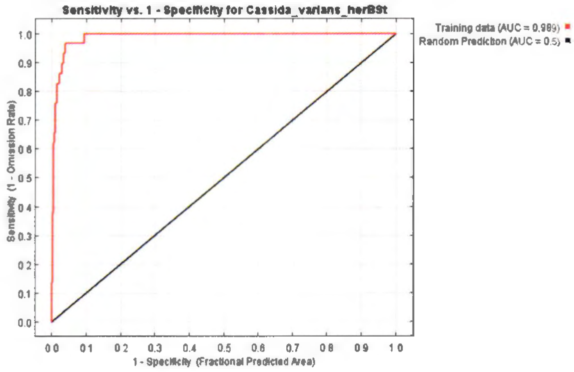
Appendix K. Omission and predicted area for *Glyphocassis trilineata* hope



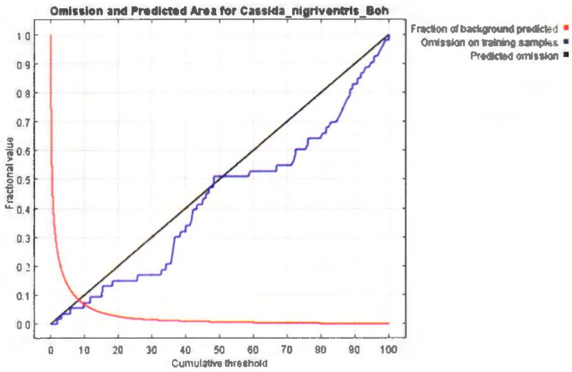
Appendix L. Sensitivity vs. Specificity for *Glyphocassis trilineata* hope



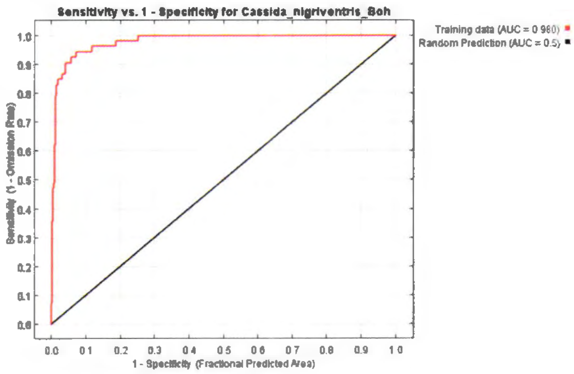
Appendix M. Omission and predicted area for *Cassida varians* herBSt



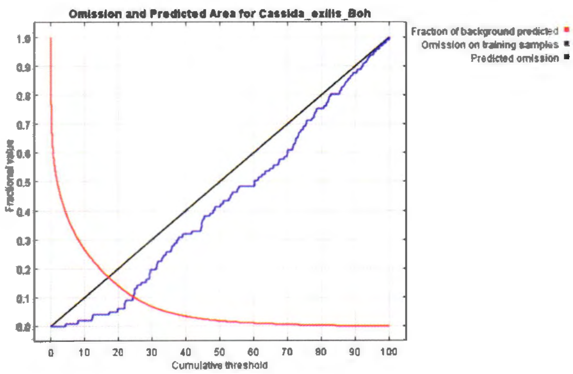
Appendix N. Sensitivity vs. Specificity for *Cassida varians* herBSt



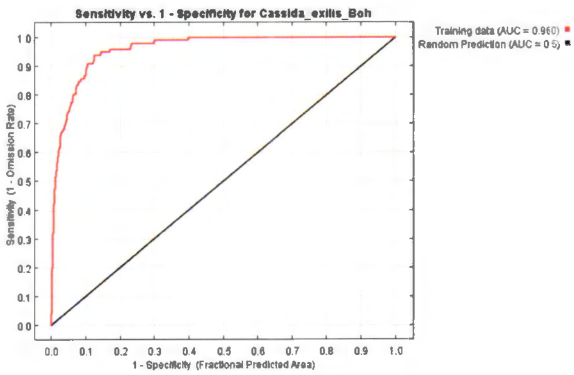
Appendix O. Omission and predicted area for *Cassida nigriventris* Boh



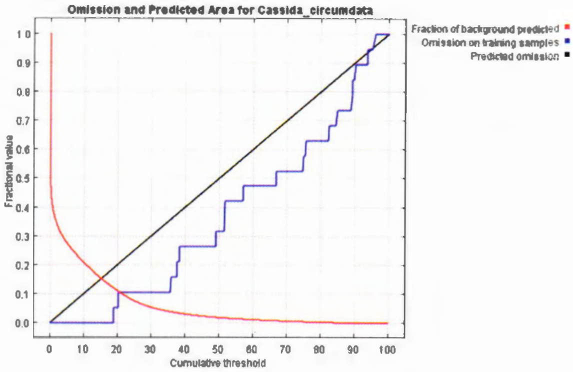
Appendix P. Sensitivity vs. Specificity for *Cassida nigriventris* Boh



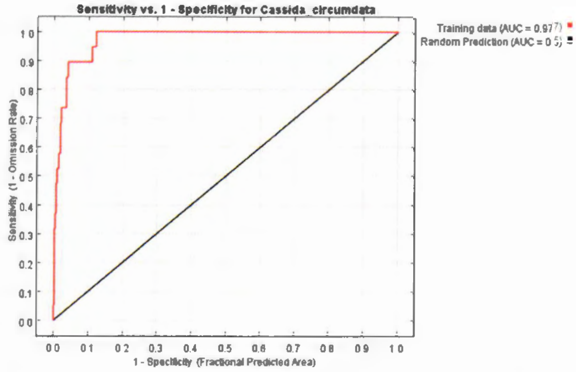
Appendix Q. Omission and predicted area for *Cassida exilis* Boh



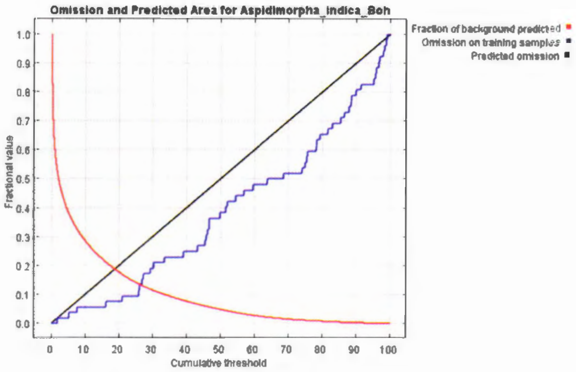
Appendix R. Sensitivity vs. Specificity for *Cassida exilis* Boh



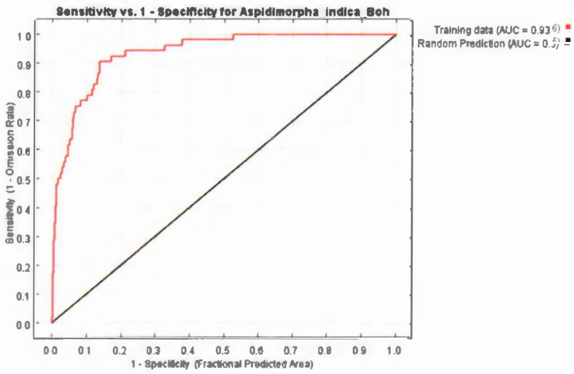
Appendix S. Omission and predicted area for *Cassida circumdata*



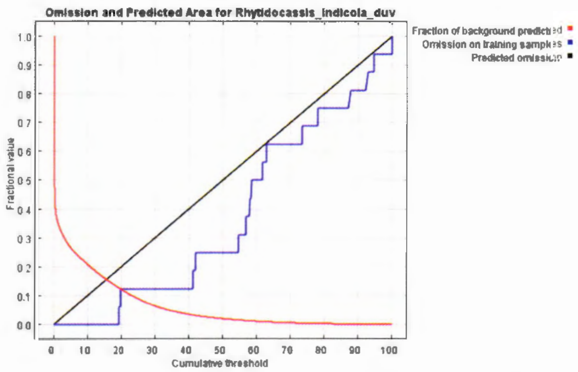
Appendix T. Sensitivity vs. Specificity for *Cassida circumdata*



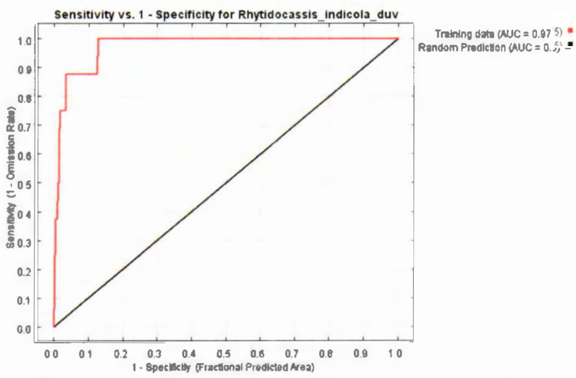
Appendix U. Omission and predicted area for *Aspidimorpha indica* Boh



Appendix V. Sensitivity vs. Specificity for *Aspidimorpha indica* Boh



Appendix X. Omission and predicted area for *Rhytidocassis indicola* duv



Appendix Y. Sensitivity vs. Specificity for *Rhytidocassis indicola* duv

Appendix Z. Analysis of variable contributions *Aspidimorpha indica* Boh

Variable	Percent contribution	Permutation importance
bio171	40.3	47.6
bio141	21.8	1.1
bio011	14.3	14.4
bio181	7.6	14.5
bio161	6.5	9.8
bio151	4.5	3.5
alti1	2.1	8.4
bio191	2.1	0.2
bio041	0.7	0
bio091	0.1	0.3
bio121	0	0.1

Appendix AA. Analysis of variable contributions *Oocassida pudibunda* Boh

Variable	Percent contribution	Permutation importance
bio181	47.4	26.8
alti1	12.6	28.3
bio161	9.6	5.6
bio101	9.1	24.5
bio141	6.6	0.2
bio171	4.6	9.2
bio051	4.5	0.2
bio081	3.7	0.3
bio011	1.2	5
bio061	0.7	0

Appendix AB. Analysis of variable contributions *Oocassida cruenta* F

Variable	Percent contribution	Permutation importance
bio181	50.2	13.5
alti1	13.1	35
bio101	9.7	33.6
bio141	9.2	1.8
bio081	6.1	2.6
bio051	5.4	0
bio191	3.1	2.7
bio061	1.6	3.1
bio011	1.5	7.8
bio041	0.1	0

Appendix AC. Analysis of variable contributions *Notsacantha* cf. *jammuensis*

Variable	Percent contribution	Permutation importance
bio141	67.8	2.5
alti1	14.2	29.5
bio181	12	0.2
bio061	2.4	66.8
bio021	2.1	0
bio091	1.4	1
bio171	0.1	0
bio191	0	0
bio121	0	0
bio011	0	0

Appendix AD. Analysis of variable contributions *Laccoptera nepalensis* Boh

Variable	Percent contribution	Permutation importance
bio181	47.8	45.9
bio141	32.2	8.1
bio161	6.5	0
alti1	6.1	21.2
bio081	5.2	2.5
bio131	1.9	17.3
bio111	0.2	5
bio191	0	0
bio121	0	0
bio171	0	0
bio061	0	0

Appendix AE. Analysis of variable contributions *Glyphocassis trilineata* hope

Variable	Percent contribution	Permutation importance
bio181	29.9	33.5
bio171	20.3	36.8
bio141	18.7	5.2
bio161	8.9	8.1
bio061	8.6	3.8
bio111	7.5	6.8
bio131	2.2	1.3
bio191	1.9	0.6
bio121	1.4	0.8
bio091	0.7	3

Appendix AF. Analysis of variable contributions *Cassida varians* herBSt

Variable	Percent contribution	Permutation importance
bio181	54.6	0.8
bio141	24.1	3.6
bio081	10.9	40.4
bio161	3.5	1.6
bio111	2.9	0
bio131	1.7	1.2
bio061	1.1	52
bio171	0.9	0
bio191	0.2	0.5
bio121	0	0

Appendix AG. Analysis of variable contributions *Cassida nigriventris* Boh

Variable	Percent contribution	Permutation importance
bio141	44.2	0.2
bio181	36.7	15.5
bio081	9.8	39.4
bio161	4.4	5.6
bio041	3.1	0.7
bio191	1	5.2
bio171	0.3	29.3
bio121	0.3	0.1
bio091	0.2	3.5
bio131	0	0.4

Appendix AH. Analysis of variable contributions *Cassida exilis* Boh

Variable	Percent contribution	Permutation importance
bio181	25.7	14
bio081	14.6	4.8
bio141	14.6	8.6
bio171	12.4	42.2
bio061	8.1	14.9
bio041	6.8	0.8
bio111	5.9	6.3
bio121	5.8	7.4
bio031	5.2	0.6
bio191	0.8	0.3

Appendix AI. Analysis of variable contributions *Cassida circumdata*

Variable	Percent contribution	Permutation importance
alti1	62	58.9
bio171	20.3	12.8
bio181	5.8	6.7
bio081	3.4	20.5
bio011	3.2	0.4
bio031	2.7	0.4
bio041	1.3	0.5
bio061	1.2	0
bio071	0	0
bio111	0	0

Appendix AJ. Analysis of variable contributions *Aspidimorpha indica* Boh

Variable	Percent contribution	Permutation importance
bio141	48.7	4.5
bio181	36.2	83.4
alti1	7.8	5.1
bio131	4.7	2.7
bio081	2.1	0
bio061	0.4	4.4
bio151	0	0
bio161	0	0
bio191	0	0
bio121	0	0
bio171	0	0

Appendix AK. Analysis of variable contributions *Rhytidocassis indicola* duv

Variable	Percent contribution	Permutation importance
bio171	40.3	47.6
bio141	21.8	1.1
bio011	14.3	14.4
bio181	7.6	14.5
bio161	6.5	9.8
bio151	4.5	3.5
alti1	2.1	8.4
bio191	2.1	0.2
bio041	0.7	0
bio091	0.1	0.3
bio121	0	0.1