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Mapping the potential distribution of *Achatina fulica* (Bowdich) (Stylommatophora: Achatinidae) in India using CLIMEX, a bioclimatic software

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ABSTRACT: Modeling of climatically similar locations was done based on the existing geographic distribution for the giant African snail, *Achatina fulica* using "Climate Match" function of CLIMEX, a bioclimatic software. Majority areas in Himachal Pradesh, Uttarakhand, Jammu and Kashmir, parts of North-Eastern India showed < 0.7 CMI (Composite Match Index), limiting the spread of the snail into such pockets. Parts of Rajasthan, Gujarat, Karnataka, Andhra Pradesh, Kerala and Tamil Nadu showed > 0.7 CMI, which are climatically very similar to the locations, where *A. fulica* is already prevalent.

Keywords: *Achatina fulica*, India, CLIMEX, Match climate

INTRODUCTION

The Inter-governmental Panel on Climate Change, (IPCC, 2007) has projected a global temperature increase of 1.1 to 6.4^{O}C by the end of this century under different scenarios. To compare and contrast climates in an organism's current range and the area under consideration, various techniques have been used: CLIMEX (Suthrest and Maywald, 1985), Maximum Entropy Method (MAXENT) and the Genetic Algorithm for Rule Set Production (GARP) (Terribile *et al*, 2010). Such bioclimatic models (envelope models or ecological niche models or species distribution models) are used to predict geographic ranges of organisms as a function of climate to forecast range shifts of organisms due to climate change, predict the eventual ranges of invasive species, infer paleoclimate from data on species occurrences (Jeschke and Strayer, 2008). In this article, climatically similar locations for the incidence of gaint African snail, *Achatina fulica* (Bowdieh) (Stylommatophora: Achatinidae) in the India were mapped using the "Climate Matching" function of the CLIMEX Software. *Achatina fulica* a native of east Africa has invaded many countries in the world and established as a polyphytophagous pest (Figure 1) and is extensively studied snail of economic, ecological and medical importance (Raut and Barker, 2002; Fontinilla *et al.*, 2007; Capinera, 2011). Its success as an introduced species is attributed to several factors *viz.*, high reproductive capacity, voracious feeding habit coupled with inadequate quarantine arrangements and human aided dispersal (Fontinilla *et al.,* 2007). The snail is reported on different hosts in most parts of India (Raut and Barker, 2002; Jayashankar *et al.*, 2013) and their alarming population explosion in different parts of Kerala has prompted a community based eradication program (Anonymous, 2011; Sajeev, 2011).

CLIMEX software used in the present modeling operates based on the assumption that species encounter favorable and unfavorable seasons that impact eco-physiological growth of the target species. Complete details of the model can be found in CLIMEX (ver.3), User's guide (Sutherst *et al.*, 2007). Its key assumption is that climate is the main determinant of the distribution of plants and animals (especially *poikilotherms*). The software comprises of two very prominent functions for exploring the effects of climate on species, the "CLIMEX model" and the "Climate Matching". The former predicts the potential geographical distribution of the species in relation to climate; the latter can compare the meteorological data of different places without reference to any particular species. Climate matching serves two purposes in invasive species management i.e., firstly to assess overall invasion risk and secondly to prioritize destination-specific management actions and has been validated as a strong indicator of establishment success (Baker and Bomford, 2009). Climate matching identifies locations that could be colonized by a potential invasive species like *A. fulica* on the basis of similarity to climates found in the species' native or known range. Thus, in the present study climate matching approach was followed to identify potential areas susceptible to invasion of *A. fulica* in India.

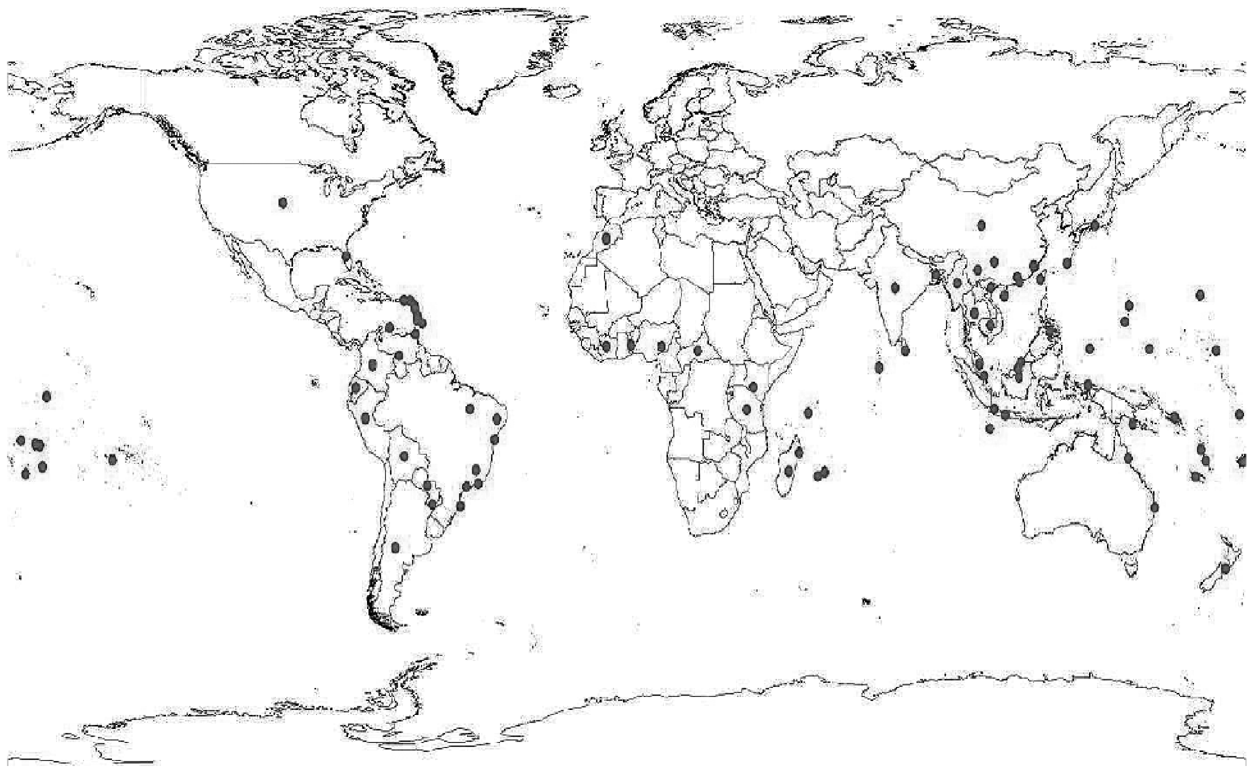

Fig. 1. Current distribution of *A. fulica* (Modified from CABI, 2014)

MATERIALS AND METHODS

Climate Matching in CLIMEX Software

The Climate Matching function of CLIMEX software has two applications, *Match Climates* and *Match Climates (Regional).* The 'Match Climates' applications compare the long-term meteorological data for each of the selected 'Away' locations with the climate of the 'Home' location. The level of similarity is given by the 'Composite Match Index, CMI', which is the product of six component indices, I*tmax,* I*tmin*, I*rain*, I*rpat*, I*hum* and I*sm*, indicating similarity in maximum and minimum temperature, total rainfall, rainfall pattern, relative humidity and soil moisture, respectively. Each of these component indices can range between 0 and 1, with a value of 1 indicating an exact match with the 'home' location. A CMI value greater than 0.8 is considered to be a close match and value < 0.6 indicates that some or all the climatic variables are quite different between the selected "home" and "away" locations (Fowler and Yu Takeuchi, 2012). The regional climate matching application is an extension of the *Match Climates* application. In effect, it takes the *Match Climates* application and runs it for many 'Away' Locations simultaneously. The results of all of these runs are combined by retaining the best result for each location from all of the runs. In the present model 62 home locations of known records with incidence of *A. fulica* in India (Figure 2) were selected to run with match climate regional application choosing entire world as 'away' location. Subsequently, the climatically similar locations globally and in India were subjected to further analysis cum interpretation.

Climate data

CLIMEX (ver. 3.0) includes weather data from a database of 2400 meteorological stations located worldwide for 1961–1990. A Global Climate Model (GCM), CSIRO-Mk-3.0 (Commonwealth Scientific and Industrial Research Organization, Australia), obtained from CLIMOND website (Kriticos, 2007), was used to project model results. Maximum and Minimum temperature, relative humidity, rainfall pattern, total rainfall and soil moisture were the variables used for modeling.

Steps involved in generating prediction maps by running the match climate model.

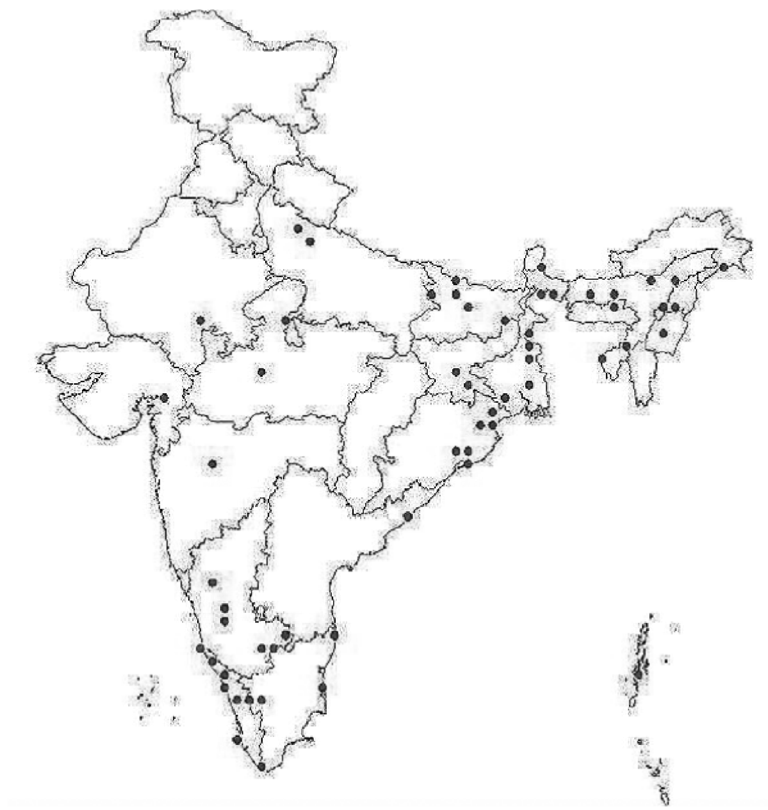

Fig. 2. Home locations from India selected for regional match climate

Step 1: Preparing the location set: Models were run with 62 'home' locations from India with known records of the pest obtained from several sources, including scientific literature, international databases and newspapers (Table 1). The 0.5^0 grid average climate dataset for 1961-1990 was obtained from CLIMOND and was used as base temperature in CLIMEX.

Step 2: Setting options in the *Match Climates (Regional)* application: The default weight setting is 1.0 for each index, except the RH index that has a default weighting of zero. The soil moisture was set at 1 considering the eco-biology of the snail.

Step 3: Run and displaying the results: When the run is completed, the results are displayed as a map. If desired, results can be exported from CLIMEX as a file that can be imported into an ARC-GIS or DIVA-GIS for quality map production.

RESULTS AND DISCUSSION

Globally the biodiverse countries on either side of the equator showed climatic suitability for the survival of *A. fulica* (Figure 3), incidentally the snail is recorded as a pest in the aforesaid countries (CABI, 2014). Evident from available literature considering 21 states and Union territories (Table 1), most parts of the country, around the selected "home" locations are found to be climatically suitable (> 0.7 CMI) for the survival of the snail (Figure 4). This is attributed to the region matching application's ability to identify the best match between each of the locations in the 'away' location selection, with all of the locations in the 'Home' region. Most parts of temperate states like Himachal Pradesh, Uttarakhand, Jammu and Kashmir showed < 0.7 CMI, and few parts of North Eastern states showed < 0.7 CMI, limiting the spread of the snail into such pockets in the near future. On the contrary, parts of Rajasthan, Gujarat, Karnataka, Andhra Pradesh, Kerala, Tamil Nadu where the snail is already established showed > 0.7 CMI validating the present model. Majority of places in Kerala with high incidence of the snail also showed climatic similarity in their surroundings, which is in conformity with the prediction model of Sajeev (2011). Thus, climate is expected to be a strong predictor of *A. fulica* density and biomass as explained by Raut and Barker (2002) and Albuquerque *et al.* (2009). As a precautionary initiative in such cases, preventing the spread of the snail is more cost effective than managing the pest when it has established in a new

Table 1. Locations of *A. fulica* incidence in India used for the modeling

S. No.	Location	State/Union territory	Latitude (° N)	Longitude (° E)	References
1	Valandayamaram	Tamil Nadu	10.65	77.00	Raut and Ghose (1984)
2	Kanyakumari	– do –	8.07	77.54	Srivastava (1992)
3	Chennai	– do –	13.08	80.27	Vanitha *et al.* (2008)
4	Annamalai Nagar	– do –	11.39	79.71	
5	Panchavati	Rajasthan	25.32	74.64	Tehsin and Sharma (2000)
6	Andaman and Nicobar	Andaman and Nicobar	11.68	92.77	Prasad *et al.* (2004)
7	Bengaluru	Karnataka	13.08	77.57	Basavaraju *et al* (2000)
8	Shivamoga	– do –	13.91	75.56	Ravikumar *et al* (2007)
9	Davanagere	– do –	14.46	75.92	Anonymous (2010)
10	Dharwad	– do –	15.45	75.00	Jayashankar (2011)
11	Kolar	– do –	13.16	78.4	Kumar *et al* (2011)
12	Kanakapura	– do –	12.55	77.41	Sridhar *et al.* (2012)
13	Assam	Assam	26.14	91.77	Srivastava (1992)
14	Kamrup	– do –	26.80	91.73	
15	Golpara	– do –	26.17	90.62	
16	Guwahati	– do –	26.18	91.73	
17	Jorhat	– do –	26.75	94.22	
18	Silonijan	– do –	26.92	93.40	
19	Kolkata	West Bengal	22.56	88.36	Raut and Ghose (1984) Srivastava (1992)
20	Chowranghie	– do –	23.80	88.25	
21	Barrackpore	– do –	22.76	88.37	
22	Gour	– do –	24.86	88.13	
23	Jangipur	– do –	24.47	88.07	
24	Coochbihar	– do –	26.32	89.45	
25	Jalpaiguri	– do –	26.52	88.73	
26	Midnapur	– do –	22.42	87.31	
27	Madhya Pradesh	Madhya Pradesh	23.25	77.41	Thakur and Kumari (1998)
28	Manipur	Manipur	24.82	93.95	Suresh (2007)
29	Aurangabad	Maharashtra	19.88	75.32	Srivastava (1992)
30	Vishakapatnam	Andhra Pradesh	17.68	83.21	Reddy and Sreedharan (2006)
31	Itanagar	Arunachal Pradesh	27.10	96.62	Srivastava (1992)
32	Ranchi	Jharkhand	23.35	85.33	
33	Dumka	– do –	25.27	81.25	
34	Chaibasa	– do –	22.57	85.82	
35	East Champaran	Bihar	26.65	84.91	
36	Muzzafarpur	– do –	26.07	85.45	

37	Samastipur	– do –	25.85	85.78	
38	Gopalganj	– do –	26.47	84.43	
39	Arundathinagar	Tripura	23.84	91.28	
40	Kumarghat	– do –	24.15	92.02	
41	Alapuzha	Kerala	9.49	76.33	Anonymous (2011)
42	Kozhikode	– do –	11.25	75.77	
43	Kasargod	– do –	12.50	75.00	
44	Mahe	– do –	11.70	75.53	
45	Malapuram	– do –	11.04	76.08	
46	Palakkad	– do –	10.77	76.65	
47	Kannur	– do –	12.87	74.90	
48	Bareilly	Uttar Pradesh	28.36	79.41	Srivastava (1992)
49	Terai	– do –	25.25	78.75	
50	Moradabad	– do –	28.83	78.78	
51	Bijanor	– do –	29.37	78.13	
52	Sikkim	Sikkim	27.33	88.62	
53	Nagaland	Nagaland	25.67	94.12	
54	Dimapur	– do –	25.80	93.78	
55	Nongpoh	Meghalaya	25.54	91.53	
56	Anandpur	Odisha	21.21	86.11	Raut and Ghose (1984); Srivastava (1992)
57	Balasore	– do –	21.49	86.93	
58	Baripada	– do –	21.94	86.72	
59	Cuttack	– do –	20.27	85.52	
60	Bhubaneshwar	– do –	20.27	85.84	
61	Puri	– do –	19.81	85.83	
62	Vadodara	Gujarat	22.30	73.20	Pandya (2009)

geographic area. Other coherent implications of the mapping include the fact that locations deemed suitable for the snail are expected to suit its natural enemies concomitantly. Secondly, our mapping shows the potential suitable areas where currently the species is not reported. The present observations will help in devising ways for restricting the entry and establishment of the pest into new potential areas within India through domestic quarantine measures.

Borrero *et al.* (2009) and Volger *et al.* (2013) have predicted the potential areas susceptible to the snail in both tropical and temperate regions of South America, using two ecological niche modeling methods, GARP and MaxEnt. In India, Sajeev (2011) using the Maximum entropy modeling has predicted an increased infestation of *A. fulica* in Kerala. Predictions of climatic suitability for *Pomacea canaliculata* indicate an increase in the suitable areas for the snail (EFSA PLH Panel on Plant Health, 2013) in Europe. Although climate is expected to influence invasion and prevalence of the snail, their adaptive behaviours (dormancy, homing *etc.*) to combat environmental stresses, host availability, interaction with other species and the extent of phenological and demographic changes (plastic response and genetic specialization) need to be holistically considered to assess the impact of climate change. The ability of CLIMEX to forecast the spread of invaders has not been tested in India, thus the present article would serve as a clue for further studies to address future climate impact on *A. fulica* outbreaks.

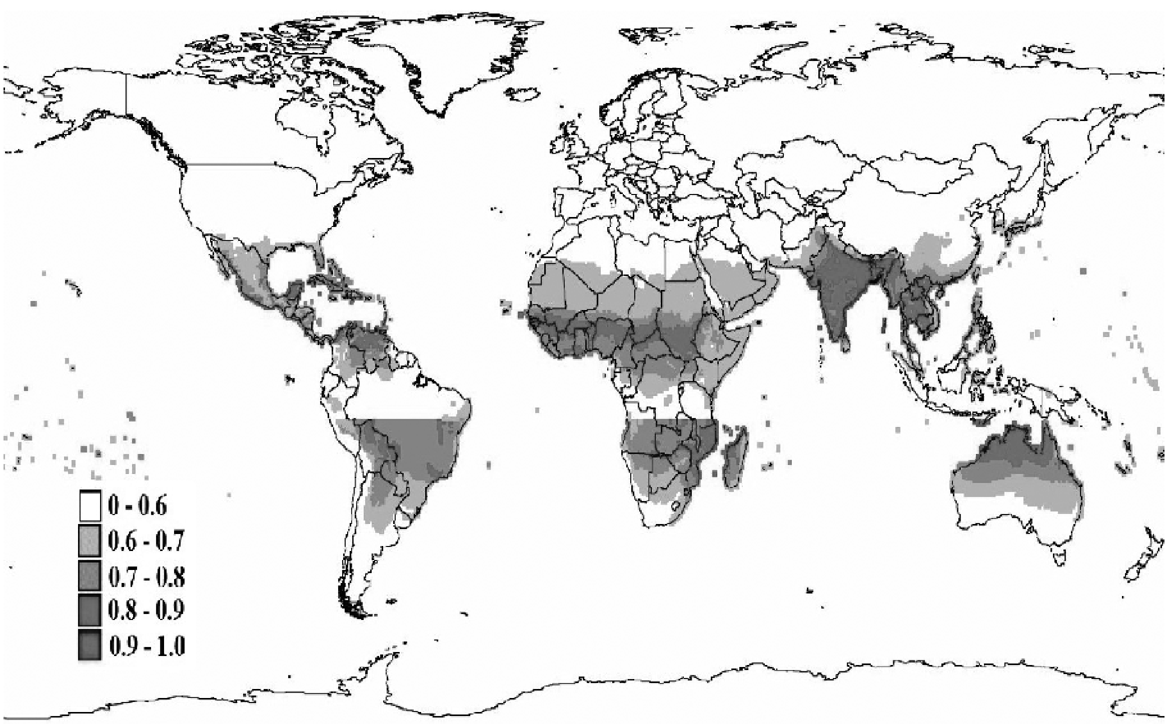

Fig. 3. World map showing climatically similar 'away' locations in relation to 62 selected 'home' locations in India

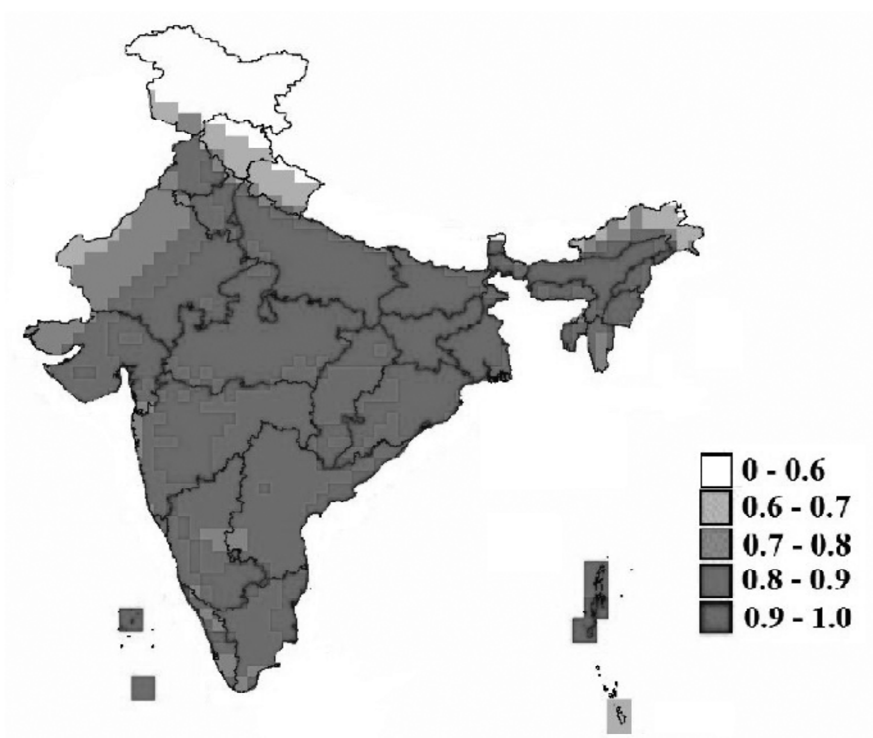

Fig. 4. Potential suitable 'away' locations for *A. fulica* in India based on Climate Matching

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