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# Estimation of the Relation among Micro -habitat parameters and Parasites Growth Using Multivariate Quadratic Surface Based Function

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## Abstract

Distribution models have always provided researchers an innovative tool to explore diverse questions in ecology, evolution, and conservation. Prediction and mapping of potential suitable habitat for threatened and endangered species is critical for monitoring and restoration of their declining native populations in their natural habitat, artificial introductions, or selecting conservation sites, and conservation and management of their native habitat. Predictive modelling of species distributions now represents an important tool in biogeography, evolution, ecology, conservation, and invasive-species management. During the present study 02 species of *Viscum*, i.e., *V. album* and V. *articulatum* growing as hemi-parasitic stem parasite on 04 tree species has been documented in Kellar forest range in NW Himalaya, India. Out of two stem hemi-parasites *V. articulatum* has been found only on 01 phorophyte i.e. *Quercus baloot*, however *V. album* is specific to *Salix alba*, *Juglans regia* and *Prunus armeniaca*. In this research paper investigation was carried out to use the different micro-habitat parameters for predicting the occurrence of parasites on a particular.

**Keywords:** Predective modelling; *Viscum*; NW- Himalaya; Kellar forest range; Phorophytes; Hemi-parasite

## Introduction

Detailed knowledge of species ecological and geographic distributions is fundamental requirement for conservation planning, forecasting and understanding ecological and evolutionary determinants of spatial patterns of biodiversity [8,32,57,58,59]. However, occurrence data for the vast majority of species are sparse and therefore inadequate for many applications. Species Distribution Models (SDM) attempt to provide detailed predictions of distributions by relating presence or absence data. Such models have been already used to study relationships between environmental parameters and species richness [44], characteristics and spatial configuration of habitats that allow persistence of species in landscapes [2,25,61], invasive potential of non-native species (Peterson, 2003; Goolsby, 2004), distribution of species in past [39,53], future climates [2,6,63,68,69] and ecological as well as geographic differentiation of the distributions of closely-related species [20,31].

Predictive modelling of species distributions now represents an important tool in biogeography, evolution, ecology, conservation and invasive species management [13,16,17,19,21,26,42,50,52,62,70,71]. These approaches combine occurrence data with ecological/environmental variables (both biotic and abiotic factors) to create a model for the basic requirements of species. Primary occurrence data exist in the form of georeferenced coordinates of latitude and longitude for confirmed localities that typically derive from vouchered museum or herbarium specimens [5,27,55,65]. Absence data are rarely available, especially in poorly sampled tropical regions where modelling may hold greatest value [1,64]. The environmental variables typically examined in such modelling efforts encompass only relatively few of the possible ecological-niche dimensions [41]. Nevertheless, currently available digital environmental coverage (digitized computer maps) provides many variables that commonly influence macro-distributions of the species [34].

Prediction and mapping of potential suitable habitat for threatened and endangered species is critical for monitoring, restoration in their natural habitat, artificial introductions, selecting conservation sites and management of their native habitat [28]. Therefore, mathematical models have been developed to solve many related ecological problems. These models are mostly based on presence and absence data of the species. But distribution data on threatened and endangered species are often sparse and clustered making commonly used habitat modelling approaches difficult [24,25]. Much conservation management policies are focused on species and habitats.




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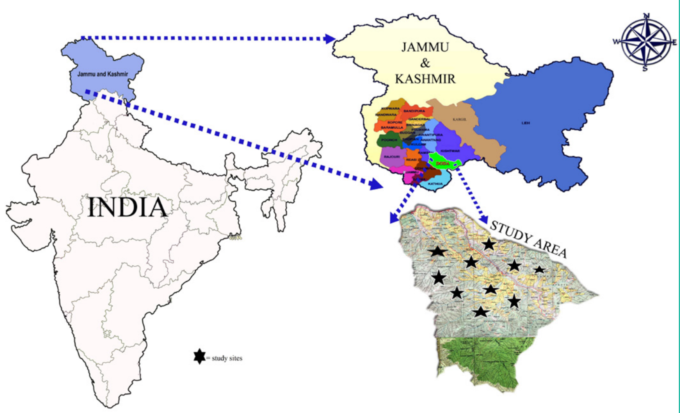


**Figure 1:** Geographical location of study area (Kellar forest range).

Now-a-days the prime concern of ecologists is to identify the possible impacts of climate change on species [38]. According to the panel the regional changes in temperature have already affected a range of physical and biological systems around the world. The existing data along with the projected future changes could have a profound effect on all aspects of species and habitat functioning and distribution [18,60]. Therefore, it is important to anticipate such changes for appropriate adaptation of the species [36]. Developing models to assess the potential impacts of climate change on individual species distributions is comparatively easy A number of researchers have used climate envelopes to model the distribution of suitable climate space for individual species [10,12,40,66,67].

Although, lot of work has been done on the SDM, using different algorithms based on the presence and absence data of the species. In the present research communication a simple algorithm is developed for quadratic relation of microhabitat parameters for predicting the number (colonies) of parasites (*Viscum album* L. *and Viscum articulatum* Pohl. ex. DC.) on their respective phorophytes.

## Materials and Methods

**Study area and materials**: Geographical area flanked between E 75°33′24.92″ to N33° 08′15.99″ and E 75°31′09.41″ to N33° 01′43.44″ and divided in two parts by a perennial stream called as Neeru in Lesser Himalayan strata of northwestern Himalaya has been chosen for the data collection on microhabitat parameters of two species of *Viscum* i.e. *Viscum album and Viscum articulatum* (Figure 1). The study area comprises 24 tree species out of which 04 species are recorded as the phorophytes of *Viscum* (Table 1). *V. album* is recorded on *Salix alba* L., *Prunus armeniaca* L. and *Juglans regia* L. however *V. articulatum* was restricted to *Quercus baloot* Griff. only in the study area.

**Sampling:** Ten random quadrates of 10m$^2$ at 10 different sites have been plotted after the detailed survey of 03 months in the study area (Figure 1 & Table 2). The criterion of the selection of the sites was the presence of both the species of *Viscum* on the phorophytes. At each quadrate, data for 06 different parameters *vis-à-vis* name of phorophyte (w1), circumference at breast height (cbh) of phorophyte (w2), mountain aspect (w3), bark pH(w4), water holding capacity (WHC) of bark (w5), and phenolic contents of bark (w6) has been collected (Table 3). For parameters coded as w4, w5 and w6, bark has been peeled off from each phorophyte and carried separately in sealed collection bags to the Ecology Laboratory at Department of Botany, University of Jammu, India for further analysis. Bark pH has been determined as per the procedure proposed by Bates (2008), water holding capacity of bark has been determined

**Table 1:** Tree species and available phorophytes for *Viscum album* and *Viscum articulatum* in the study area.

| S. No. | Name of the tree species | Family |
|---|---|---|
| 1 | *Alnus nitida* Endl. | Betulaceae |
| 2 | *Cedrus deodara* Loudon # | Coniferaceae |
| 3 | *Cydonia oblanga* Mill. | Rosaceae |
| 4 | *Dalbergia sisoo* L.F. | Fabaceae |
| 5 | *Ficus palmate* Forssk. | Moraceae |
| 6 | *Juglans regia* L. * | Juglandaceae |
| 7 | *Melia azedarach* L. | Meliaceae |
| 8 | *Olea caspidata* L. | Oleaceae |
| 9 | *Pinus roxburghii* Sarg. # | Coniferaceae |
| 10 | *Pinus wallichiana* A.B.Jacks. # | Coniferaceae |
| 11 | *Platanus indica* L. | Platanaceae |
| 12 | *Populus ciliata* L. | Salicaceae |
| 13 | *Prunus armeniaca* L. * | Rosaceae |
| 14 | *Prunus persica* A.B.Jacks. | Rosaceae |
| 15 | *Punica granatum* L. | Lythraceae |
| 16 | *Pyrus malus* L. | Rosaceae |
| 17 | *Pyrus pashia* L. | Rosaceae |
| 18 | *Q. floribunda* Wall. | Fagaceae |
| 19 | *Q.semicarpifolia* L. | Fagaceae |
| 20 | *Quercus baloot* Griff. * | Fagaceae |
| 21 | *Salix alba* L. * | Salicaceae |
| 22 | *Tectona grandis* L.F. | Lamiaceae |
| 23 | *Trema politra* L. | Ulmaceae |
| 24 | *Viburnum grandiflora* L. | Caprifoliaceae |

* Phorophytes of *Viscum album* and *Viscum articulatum; # Gymnosperms*

**Table 2:** Study sites with geographical (GPS) co-ordinates.

| Study sites | Geographical co-ordinates | Elevation (masl) |
|---|---|---|
| I | N-33° 05.477′ & E-075° 33.93′ to N-33° 05.484′ & E- 075° 33.963′ and N-33° 05.477′ & E-075° 33.993′ to N- 33° 05.496′ & E- 075° 33.975 | **1767** |
| II | N- 33° 04·771′ & E- 075° 34.673′ to N 33° 04.783′ & E- 075° 34.698′ and N- 33° 04·830′ & E- 075° 34′.694′ to N- 33° 04.844′ & E- 075° 34 .714′. | **1666** |
| III | N-33° 02.203′ & E- 075° 35.495′ to N – 33° 02.216′ & E- 075° 35.498′ and N- 33° 02 .203′ & E- 075° 35.914′ to N-33° 02.219′ & E 075° 35.921′ | **1621** |
| IV | N- 33° 02 .681′ & E- 075° 36 .285′ to N- 33° 02 .711′ & E-075° 36 .311′ and N- 33° 02. 683′ & E-075° 36 .311′ to N-33° 02. 694′ & E- 075° 36. 319′. | **1571** |
| V | N- 33° 01 .549′ & E- 075° 36 .261′ to N – 33° 01. 557′ & E – 075° 36. 250 and N- 33° 01.562′ & E- 075° 36.287′ to N- 33° 01′. 578 & E- 075° 36. 281′ | **1629** |
| VI | N-33° 03. 008′ & E- 075° 39.510′ to N- 33° 02 .989′ & E- 075° 39 .507′ and N- 33° 02. 999 ′& E- 075° 39. 504′ to N- 33° 02. 989′ & E- 075° 39.489′ | **1448** |
| VII | N-33° 05.714′ & E-075° 35.725′ to N -33° 05.734′ & E– 075° 35 .734′ and N– 33° 05. 805′ & E– 075° 35 . 816′to N- 33° 05. 815′& E- 075° 35.826′ | **1470** |
| VIII | N-33° 06.191′ & E- 075° 35.578′ to N- 33° 06.286′ E- 075° 35.659′ and N-33° 06.303′ & E- 075° 35.743′ to N- 33° 06.312′ 7 E- 075° 35·701′ | **1679** |
| IX | N- 33° 01·274′ & E- 075° 36.939′ to N- 33° 01.262′ & E-075° 36.948′ and N-33° 01.250′ &E- 075° 36.998′ to N-33° 01.242′ & E- 075° 36.968′ | **1699** |
| X | N– 33° 04.473′ & E- 075° 35.773′ to N- 33° 04.487′ & E–075° 35 .786′ and N- 33° 04.569 ′& E– 075° 35. 896 ′to N- 33° 04.581′ & E- 075° 35.993′ | **1644** |

as per Bermudez (2000) while Negi *et al*., (2012) has been followed to determine the phenolic contents of the bark of each sample.

To predict the growth and number of colonies of the parasites, Multivariate Quadratic Surface Fitting (MQSF) algorithm has been developed using MATLAB and data of 06 aforesaid parameters.

**MQSF:** A multidimensional function $g(w_1, w_2, w_3, w_4, w_5, w_6)$ is known only at q points, therefore, a quadratic surface $f(w_1, w_2, w_3, w_4, w_5, w_6)$ can be constructed such that it approximates the given function within some error $e(w_1, w_2, w_3, w_4, w_5, w_6)$ at each point. (Philips, 2003; Dyer and Dyer, 2001; Yom- Tov and Kadmon, 1998).

Mathematically:

$$g({}^sw_1, {}^sw_2, {}^sw_3, {}^sw_4, {}^sw_5, {}^sw_6) = f({}^sw_1, {}^sw_2, {}^sw_3, {}^sw_4, {}^sw_5, {}^sw_6) + e({}^sw_1, {}^sw_2, {}^sw_3, {}^sw_4, {}^sw_5, {}^sw_6)$$
$$where: s = 0,1,2,.....,q-1$$

eqn. 1

The multivariate quadratic surface function can be written as

$$f(w_1, w_2, w_3, w_4, w_5, w_6) = \sum_{i=0}^{p-1} c_i \alpha_i (w_1, w_2, w_3, w_4, w_5, w_6)$$

eqn. 2

where *p* is the number of terms in the quadratic equation formed by *w* variables, $c_i$ represents coefficient of quadratic term *i*, and $\alpha_i(w_1, w_2, w_3, w_4, w_5, w_6)$ represents the term *i* itself.

$$P(c_0,........,c_{p-1}) = \sum_{n=0}^{q-1} \left[ h({}^sw_1, {}^sw_2, {}^sw_3, {}^sw_4, {}^sw_5, {}^sw_6) - b({}^sw_1, {}^sw_2, {}^sw_3, {}^sw_4, {}^sw_5, {}^sw_6; c_0,........,c_{p-1}) \right]^2$$

eqn. 3

Now (1) and (2) can be combined to form the matrix system of equations

$$\mathbf{b} = \mathbf{Az} + \mathrm{e} \quad .4$$

where vectors b, z, and ε are given by

$$\mathbf{b}^T = [g_0 \quad g_1 \quad \cdots \quad g_{q-1}]$$

$$A_{n,k} = \alpha_i({}^sw_1, {}^sw_2, {}^sw_3, {}^sw_4, {}^sw_5, {}^sw_6), 0 \le n \le q-1, 0 \le i \le p-1$$

$$\mathbf{z}^T = [c_0 \quad c_1 \quad \cdots \quad c_{p-1}] \qquad \text{eqn. 5}$$

$$e^T = [e_0 \quad e_1 \quad \cdots \quad e_{q-1}]$$

$$\mathbf{z} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{b} \qquad \text{eqn.6}$$

where $(\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T$ is known as pseudo–inverse of A [14,43].

**Z** is function which depicts the relation between input and output parameters.

## Results

The pattern of host specificity in mistletoes covers a wide spectrum from highly host specific to host generalists [7]. Some mistletoe parasitizes a large number of hosts e.g. *V. album* ssp. *album* parasitizes on more than 450 host species and a few mistletoes like some dwarf mistletoes parasitizes only one host species [8,29]. Some dwarf mistletoes are so host specific that their host specificity is a useful taxonomic tool for distinguishing host populations [37,45. Tree species acting as host of angiospermic parasites are called as phorophytes. During the study, *ca*. 24 tree species are recorded growing in the study area (Table 1 & Figure 1), out of which 03 tree species vis-à-vis *Salix alba* L., *Prunus armenica* Thunb., *Juglans regia* L. are available phorophytes for *V. album,* however, *Quercus baloot* Griff. act as an available phorophyte for *V. articulatum*. Their host specificity in the area has been investigated on 10 study sites of each of 10m$^2$ quadrate (Table 2 & Figure 1), wherein, a total of 24 individuals of the phorophytes including all the four species has been recorded (Table 1). The restricted distribution of the both the species of *Viscum* on few tree species only was the rationale of the study therefore, 06 most relevant microhabitat parameters has been selected to generate the data for further investigation (Table 3).

In case of *Q. baloot* (CBH= 65cm, pH=6.3,WHC=74% , Phe-

**Table 3:** Micro-habitat parameters used in the study.

| | |
|---|---|
| Name (Category) of phorophyte | w1 |
| Circumference at breast height (CBH) of phorophyte | w2 |
| Aspect of the mountain on which phorophyte was found | w3 |
| pH of bark of phorophyte | w4 |
| Water holding capacity (WHC) of bark of phorophyte | w5 |
| Phenolic contents of bark of phorophyte | w6 |

**Table 4:** Data for micro-habitat parameters of *Viscum* species (field data).

| S.No. | Category | CBH | Mountain aspect | pH of bark | WHC of bark (%) | Phenolic content (mg/g GAE) | Colonies of *Viscum* sp. (occurrence) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 35 | 0 | 6.1 | 70 | 38.5 | 19* |
| 2 | 1 | 112 | 0 | 6.1 | 70 | 38.5 | 8* |
| 3 | 1 | 41 | 0 | 6.1 | 70 | 38.5 | 12* |
| 4 | 1 | 62 | 0 | 6.1 | 70 | 38.5 | 10* |
| 5 | 1 | 29 | 0 | 6.1 | 70 | 38.5 | 5* |
| 6 | 1 | 95 | 0 | 6.3 | 70 | 39 | 16* |
| 7 | 1 | 46 | 0 | 6.3 | 70 | 40 | 13* |
| 8 | 1 | 64 | 0 | 6.3 | 74 | 40 | 22* |
| 9 | 1 | 31 | 0 | 6.3 | 74 | 40 | 7* |
| 10 | 1 | 75 | 0 | 6.3 | 74 | 40 | 15* |
| 11 | 1 | 105 | 0 | 6.4 | 74 | 40 | 10* |
| 12 | 1 | 96 | 0 | 6.4 | 74 | 41.5 | 20* |
| 13 | 1 | 62 | 0 | 6.6 | 74 | 41.5 | 18* |
| 14 | 1 | 110 | 0 | 6.6 | 74 | 41.5 | 4* |
| 15 | 1 | 99 | 0 | 6.6 | 76 | 41.5 | 9* |
| 16 | 1 | 86 | 0 | 6.6 | 76 | 41.5 | 14* |
| 17 | 1 | 103 | 0 | 6.7 | 79 | 41.5 | 11* |
| 18 | 1 | 87 | 1 | 6.7 | 79 | 41.5 | 12* |
| 19 | 1 | 76 | 1 | 6.7 | 79 | 41.5 | 7* |
| 20 | 1 | 91 | 1 | 6.7 | 79 | 41.5 | 10* |
| 21 | 2 | 90 | 4 | 4.6 | 65 | 36 | 7# |
| 22 | 2 | 101 | 4 | 4.6 | 65 | 36 | 11# |
| 23 | 2 | 91 | 4 | 4.6 | 65 | 36 | 15# |
| 24 | 2 | 96 | 0 | 4.6 | 65 | 36.5 | 10# |
| 25 | 2 | 120 | 0 | 4.8 | 65 | 36.5 | 12# |
| 26 | 2 | 90 | 1 | 4.8 | 68 | 37.5 | 4# |
| 27 | 2 | 81 | 1 | 5.3 | 68 | 37.5 | 9# |
| 28 | 2 | 109 | 1 | 5.4 | 74 | 37.5 | 19# |
| 29 | 2 | 111 | 1 | 5.8 | 74 | 37.5 | 25# |
| 30 | 2 | 98 | 1 | 5.8 | 74 | 37.5 | 5# |
| 31 | 2 | 105 | 1 | 5.8 | 74 | 37.5 | 9# |
| 32 | 3 | 125 | 0 | 5.4 | 73 | 34.5 | 49# |
| 33 | 3 | 106 | 0 | 5.4 | 73 | 34.5 | 23# |
| 34 | 3 | 88 | 1 | 5.4 | 73 | 35 | 17# |
| 35 | 3 | 101 | 1 | 5.8 | 78 | 35 | 14# |
| 36 | 3 | 102 | 2 | 6.1 | 80 | 35 | 12# |
| 37 | 3 | 112 | 2 | 6.1 | 80 | 35 | 18# |
| 38 | 4 | 96 | 0 | 5.7 | 67 | 36.5 | 4# |
| 39 | 4 | 118 | 1 | 6.1 | 77 | 36.5 | 4# |

Category 1= *Quercus baloot*; 2= *Prunus armeniaca*, 3= *Juglans regia*, 4= *Salix alba;* CBH= circumference at breast height; Aspect 0= eastern, 1= western, 2= northern, 3= southern and 4= zero aspect; WHC= water holding capacity; * = *Viscum articulatum, # = V. album.*

nolic content =40.0mg/g) growing on the eastern aspect (i.e. 0) of the mountain in the study area has accommodated the maximum number of hemi-parasite colonies i.e *V. articulatum* (n=22) in study area, whereas, minimum colonies (n=4) have been recorded on the phorophyte (*Q. baloot*) with CBH=110cm , pH=6.5,WHC=74% , phenolic content =41.4mg/g on the same mountain aspect. This indicates that only single micro-habitat parameter do not influence much on the occurrence of *V. articulatum* colonies. Similar observations are made when further explorations were conducted on another species of hemi-parasite i.e. *V. album* parasitizing on *P. armeniaca*. Individual phorophyte with CBH=111cm, pH=5.8, WHC=74%, Phenolic content =37.5mg/g growing on western aspect of the mountain in the study area had accommodated 25 colonies of the hemi-parasite. Minimum colonies (n=04) of *V. album* has been recorded on *P. armeniaca* individuals with CBH= 90cm, pH=4.4, WHC=64%, phenolic content =37.5mg/g growing at the same mountain aspect. As per the field data maximum number of colonies of *V. album* has been recorded on *J. regia* with CBH=125cm, bark pH=5.4. bark WHC=73 and bark phenolic contents =36.5 growing at eastern aspect of the mountain. This indicates that older individuals of *J. regia* (CBH= 125cm) are excellent phorophytes for the occurrence of the *V. album,* however, each microhabitat parameter may influence the occurrence of the parasite colonies like CBH, mountain aspect, pH, WHC or phenolic contents (Table 4). Further, the individuals of *S. alba* growing on the eastern and western aspect of the mountain in the study area also execute the same phenomenon (Table 4). This indicates that this is not a single microhabitat parameter but amalgam of two or more parameters responsible for the presence and number of colonies of hemiparasite on the trees species. Therefore, the quadratic relation of the micro-habitat parameters has been estimated on the principle given below:

**Estimation of The Quadratic Relation**

Different coded micro-habitat parameters (Table 3) were used to estimate the number of parasites colonies on the basis of quadratic relation between them as below:

$$\begin{aligned}(w_1+w_2+w_3+w_4+w_5+w_6)^2 &= c_0+c_1w_1+c_2w_2+c_3w_3+c_4w_4+c_5w_5+c_6w_6\\ &+c_7w_1^2+c_8w_2^2+c_9w_3^2+c_{10}w_4^2+c_{11}w_5^2+c_{12}w_6^2\\ &+c_{13}w_1w_2+c_{14}w_1w_3+c_{15}w_1w_4+c_{16}w_1w_5+c_{17}w_1w_6\\ &+c_{18}w_2w_3+c_{19}w_2w_4+c_{20}w_2w_5+c_{21}w_2w_6+c_{22}w_3w_4\\ &+c_{23}w_3w_5+c_{24}w_3w_6+c_{25}w_4w_5+c_{26}w_4w_6+c_{27}w_5w_6\end{aligned} \quad \text{eqn. 7}$$

where C0, C1...........C27 are the coefficients

## Discussion

The study assumes that the number of the colonies of hemiparasite on its respective phorophyte depends upon amalgam of two or more micro-habitat parameters. An important ecological characteristic of mistletoes is their degree of host specificity, which is a composite measure of a number of host species parasitized by mistletoes and the relative abundance of parasite on their hosts [46]. The majority of mistletoe species are host-generalists but still show preference for a particular host. Therefore, it can be concluded that extreme host specialization is rare in mistletoes. The degree of host specificity depends upon the scale of observations [33]. Zuber and Widmer (2001) while working on host specificity has also tried to explore the molecular evidences for host specificity, but no significant results were obtained except a little variation in the nuclear ribosomal DNA (nrDNA), ITS sequence and partial sequences of three non-coding chloroplast DNA (cpDNA) within the host of *V. album*. Study on parasites offer many opportunities to under

**Table 5:** Prediction of occurrence of colonies of *Viscum* species on their respective phorophytes using MQSF algorithm on simulated data.

| ***Quercus baloot*** **( category 1)** | | | | | | |
|---|---|---|---|---|---|---|
| **Category** | **CBH** | **Mountain aspect** | **pH of bark** | **WHC of bark (%)** | **Phenolic content (mg/g GAE)** | **Colonies of *Viscum* sp. (occurrence)** |
| 1 | 48 | 1 | 6.7 | 79 | 41.5 | 14.947* |
| 1 | 50 | 1 | 6.7 | 79 | 41.5 | 14.923* |
| 1 | 63 | 1 | 6.7 | 79 | 41.5 | 14.04* |
| 1 | 66 | 1 | 6.7 | 79 | 41.5 | 13.658* |
| 1 | 78 | 1 | 6.7 | 79 | 41.5 | 11.461* |
| 1 | 87 | 1 | 6.7 | 79 | 41.5 | 9.111* |
| 1 | 101 | 1 | 6.7 | 79 | 41.5 | 4.2587* |
| 1 | 113 | 1 | 6.7 | 79 | 41.5 | 0* |
| 1 | 136 | 1 | 6.7 | 79 | 41.5 | 0* |
| 1 | 145 | 1 | 6.7 | 79 | 41.5 | 0* |
| 1 | 160 | 1 | 6.7 | 79 | 41.5 | 0* |
| 1 | 87 | 0 | 6.7 | 79 | 41.5 | 13.69* |
| 1 | 87 | 0 | 6.7 | 79 | 41.5 | 13.69* |
| 1 | 87 | 1 | 6.7 | 79 | 41.5 | 9.111* |
| 1 | 87 | 1 | 6.7 | 79 | 41.5 | 9.111* |
| 1 | 87 | 1 | 6.7 | 79 | 41.5 | 9.111* |
| 1 | 87 | 1 | 6.7 | 79 | 41.5 | 9.111* |
| 1 | 87 | 1 | 6.7 | 79 | 41.5 | 9.111* |
| 1 | 87 | 2 | 6.7 | 79 | 41.5 | 13.321* |
| 1 | 87 | 2 | 6.7 | 79 | 41.5 | 13.321* |
| 1 | 87 | 4 | 6.7 | 79 | 41.5 | 48.11* |
| 1 | 87 | 4 | 6.7 | 79 | 41.5 | 48.11* |
| 1 | 87 | 1 | 3.6 | 79 | 41.5 | 73.869* |
| 1 | 87 | 1 | 4.1 | 79 | 41.5 | 14.955* |
| 1 | 87 | 1 | 4.6 | 79 | 41.5 | 0* |
| 1 | 87 | 1 | 5.1 | 79 | 41.5 | 0* |
| 1 | 87 | 1 | 5.2 | 79 | 41.5 | 0* |
| 1 | 87 | 1 | 5.9 | 79 | 41.5 | 0* |
| 1 | 87 | 1 | 6.2 | 79 | 41.5 | 0* |
| 1 | 87 | 1 | 7.1 | 79 | 41.5 | 52.952* |
| 1 | 87 | 1 | 7.4 | 79 | 41.5 | 93.663* |
| 1 | 87 | 1 | 7.8 | 79 | 41.5 | 158.38* |
| 1 | 87 | 1 | 8.5 | 79 | 41.5 | 300.35* |
| 1 | 87 | 1 | 6.7 | 60 | 41.5 | 451.36* |
| 1 | 87 | 1 | 6.7 | 65 | 41.5 | 295.63* |
| 1 | 87 | 1 | 6.7 | 68 | 41.5 | 215.69* |
| 1 | 87 | 1 | 6.7 | 70 | 41.5 | 168.01* |
| 1 | 87 | 1 | 6.7 | 72 | 41.5 | 124.83* |
| 1 | 87 | 1 | 6.7 | 73 | 41.5 | 104.93* |
| 1 | 87 | 1 | 6.7 | 75 | 41.5 | 68.492* |
| 1 | 87 | 1 | 6.7 | 78 | 41.5 | 22.27* |
| 1 | 87 | 1 | 6.7 | 80 | 41.5 | 0* |
| 1 | 87 | 1 | 6.7 | 82 | 41.5 | 0* |
| 1 | 87 | 1 | 6.7 | 84 | 41.5 | 0* |
| 1 | 87 | 1 | 6.7 | 79 | 28.5 | 1499.8* |
| 1 | 87 | 1 | 6.7 | 79 | 29.5 | 1304.1* |
| 1 | 87 | 1 | 6.7 | 79 | 32.1 | 858.34* |
| 1 | 87 | 1 | 6.7 | 79 | 33.5 | 656.18* |
| 1 | 87 | 1 | 6.7 | 79 | 35.5 | 413.33* |
| 1 | 87 | 1 | 6.7 | 79 | 40 | 64.556* |
| 1 | 87 | 1 | 6.7 | 79 | 43.5 | 0* |
| 1 | 87 | 1 | 6.7 | 79 | 44.5 | 0* |

stand degree of specificity and transmission capacities in term of species ecological and evolutionary dynamics [48]. Ecology of mistletoes has opened many areas of research to understand plant parasitism and species distributions at multiple spatial scales. Mistletoes are vector borne parasites and play dual role (parasites on trees and mutualists with birds) in biological communities [4,47]. The analysis of species–environment relationship has always been a central issue in ecology to understand the importance of climate on animal and plant distribution [22].

The niche of a species is the performance of the species in a set of environmental variables that determine the geographical distribution of that species. It may be either in the presence of biotic interactions i.e., the realized niche, or without these biotic interactions i.e., the fundamental niche [56]. Ecological niche models use various mathematical techniques to relate the occurrence of species to environmental data [35]. Niche modelling has now-a-days received increased attention because it has important implications for conservation and management efforts, the spread of invasive species and the response of species to global climate change [51,53. However, niche models often ignore genetic variation in habitat use and the evolutionary potential for niches to diverge among populations of a species [51]. Our predictive model of the occurrence of the two species of the *Viscum* is based on the quadratic function of the microhabitat parameters of both the species.

**Evaluation**

The estimation of quadratic function was implemented in two steps namely training and testing. Training and testing has been implemented on three data sets. In first set, same data has been used for training as well as testing phase. In second set, 77% of data has been used as training while remaining 23% of data was used for testing with a mean error of 1.36. In the third set, training was done on actual data while simulated data was used as testing with mean error 2.11. Simulated data for each parameter was generated for each parameter separately between ± 5% of the standard deviation of the actual data (Table 5).This simulation of one parameter is always independent from the another parameter (Table 5). Therefore, for each parameter, 11 values have been generated amounting 55 values for one phorophyte. The simulated data was arranged in accordance with the name of the phorophyte in the data sheet.

**Occurrence of *Viscum articulatum* on *Quercus baloot***

Algorithm (MQSF) suggests that at western aspect with constant values of bark (pH=6.7, WHC=79% and BP=41.5 mg/g) for *Q. baloot* individuals with CBH=87cm may support the maximum colonies of *V. articulatum* (n=09). Further, on eastern, northern and zero aspects, with constant values of above parameters on same individuals with CBH=87, an increase in the colonies of hemi-parasite is predicted. However, no colony of *V. articulatum* is predicted on *Q. baloot* with same CBH and same constant values at southern aspect. According to the actual field data the absence of *Q. baloot* individuals on southern aspect of the mountain authenticate the results of the study. MQSF (algorithm) further suggests that change in the pH of bark of *Q. baloot* towards alkalinity or towards extreme acidity at western aspect may help in increase in the number of colonies of *V. articulatum*, however the suggested fluctuation in pH is not possible in nature. Further, with the step downward decrease in the WHC of bark and constancy in the value of CBH (87cm) and phenols (41.5 mg/g), an increase in the number of *V. articulatum* colonies are predicted. However, no colony of *V. ar*

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 87 | 1 | 6.7 | 79 | 46.5 | 43.894* |
| 1 | 87 | 1 | 6.7 | 79 | 47.5 | 91.393* |
| 1 | 87 | 1 | 6.7 | 79 | 48.5 | 152.41* |
| ***Prunus armeniaca* (category 2)** | | | | | | |
| 2 | 48 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 50 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 63 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 66 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 78 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 101 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 113 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 136 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 145 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 160 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 0 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 0 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 2 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 2 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 4 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 4 | 6.7 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 3.6 | 79 | 41.5 | 498.13# |
| 2 | 87 | 1 | 4.1 | 79 | 41.5 | 359.92# |
| 2 | 87 | 1 | 4.6 | 79 | 41.5 | 240.36# |
| 2 | 87 | 1 | 5.1 | 79 | 41.5 | 139.44# |
| 2 | 87 | 1 | 5.2 | 79 | 41.5 | 121.5# |
| 2 | 87 | 1 | 5.9 | 79 | 41.5 | 16.747# |
| 2 | 87 | 1 | 6.2 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 7.1 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 7.4 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 7.8 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 8.5 | 79 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 60 | 41.5 | 369.26# |
| 2 | 87 | 1 | 6.7 | 65 | 41.5 | 217.42# |
| 2 | 87 | 1 | 6.7 | 68 | 41.5 | 139.8# |
| 2 | 87 | 1 | 6.7 | 70 | 41.5 | 93.68# |
| 2 | 87 | 1 | 6.7 | 72 | 41.5 | 52.054# |
| 2 | 87 | 1 | 6.7 | 73 | 41.5 | 32.928# |
| 2 | 87 | 1 | 6.7 | 75 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 78 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 80 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 82 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 84 | 41.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 28.5 | 939.75# |
| 2 | 87 | 1 | 6.7 | 79 | 29.5 | 781.89# |
| 2 | 87 | 1 | 6.7 | 79 | 32.1 | 434.73# |
| 2 | 87 | 1 | 6.7 | 79 | 33.5 | 285.63# |
| 2 | 87 | 1 | 6.7 | 79 | 35.5 | 118.58# |
| 2 | 87 | 1 | 6.7 | 79 | 40 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 43.5 | 0# |
| 2 | 87 | 1 | 6.7 | 79 | 44.5 | 35.809# |
| 2 | 87 | 1 | 6.7 | 79 | 46.5 | 166.07# |
| 2 | 87 | 1 | 6.7 | 79 | 47.5 | 251.47# |

*ticulatum* is predicted when WHC increases gradually on the *Q. baloot* with CBH=87cm. This may be because young individuals (WHC=87cm) of *Q. baloot* cannot retain much of water in its young and thin bark. On *Q. baloot* with same CBH (young individuals) on western aspect and constant values of pH, WHC, low value of phenols may allow more *V. articulatum* to parasitized the phorophyte and vice versa (Table 4,5).

Therefore, it is also revealed that at the same constant values, the younger individuals (minimum CBH) of *Q. baloot* may be parasitized by higher number of (*V. articulatum*) and vice versa. Therefore, the constant values acts as threshold values in case of *Q. baloot* (Table 6).

**Occurrence of *Viscum album* on *Prunus armeniaca***

The MQSF algorithm suggests that at western aspect of the mountain, the phorophytes with CBH=48-160cm and constant values for bark WHC=79%, bark phenolic content=41.5 mg/g and bark pH=6.7 predict no hemi-parasite (*V. album*). On the same aspect *i.e.* western face of the mountain with moderate sun exposure, the phorophytes with CBH=87cm and constant values for bark WHC=79%, bark phenols 41.5 mg/g may predict more *V. album* colonies when pH of the bark decreases from 5.9 -3.6 (acidic). On the same scale of constant valves and on the same mountain aspect (western), the increase in the pH of the bark (6.2-8.5) predicts zero number of *V. album* colonies.

Algorithm further suggests that at western aspect of the mountain the threshold value of pH is 5.9 and play important role in the occurrence of *V. album* colonies. In nature the pH of the bark of *P. armeniaca* cannot decrease towards acidic conditions as per the algorithm, therefore the number of the *V. album* colonies also do not expand. An increase in the *V. album* colonies is predicted when WHC decreases from 73 to 60% at constant values of other parameters (CBH=87cm, pH=6.7 and Phenol=41.5 mg/g) on western aspect. However, a small increase in the WHC of the bark as 75% donot predicts any individuals of *V. album* on the *P. armeniaca*. This is in consonance with the field data, because the young phorophytes (CBH=87cm) cannot hold much of water. Further it is observed that only 2% fluctuation in the water holding capacity play very important when other parameters show a particular constant value and therefore WHC=73% act as a threshold value at eastern aspect. According to the algorithm, the bark phenols play a dramatic role in occurrence of *V. album* on *P. armeniaca*. Keeping constant values for CBH =87cm, pH 6.7, WHC=79% of bark of *P. armeniaca* at western aspect of the mountain, the bark phenols between 35.5- 43.5 mg/g do not allow the *V. album* infection. However, below and above this range is responsible for the occurrence of number of *V. album* colonies. This suggests two threshold values of bark phenols in *P. armeniaca* for the establishment of *V. album*. The MQSF also suggests that on eastern, northern or zero aspect the phorophyte with the above constant parameters may not allow the establishment of *V. album*. The field data also suggests that at eastern aspect phorophytes with CBH 96cm and 120cm with pH= 4.6 and 4.8, WHC 65% and phenolic contents 36.5 mg/g show the occurrence of *V. album*. The phorophytes with CBH=90-101cm on zero aspect also show the occurrence of the *V. album* but beyond the threshold values of the studied parameters (Table 5 & 6).

***Occurrence of Viscum album on Juglans regia***

The Multivariate Quadratic Surface Fitting algorithm suggests that at western aspect, the phorophytes with CBH=48-

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | 87 | 1 | 6.7 | 79 | 48.5 | 350.38# |
| ***Juglans regia*** **(category 3 )** | | | | | | |
| 3 | 48 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 50 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 63 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 66 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 78 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 101 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 113 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 136 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 145 | 1 | 6.7 | 79 | 41.5 | 0.23237# |
| 3 | 160 | 1 | 6.7 | 79 | 41.5 | 7.1671# |
| 3 | 87 | 0 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 0 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 2 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 2 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 4 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 4 | 6.7 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 3.6 | 79 | 41.5 | 1005.6# |
| 3 | 87 | 1 | 4.1 | 79 | 41.5 | 788.14# |
| 3 | 87 | 1 | 4.6 | 79 | 41.5 | 589.28# |
| 3 | 87 | 1 | 5.1 | 79 | 41.5 | 409.08# |
| 3 | 87 | 1 | 5.2 | 79 | 41.5 | 375.27# |
| 3 | 87 | 1 | 5.9 | 79 | 41.5 | 159.52# |
| 3 | 87 | 1 | 6.2 | 79 | 41.5 | 78.238# |
| 3 | 87 | 1 | 7.1 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 7.4 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 7.8 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 8.5 | 79 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 60 | 41.5 | 370.39# |
| 3 | 87 | 1 | 6.7 | 65 | 41.5 | 222.44# |
| 3 | 87 | 1 | 6.7 | 68 | 41.5 | 147.16# |
| 3 | 87 | 1 | 6.7 | 70 | 41.5 | 102.59# |
| 3 | 87 | 1 | 6.7 | 72 | 41.5 | 62.521# |
| 3 | 87 | 1 | 6.7 | 73 | 41.5 | 44.172# |
| 3 | 87 | 1 | 6.7 | 75 | 41.5 | 10.846# |
| 3 | 87 | 1 | 6.7 | 78 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 80 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 82 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 84 | 41.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 28.5 | 462.93# |
| 3 | 87 | 1 | 6.7 | 79 | 29.5 | 342.98# |
| 3 | 87 | 1 | 6.7 | 79 | 32.1 | 94.359# |
| 3 | 87 | 1 | 6.7 | 79 | 33.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 35.5 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 40 | 0# |
| 3 | 87 | 1 | 6.7 | 79 | 43.5 | 82.663# |
| 3 | 87 | 1 | 6.7 | 79 | 44.5 | 165.42# |
| 3 | 87 | 1 | 6.7 | 79 | 46.5 | 371.49# |
| 3 | 87 | 1 | 6.7 | 79 | 47.5 | 494.79# |
| 3 | 87 | 1 | 6.7 | 79 | 48.5 | 631.6# |

**Table 6:** Threshold values of different parameters on different phorophytes.

| | Phorophytes | | | |
|---|---|---|---|---|
| **Microhabitat parameters** | ***Prunus armeniaca*** | ***Quercus baloot*** | ***Juglans regia*** | ***Salix alba*** |
| **pH** | 3.6-8.5 | 3.6-4.1 | 3.6-6.2 | 3.6-6.2 |
| **Phenols** | 28.5-35.5 | 28.5-40 | 28.5-43.5 | 28.5-48.5 |
| **CBH** | Nil | 48-101 | 145-160 | 63-160 |
| **Aspect** | Nil | 0,1,2 and 4 | Nil | 0,1,2 and 4 |
| **WHC** | 60-73 | 60-78 | 60-75 | 60-84 |

pH = potential of hydrogen ion; Phenols = mg/g GAE; CBH= circumference at breast height; Aspect 0= eastern, 1= western, 2= northern, 3= southern and 4= zero aspect; WHC= water holding capacity.

136cm and constant values for bark WHC = 79%, bark phenolic content=41.5 mg/g and bark pH=6.7 do not predict any establishment of *V. album*. However, the phorophytes with CBH ranging from 145-160cm on the western aspect of the mountain with same constant values predict the availability of *V. album*. Therefore, under the above constant values CBH=145-160cm act as a threshold value for the occurrence of the *V. album* on the western aspect of the mountain. On the same aspect i.e. western face of the mountain with moderate sun exposure the phorophytes with CBH=87cm and constant values for bark WHC=79%, bark phenols 41.5 mg/g may increase the possibility of more *V. album* as pH of the bark decreases towards the acidity (6.2 to 3.6). The increase in the pH of the bark (7.1 to 8.5) affect negatively on the occurrence of the *V. album* when other parameters are kept constant on the same aspect.

Algorithm further suggests that the threshold value of pH is 6.2 when other parameters show constant values for CBH, pH, WHC and phenolic contents at eastern aspect. In nature the pH of the bark of *J. regia* cannot decrease towards acidic conditions in accordance with the algorithm, therefore the number of the *V. album* also do not increase. Keeping the values of CBH=87, pH=6.7 and Phenol=41.5mg/g as constant at western aspect, the algorithm suggests that there may be increase in the colonies of *V. album* along with the decrease in WHC of bark from 75 to 60%. Therefore, the threshold value for the WHC at eastern aspect is calculated as 75%. According to the algorithm, the phenolic contents play a dramatic role in infection of *V. album* on *J. regia*. Keeping constant values for CBH=87cm, pH= 6.7, WHC=79% of bark of *J. regia* at western aspect of the mountain, the bark phenols between 33.2- 40 mg/g do not allow the *V. album* to get established. However, below and above this range may invite more *V. album* to get established. This suggests two threshold values of bark phenols in *J. regia* for the establishment of *V. album*. The field data also suggests that at eastern aspect, phorophytes with CBH=106 -125cm with pH= 5.4, WHC 73% and phenolic contents 34.4 mg/g show the occurrence of *V. album*. The phorophytes with CBH=102-112cm on northern aspect also show the presence of the *V. album* but beyond the threshold values of the studies parameters (Table 5 & 6).

### Occurrence of *Viscum album* on *Salix alba*

The Multivariate Quadratic surface (algorithm) suggests that at western aspect, the phorophytes with CBH=48-50cm and constant values for bark WHC=79%, bark phenolic content=41.5 mg/g and bark pH=6.7 do not predict the occurrence of parasite (*V. album*). However, the phorophytes with CBH ranging from 63-160 on the same aspect of mountain i.e. western and same constant values predict the occurrence of *V. album*. In addition to this prediction the number of individuals of *V. album* is also supposed to get increase with the increase in the CBH of the

| *Salix alba* (Category 4) | | | | | | |
|---|---|---|---|---|---|---|
| 4 | 48 | 1 | 6.7 | 79 | 41.5 | 0# |
| 4 | 50 | 1 | 6.7 | 79 | 41.5 | 0# |
| 4 | 63 | 1 | 6.7 | 79 | 41.5 | 16.993# |
| 4 | 66 | 1 | 6.7 | 79 | 41.5 | 22.207# |
| 4 | 78 | 1 | 6.7 | 79 | 41.5 | 42.397# |
| 4 | 87 | 1 | 6.7 | 79 | 41.5 | 56.837# |
| 4 | 101 | 1 | 6.7 | 79 | 41.5 | 78.103# |
| 4 | 113 | 1 | 6.7 | 79 | 41.5 | 95.171# |
| 4 | 136 | 1 | 6.7 | 79 | 41.5 | 124.89# |
| 4 | 145 | 1 | 6.7 | 79 | 41.5 | 135.45# |
| 4 | 160 | 1 | 6.7 | 79 | 41.5 | 151.72# |
| 4 | 87 | 0 | 6.7 | 79 | 41.5 | 110.88# |
| 4 | 87 | 0 | 6.7 | 79 | 41.5 | 110.88# |
| 4 | 87 | 1 | 6.7 | 79 | 41.5 | 56.837# |
| 4 | 87 | 1 | 6.7 | 79 | 41.5 | 56.837# |
| 4 | 87 | 1 | 6.7 | 79 | 41.5 | 56.837# |
| 4 | 87 | 1 | 6.7 | 79 | 41.5 | 56.837# |
| 4 | 87 | 1 | 6.7 | 79 | 41.5 | 56.837# |
| 4 | 87 | 2 | 6.7 | 79 | 41.5 | 11.587# |
| 4 | 87 | 2 | 6.7 | 79 | 41.5 | 11.587# |
| 4 | 87 | 4 | 6.7 | 79 | 41.5 | 0# |
| 4 | 87 | 4 | 6.7 | 79 | 41.5 | 0# |
| 4 | 87 | 1 | 3.6 | 79 | 41.5 | 1596.4# |
| 4 | 87 | 1 | 4.1 | 79 | 41.5 | 1299.6# |
| 4 | 87 | 1 | 4.6 | 79 | 41.5 | 1021.5# |
| 4 | 87 | 1 | 5.1 | 79 | 41.5 | 761.96# |
| 4 | 87 | 1 | 5.2 | 79 | 41.5 | 712.29# |
| 4 | 87 | 1 | 5.9 | 79 | 41.5 | 385.53# |
| 4 | 87 | 1 | 6.2 | 79 | 41.5 | 256.68# |
| 4 | 87 | 1 | 7.1 | 79 | 41.5 | 0# |
| 4 | 87 | 1 | 7.4 | 79 | 41.5 | 0# |
| 4 | 87 | 1 | 7.8 | 79 | 41.5 | 0# |
| 4 | 87 | 1 | 8.5 | 79 | 41.5 | 0# |
| 4 | 87 | 1 | 6.7 | 60 | 41.5 | 454.78# |
| 4 | 87 | 1 | 6.7 | 65 | 41.5 | 310.71# |
| 4 | 87 | 1 | 6.7 | 68 | 41.5 | 237.76# |
| 4 | 87 | 1 | 6.7 | 70 | 41.5 | 194.75# |
| 4 | 87 | 1 | 6.7 | 72 | 41.5 | 156.23# |
| 4 | 87 | 1 | 6.7 | 73 | 41.5 | 138.66# |
| 4 | 87 | 1 | 6.7 | 75 | 41.5 | 106.89# |
| 4 | 87 | 1 | 6.7 | 78 | 41.5 | 67.664# |
| 4 | 87 | 1 | 6.7 | 80 | 41.5 | 47.134# |
| 4 | 87 | 1 | 6.7 | 82 | 41.5 | 31.101# |
| 4 | 87 | 1 | 6.7 | 84 | 41.5 | 19.564# |
| 4 | 87 | 1 | 6.7 | 79 | 28.5 | 69.358# |
| 4 | 87 | 1 | 6.7 | 79 | 29.5 | 0# |
| 4 | 87 | 1 | 6.7 | 79 | 32.1 | 0# |
| 4 | 87 | 1 | 6.7 | 79 | 33.5 | 0# |
| 4 | 87 | 1 | 6.7 | 79 | 35.5 | 0# |
| 4 | 87 | 1 | 6.7 | 79 | 40 | 0# |
| 4 | 87 | 1 | 6.7 | 79 | 43.5 | 257.62# |
| 4 | 87 | 1 | 6.7 | 79 | 44.5 | 378.28# |
| 4 | 87 | 1 | 6.7 | 79 | 46.5 | 660.15# |
| 4 | 87 | 1 | 6.7 | 79 | 47.5 | 821.35# |
| 4 | 87 | 1 | 6.7 | 79 | 48.5 | 996.07# |

Category 1= *Quercus baloot*; 2= *Prunus armeniaca*, 3= *Juglans regia*, 4= *Salix alba;* CBH= circumference at breast height; Aspect 0= eastern, 1= western, 2= northern, 3= southern and 4= zero aspect; WHC= water holding capacity; * = *Viscum articulatum, # = V. album.*

stem from 63 – 160cm. Hence, it is concluded that the probability of infection is more on the older trees of *S. alba* as compared to the younger ones. It is pertinent to say that CBH=63cm act as a threshold value for the infection on western aspect of the mountain in the study area. On the same aspect i.e. western face of the mountain the phorophytes with CBH=87cm and constant values for bark WHC=79%, bark phenols=41.5 mg/g may increase the possibility of more *V. album* as pH of the bark decreases i.e., towards the acidity (6.2 to 3.6). On the same scale of constants and on the same aspect, the increase in the pH (7.1 -8.5) of the bark affect negatively the occurrence of the *V. album.* Algorithm further suggests that pH=6.2 act as a threshold value when other parameters are constant on the western aspect of the mountain.

In accordance to the algorithm the colonies of the *V. album* are not predicted when the pH falls to acidic values. This means that in the constant given value for various parameters, the pH do not fall beyond 6.2. Keeping the values of CBH=87, pH=6.7 and phenolic contents=41.5 as constant at western aspect, the algorithm suggests that there may be decrease in the individuals of *V. album* along with the increase in WHC of bark from 60 to 84%. According to the algorithm, the bark phenols play a dramatic role in occurrence of *V. album* on *S. alba*. Keeping constant values for CBH=87cm, pH= 6.7, WHC=79% of bark of *S. alba* at western aspect of the mountain, the bark phenols between 29.5- 40 mg/g do not allow the *V. album* infection. However, below and above this range may invite more *V. album* to get established.

This suggests two threshold values of bark phenols in *S. alba* for the establishment of *V. album*. Multivariate Quadratic surface fitting also suggest that on eastern and northern aspect the phorophyte with the above constant parameters may permit the establishment of *V. album*. Further Algorithm suggests that the phorophytes with the above constant parameters on the zero aspect of the mountain may not allow the establishment of the *V. album*. The field data also suggests that at eastern aspect phorophytes with CBH=96 cm with pH=5.7, WHC=67 and phenolic contents=36.5 mg/g show the presence of *V. album*. The phorophytes with CBH =118cm on western aspect with pH=6.1, WHC=77% and phenolic contents=36.5 mg/g also show the presence of the *V. album* but beyond the threshold values of the studies parameters (Table 5 & 6).

## Conclusions

In this research, various micro-habitat parameters of two species of *Viscum* (hemi-parasite) have been evaluated for predicting the number/occurrence on their respective phorophytes. Other hand, the data generated has been used for the predictive modelling of the parasites on their respective phorophyte. Multiviarate Quardratic Surface Fitting (MQSF) was used to predict the number of parasites and the most significant micro-habitat parameters for the occurrence of hemi-parasite on their respective phorophyte is bark pH. This means that the parasite is very sensitive to the pH of the bark of its host. This can be one of the reasons responsible for its host specificity. After investigation, it has been concluded that for the occurrence of parasite on its phorophyte, a critical value of each microhabitat parameter is required. This critical value is the threshold value of each parameter. The threshold values of studied parameters for the occurrence of two species of *Viscum* are different for each phorophyte (Table 6).

This can help us in creating/formulating such conditions which can help in management of this havoc causing parasite to its phorophytes. It can also lead to a new direction in which we can generate/produce such conditions manually which can help in control of this parasite on its phorophyte. From the present study, it has been concluded that:

i. pH plays an important role in host-specificity as the parasite is found preferably on tree species having acidic pH.

ii. by comparing three parameters i.e., Water Holding Capacity (WHC), density and Circumference at Breast Height (CBH), it is concluded that the phorophyte with maximum WHC and maximum CBH favours the maximum colonies of the *Viscum* species.

iii. Phenols as an individual factor do not play a crucial role in resistance of phorophyte.

iv. From the analysis of co-efficient it has been evaluated that the most significant factor for the establishment of the parasite is the co-efficient c27, which is the product of WHC (w5) and phenolic content (w6) of the bark.

v. The second most significant co-efficient is c12 which is the square of w6 (Phenolic content).

vi. The third most significant single co-efficient is c4 (pH).

The least significant co-efficient is c24 which is the product of the combination of w3 & w6 (pH and phenolic content).

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