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Habitat mapping through improving the conservation status of genus *Clausina*- an important medicinal plant of Assam, India

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ABSTRACT

The genus *Clausina* is one of the important medicinal components of Flora of Assam. In Assam, only three species of *Clausina* are reported i.e., *C. lansium*, *C. excavata* and *C. heptaphylla*, and all of these species are restricted only a few pockets of forest of Assam. Thus, it is important to conserve this species using appropriate research. The present study focuses on the distribution, population size estimation and to find out the predicted distributional locations of genus *Clausina* by Maximum Entropy (Maxent) modeling for the purposes of conservation. The model is based on geospatial data sets of past and current distribution of *Clausina* species, climatic data and topographic attributes. The Maxent model was used to identify the current potential habitat of *Clausina* species and to predict the suitable habitat of the genus in the future. In our present investigation, the population size for all the species of *Clausina* was found to be very poor i.e., mean density, frequency of occurrence and abundance in relation to other associated species was 0.165, 12.593 and 1.576 for *C. lansium*; 0.544, 26.296 and 2.230 for *C. excavata* and 0.381, 34.44 and 11.166 for *C. heptaphylla*. So the present investigation is to find out the population status and distributional locations of genus *Clausina* for reintroduction in Assam.

***Key words**: Assam, Clausina, Conservation, Ecological Niche modelling, Maxent*

Introduction

With 14 species, *Clausena* is a significant genus within the Rutaceae family, primarily found in tropical Asia and India (Burkill, 1966). Almost all species of this genus popularly used as remedy in folk medicine. One of the most important characteristics of this genus is that it is present in many parts of the world, mainly in India, tropical Asia and South Africa. They are easy to grow, pest-free and can withstand heavy pruning (Swarbrick, 1997). In Assam the genus *Clausena* represents only three species, i.e. *C. lansium*, *C. exavata* and *C. heptaphylla* and different parts of these species are use locally in traditional health care practices (Kanjilal *et al*., 1934; Roy and Rahman, 2016; Panda *et al*., 2019).

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Clausenalansium Skeels (wampee) is a tropical tree and has long been widely grown in southern China, Southeast Asia and North America. The grape-like fruit is considered a famous sour fruit and can be eaten with its skin. The pulp is often used to prepare fruit bowls, desserts, jams or jellies. The leaves and seeds have hepatoprotective, antiplatelet, hypoglycemic, antifungal and antiviral effects (Morton, 1987; Liu *et al*., 1996; Shen *et al*., 1989; Ng *et al*., 2003). In Assam, this fruit is traditionally used to treat stomach infections, bronchitis and has deworming effects. The leaves and roots are used to treat digestive disorders, viral hepatitis, coughs and asthma (Li *et al*., 2017) and the seeds cure ulcers and gastrointestinal inflammation (Auranwiwat, 2014). In addition to being rich in vitamins, the fruit can also be used to make classical medicines.

C. excavata is a shrub that grows from China and the Himalayas to Peninsula Malaysia (Manosroi *et al*., 2004; Chaudhari *et al*., 2001). It has a strong, unpleasant odor. Traditionally, Clausenaexcavata was used as a detoxifying agent and to heal snake bite and abdominal pain (Ridley, 1922). Both the crushed root and the leaves can be applied topically to treat lesions, such as nasal ulcers. A root decoction is consumed for digestive issues (Ali *et al*., 2000). The decoction of flowers and leaves boiled and the taken for colic and also given after child birth (Griev and Scora, 1980; Yoshida, 1996).

The bushy shrub *Clausena heptaphylla* is indigenous to Bangladesh, India, Laos, Myanmar, Nepal, Thailand, and adjacent areas. It grows well in some of the areas of North Eastern India up to an altitude 1330 m. where the leaves are known traditionally for chewing with betel leaves and flavouring tobacco. The leaves of the plant possess a strong and pleasant aromatic odour.The plant is used in many traditional remedies for headaches, malaria, and muscle soreness. It is also used as an insecticide, astringent, diuretic, and vermifuge (Ahmed *et al*., 2008; Fakruddin *et al*., 2012).

The three important species of *Clausina* have been found to be limited only a few places of Assam. The species *C.lansium* is found only few pockets of western and Eastern Assam, whereas *C. exavata* is restricted in parts of Eastern Assam and *C. heptaphylla* is found only in few localities of Barak valley of Assam. The population stock of the genus *Clausina* has been quickly declining in its natural habitats due to habitat degradation, a rapidly changing temperature, alien species invasion, and overexploitation. This has made it difficult for the plant to be sufficiently propagated in its natural condition. Utilizing ecological niche modeling or habitat distribution modeling (HDM), several environmental parameters influencing species dispersion are evaluated (Reed and Frankham, 2003; Elith *et al*., 2006; Borthakur *et al*., 2018; Deka *et al*., 2017). Temperature, precipitation, soil, vegetation, and land cover are all accounted for in the modeling of these ecological parameters, a large portion of the data comes from Geographic Information System (GIS) databases (www.worldclim.org and www.diva-gis.org.). Accuracy of the models is improved by combining high resolution satellite imagery with environmental factors and geographical databases on vegetation and climate. Because ENM forecasts a species' occurrence, it can be utilized, among other things, to extrapolate the distribution of species throughout a landscape in both space and time (Schmitt *et al*., 2017; Wittmann *et al*., 2010). Because of this, species distribution maps created with ENM has a high degree of statistical confidence and can be used to quickly identify appropriate locations for the reintroduction of threatened species (Elith *et al*., 2006; Kumar and Stohlgren, 2009). Predictive modelling of species distributions is being increasingly favored by conservation managers to study biogeography, evolution, ecology, conservation, and invasive-species management (Aubry *et al*., 2017).

Reintroducing or strengthening species is one of the most effective ecological engineering strategies for restoring reduced species populations as well as damaged habitats and ecosystems (Kuzovkina and Volk, 2009). Reinforcement is the process of adding individuals to an existing population in an attempt to improve population size or variety, whereas reintroduction is the broad term for the regulated introduction of plant material into a natural or managed ecological area (Godefroid *et al*., 2011). This makes conservation planning possible, allowing for the successful rescue and recovery of threatened species in the face of difficult conditions brought on by environmental degradation and climate change (Barik and Adhikari, 2011). Thus, habitat distribution modeling aids in the development of successful species conservation strategies as well as the identification of places for species reserves and reintroduction. It has proven effective in forecasting the effects of environmental and climatic change on species and ecosystems as well as in recovering important habitats (Polak and Saltz, 2011). Because initially impressive survival rates are frequently followed by reversals over time, long-term monitoring is required (Hutchings, 2010).

Considering the significance of the presence of *Clausina spp*. in Assam, a comprehensive account of population survey of these species with its predicted mapping was carried out in the present investigation, for that further step to improve conservation in its natural habitat.

Materials and Methods

Survey of the species and population status

Based on previous reports, field surveys were repeated to locate the plant in different parts of Assam, India, during the period 2019-2022. Extensive field surveys were conducted in locations where this species has been reported to assess the current population status. The species' total population was determined by counting every individual directly, taking into account saplings (taller>1 m) and mature individuals (taller ≤ 1.37 m) in each 200 m × 200 m grid of occurrence within the anticipated locales.

The following formulas were used to determine the plant species' density, frequency, and abun-

$$\text{Density} = \frac{\text{Total number of Individuals in all sampling units}}{\text{Total number of sampling units studied}}$$

$$\text{Frequency} = \frac{\text{Number of sampling units in which the species occur}}{\text{Total number of sampling units studied}}$$

$$\times 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occured}}$$

Habitat distribution modeling (HDM) for recognizing the suitable habitats for conservation

Species occurrence data

Primary distributional records for the species *Clausena lansium* was collected rom Baksa, Kamrup, Jorhat, Sivasagar and Golaghat districts of Assam, India. For *C. heptaphylla* the distributional record was collected from Dima Hasao, Cachar, Hailakandi and Karimganj district where as for *C. excavata* the distributional record was collected from Dibrugarh, Jorhat, Karbi Anglong and Golaghat districts of Assam. Using a GPS (Garmin), the coordinates of every occurrence location were recorded with a precision of 10–40 m. In order to predict the distribution of suitable habitats for the species within its natural range, the coordinates were first transformed to decimal degrees. Diva-GIS were used to check these records for spatial problems, and MS Excel was used to remove any duplicate entries from the dataset (Elith *et al*., 2006).

Environmental variable

The main purpose of using MaxEnt model in GIS is to get an overall idea of potential habitable zones of the said species (Phillips and Dudik, 2008). 19 environmental variables from *worldclim.org* have been downloaded to serve the purpose (Fick and Hijmans, 2017). The Terra and Aqua Combined Moderate Resolution Imaging Spectro-radiometer (MODIS), MCD12Q1l and cover type is used for Landuse raster (Friedl and Sulla-Menashe, 2019). A multicolinearity test is also conducted between the 19 variables and the cross correlation of 8 and more than 8 of variables were excluded from the model (Mehmud *et al*., 2022). The Shuttle Radar Topography Mission (SRTM) elevation raster is also used in the study area (Rodríguez *et al.*, 2005).

Validation of model robustness

The model was constructed using maximum entropy modeling, and the pixel dimension was 250 m × 250 m grid cell to examine the habitat modeling. We ran 500 iterations for each species using a threshold criterion of 10 percentile training presence in order to verify the resilience of the model. In the replicated runs, cross validation technique was employed where samples were divided into replicate folds and each fold was used for test data. Model quality was evaluated based on Area Under Curve (AUC) value and the model was graded following Mehmood *et al*. (2022) as 0-0.2 (Least Potential), 0.2-0.4 (Moderate Potential), 0.4-0.6 (Good Potential) and 0.6 to 0.99 (High Potential).

Population status vis-à-vis model thresholds

To predict the population status of *C.lansium*, *C.heptaphylla* and *C.excavata*, a field survey was conducted to explore the robustness and suitability of the model. The total population of the species was determined by directly counting all saplings (>1 m height) and matured individuals (≤1.37 m height) in each 250 m × 250 m occurrence grid at predicted locations. The species population data in each locality was then correlated with the corresponding distribution model threshold level to determine whether regions covered by the higher thresholds maintain higher populations, which improves habitat conditions for the establishment of the species, and vice versa.

Assessment of habitat status and identification of areas for reintroduction

The predicted potential areas were superimposed on GoogleEarth pro (www.google.com/earth). Using Diva GIS ver. 7.3, the predicted suitability maps were exported in KMZ format (www.diva-gis.org). The KMZ files that were exported were superimposed on Google Earth satellite pictures in order to determine the true habitat conditions that were present in the places where they occurred (Deka *et al*., 2017).

Results and Discussion

Population size, density and abundance of genus*Clausina* in Assam

Species with a restricted range are more crucial for conservation initiatives. A total of 23.7 km of transects yielded 36 quadrat observations. For each of the three species of *Clausina*, data on density, occurrence frequency, and abundance were obtained. The observations tabulated here show an average C.*lansium* density of 0.165, an occurrence frequency of 12.593 and abundance relative to other related species of 1.576. For *C.excavata*, the average density was 0.544, the frequency of occurrence was 26.296, and the abundance relative to other related species was 1.576. While *C. heptaphylla*, average density 0.381, frequency 34.444 and abundance relative to other related species 1.166.

Calibration of models to predict potential habitat for reintroduction of genus *Clausina* in Assam

The training and test AUC for the species *C. lansium* are 0.967 and 0.921, which gives a very high acceptability of the model. In this model the variable slope and 14 have 63.3 and 20 percent contribution. Other notable contributors are 3, 15 and 2. The High potential suitability of the map is covering the entire upper Assam, Northern stretch of Dima Hasao, Cachar, Hailakandi and Karimganj. The good potential areas are covering almost entire Assam. The total High potential area is 29206619146.9 sq m. (29206.6 km^2).

The training and test AUC of the species *C. Excavate* are 0.986 and 0.935, which gives a very high acceptability of the model. In this model the variable 17 and 15 have 55.8 and 39 percent contribution. The High potential suitability of the map is covering the area of Dhemaji, Tinsukia, Dibrugarh, Few parts of Lakhimpur, Majuli, Sivasagar, Jorhat, Southern part of East Karbi Anglong, Eastern stretch of Dima Hasao, Cachar, Hailakandi and Karimganj district of Assam. The total High potential area is 6055194532.32 sq.m (6055.19 km^2).

The training and test AUC of the species *C. heptaphylla* are 0.982 and 0.951, which gives a very high acceptability of the model. In this model the variable 3 and land use have 31.6 and 30.5 percent contribution. Other notable contributors are 15 and 17. The High potential suitability of the map is cov-

Fig. 1: A. & B. Habitat of *C. excavata*, C. & D. Habitat and fruit of *C. heptaphylla* and E. & F. Habitat and fruit of *C. lansium*

ering the area of Tinsukia, Lakhimpur, Majuli, Sivasagar, Jorhat, Southern tip of East Karbi Anglong, Eastern stretch of Dima Hasao, Cachar, Hailakandi and Karimganj district of Assam. The total High potential area is 6306342551.26 sq.m (6306.34 km ^{2}).

The genus *Clausina* is a significant medicinal component of flora of Assam. Thefruit of *C. lansium* is sour sweet in taste and is popular in villages. Various parts of the plant are used in traditional systems of medicine, including stomach ailments, bronchitis, coughs, asthma, hepatitis, and gastrointestinal diseases. *C.excavata* is of great ethnobotanical importance. It is traditionally used in the treatment of snakebites, colic, intestinal disorders and as a detoxifier. The leaves of *C. heptaphylla* possess a strong aromatic odour and is chewing with betel leaves and

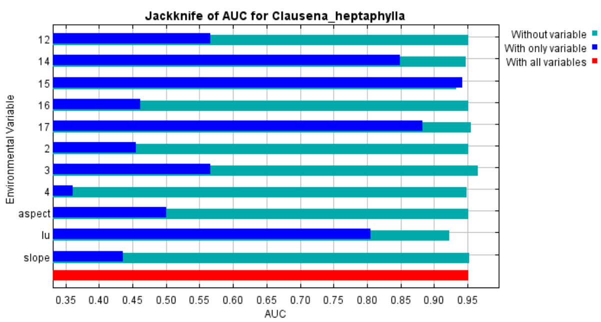

Fig. 2. Jackknife test of variable importance for *C. excavata*: individual variable contribution (blue bar), contribution when a given variable is excluded (green bar), whole set of variables (red bar). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

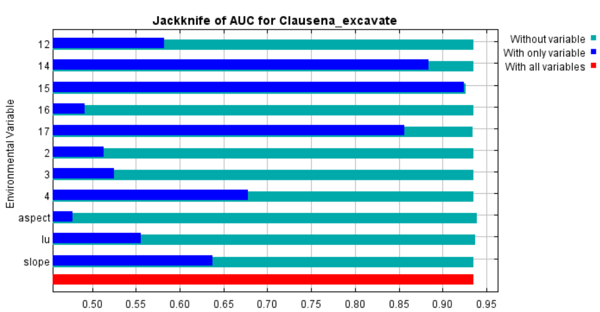

Fig. 3. Jackknife test of variable importance for *C. heptaphylla*: individual variable contribution (blue bar), contribution when a given variable is excluded (green bar), whole set of variables (red bar). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

flavouring tobacco. Different parts of the plant are used to treat muscle pain, headache and malaria. Due to a number of reasons, including habitat fragmentation, overexploitation, and other anthropogenic activities, the population stock of *Clausina* in its native habitats has been rapidly declining.Thus, it is imperative that the conservation status of these significant medicinal plants be improved.

A possible habitat for the genus *Clausina* is one, that has certain ecological characteristics necessary for the species to survive and reproduce.Previous records from secondary sources indicate that *C.lansium* is present in parts of western Assam (Baksa and Kamrup). However, this plant could not be detected from Eastern Assam. For *C. heptaphylla* the distributional record was collected from Hailakandi and Karimganj district where as for *C. excavata* the distributional record was collected from Karbi Anglong and Golaghat districts of Assam only. However, during our comprehensive field survey, several new locations of *C.lansium* were reported, namely Jorhat, Sivasagar and Golaghat districts of Assam. For *C. heptaphylla* the newly distributional record was collected from Dima Hasao and Cachar districts where as for *C. excavata* the new distributional record was collected from Dibrugarh and Jorhat districts of Assam. Surprisingly, the populations discovered so far indicate low population strength. Overexploitation or the direct or indirect effects of numerous anthropogenic activities are the main causes of the declining numbers of people in each group. However, by reinstating or reintroducing more individuals into their appropriate natural

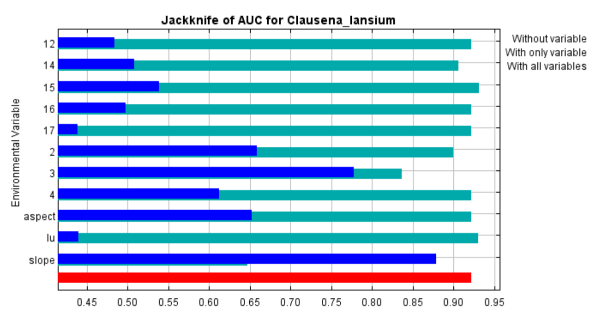

Fig. 4. Jackknife test of variable importance for *C. lensium*: individual variable contribution (blue bar), contribution when a given variable is excluded (green bar), whole set of variables (red bar). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

habitat, the population status could be altered. The ecological modeling technique, which has been applied in this work, makes it possible to determine the plant's precise and adequate habitat, which is crucial for reintroduction.

In this study, ENM showed overall good performance in the native range. For *C. lansium*, *C. excavata* and *C. heptaphylla* the high AUC values of training and testing are 0.967 and 0.921; 0.986 and 0.935; 0.982 and 0.951 respectively. This suggests that niche models can successfully distinguish between regions of species presence and absence. The results of model output and field investigations showed thathumid tropical and subtropical forests in Assam's higher elevations (about 500-4500 m) corresponded with the species' appropriate natural habitats. The majority of the validation points in the Indian subcontinent could be accurately predicted by the niche model, demonstrating its reasonable transferability. However, it may be said that in the North-eastern region of the subcontinent, the species has maintained its native niche characteristics. Further research is necessary to rule out the potential that the species is shifting its niche, as shown by the decreased degree of prediction likelihood for several of the validation points. This information will serve as a guide for the reintroduction of *Clausina* spp. in Assam and improve population status of the said plant species for conservation purpose. According to the current study, certain regions of Assamese tropical and subtropical forests that are continuous and unbroken offer the species with a stable habitat.It has been determined that the eastern regions of Assam, which include the transition zone between Assam and Arunachal Pradesh, provide appropriate environmental conditions for prospective habitats at greater probabilities of this species.As a result, these forest regions might act as in-situ conservation habitats. The present habitat distribution modelling has proven more useful in identifying probable locations of threatened species for reintroduction. The results show a significant relationship between population size and model threshold. Therefore, the results will greatly assist policy makers and natural resource managers in managing this species and conserving the overall biodiversity of the region.

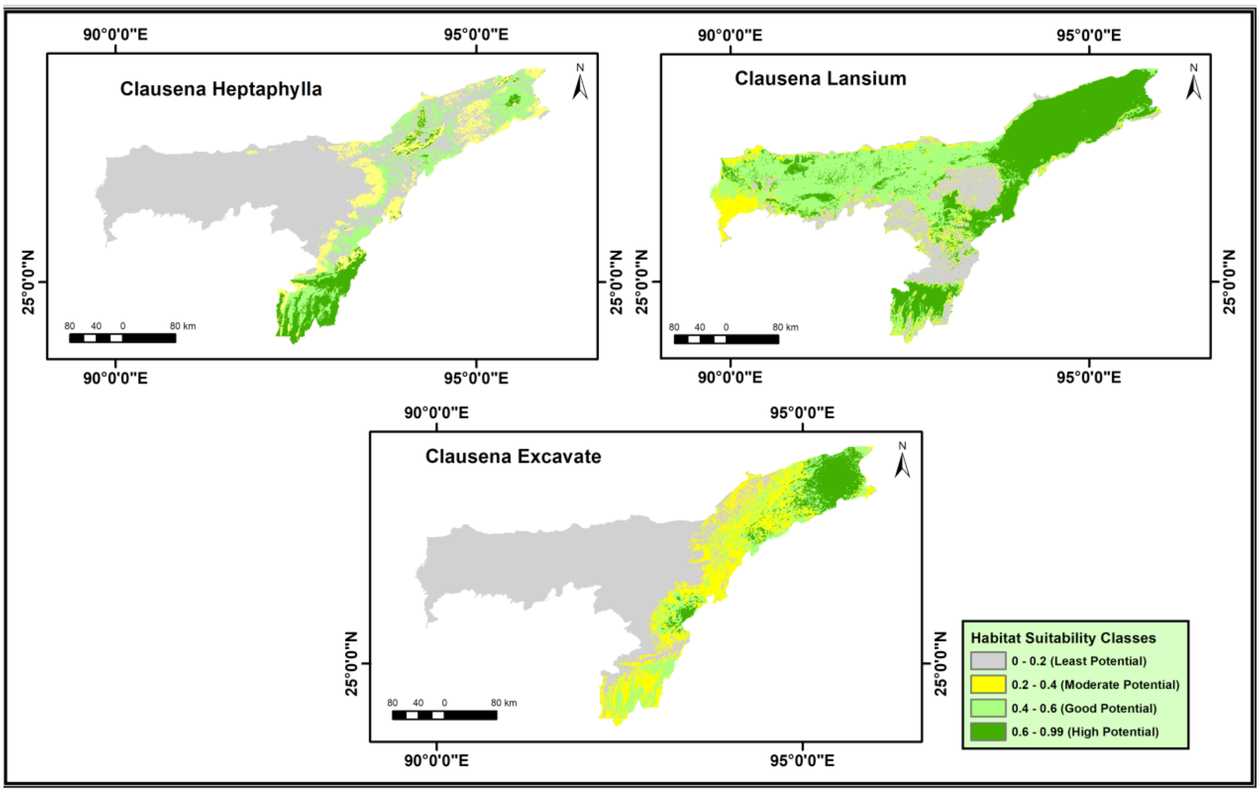

Fig. 5. Map showing sample collection sites of *Clausina* spp., potential habitat distribution in Assam (India). The green patches in the map represent the highly predicted localities. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

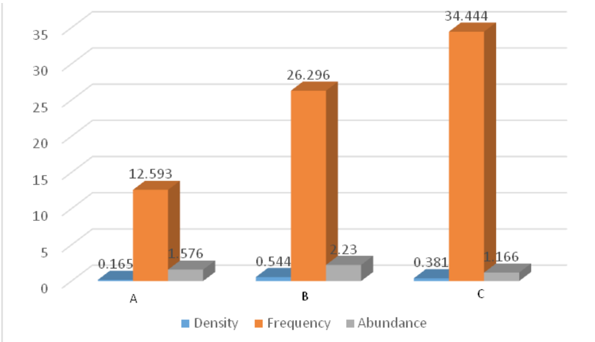

Fig. 6. Population structure of *C. lansium*, *C. excavata*, and *C. heptaphylla* in Assam

Competing interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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