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Article Overview

Rhododendrons are an important, dominant, and primitive group of flowering plants with considerable ecological and economic importance found in the temperate, subalpine and alpine regions of western Arunachal Pradesh, India. In addition to aesthetic, sacred, and ethnomedicinal values, several species have commercial and social importance. Rhododendrons are one of the preferred plant species used by local inhabitants in the region. Anthropogenic disturbance associated with deforestation, unsustainable extraction, over-exploitation, and agricultural practices have collectively put pressure on *Rhododendron* species; as a result many species have become endangered, rare, or threatened. Knowledge of the specifics of a species' distribution is essential for its *in situ* conservation and management. We focused, in this study, on four rare *Rhododendron* species (*R. edgeworthii*, *R. kendrickii*, *R. keysii*, and *R. maddenii*). We recorded geographic locations of the selected species through extensive field surveys, and obtained additional occurrences from secondary sources. We used a NASA-MODIS/Terra data set to summarize environmental characteristics. We incorporated location and environmental data into evolutionary-computing approaches to develop ecological niche model predictions of the likelihood of occurrence of these species. Seven new populations of the studied species were encountered in subsequent field surveys of the predicted sites. Ecological niche modeling can thus serve an important role in various *in situ* as well as *ex situ* measures for establishment of arboreta, sanctuaries, parks and reserve forests, protected areas through community management, botanical gardens, and also for *in vitro* research activities for species conservation.

R. edgeworthii. Photo by Pijush Kumar Dutta.

R. kenderickii. Photo by Ashish Paul.

R. kenderickii. Photo by Ashish Paul.

R. maddenii 'Gigha', form *jenkinsii.* Photo by Steve Hootman.

R. maddenii. Photo by Pijush Kumar Dutta.

R. keysii. Photo by Ashish Paul.

Figure 1. Examples of *Rhododendron* taxa occurring in western Arunachal Pradesh. (*a*) *R. edgeworthii*, (*b*) *R. kendrickii*, (*c*) *R. keysii*, and (*d*) *R. maddenii.*

Figure 3. Sites predicted with high probability of *Rhododendron* species occurrence falling far from known sites of occurrence used to guide initial field sampling efforts. Yellow dots are known occurrences, and the red circles are areas that were of interest based on repeated prediction of potential occurrence of species.

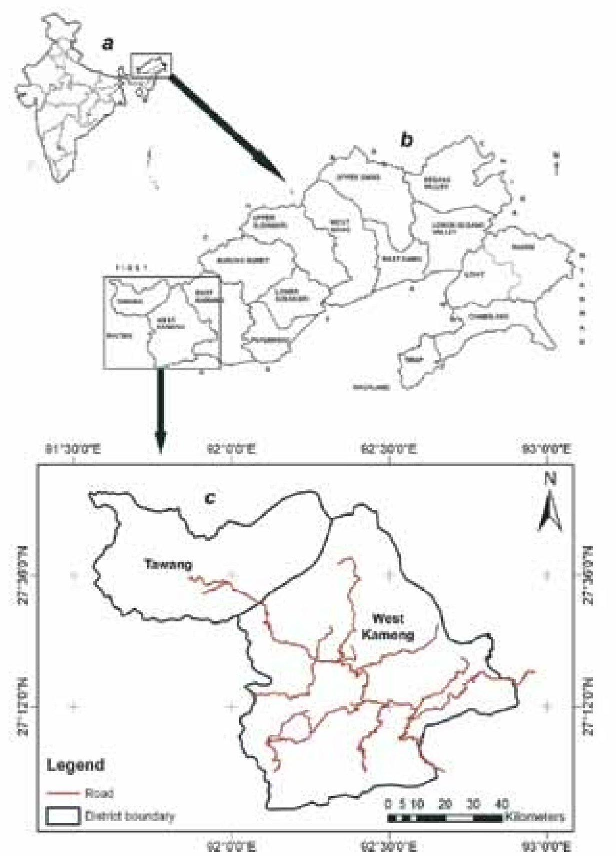

Figure 2. Map of study area: (*a*) India, (*b*) Arunachal Pradesh, and (*c*) Tawang and West Kameng district.

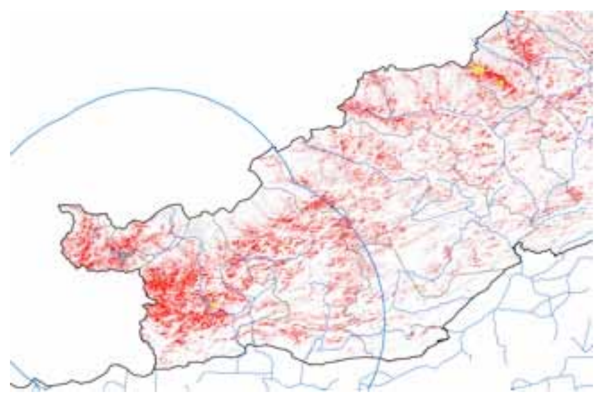

Figure 4. Niche model predictions (red areas) for one *Rhododendron* species (*R. kendrickii*). The arc indicates the boundaries of the area used for calibrating ecological niche models. Yellow areas indicate location of new populations from field surveys.

Figure 5. Sites identified for field surveys based on niche model predictions and accessibility. Purple lines are major roads and blue lines are district boundaries.

Abstract

Rhododendron species serve an important ecological and economic role in the mountains of the Eastern Himalayas. Recent changes in this once-pristine landscape have resulted in the classification of many *Rhododendron* species as threatened or endangered. This study used field surveys and ecological niche modeling to expand existing knowledge about *Rhododendron* species' distributions in the region, with a view to helping develop strategies for conservation action and possible reintroductions.

Introduction

Keystone species play a crucial role in maintaining the organization and diversity of their ecological communities. Rhododendrons (Figure 1) act as keystone species in the high-elevation portions of the Eastern Himalayas. The subalpine-to-alpine transition zone that includes timberline is the most fragile ecosystem in this part of the Himalayas. *Rhododendron* is the only group of plants that extends broadly across this ecotone. Unfortunately, however, increasing anthropogenic demands and technological development have rendered the region no longer immune to large-scale land-use change (Menon *et al.* 2001), and the last few decades have seen major transformations of once-pristine landscapes. As many as 46 *Rhododendron* species have been classified as rare or threatened in the Eastern Himalayas of India (Paul *et al.*, 2005). Many of the species also have ethnobotanical significance, as local people use rhododendrons as fuelwood and for medicinal purposes (Paul *et al.*, 2010).

Often, knowledge about the locations of populations of species is constrained by limited field surveys owing to rugged terrain and low population sizes with widely dispersed individuals. Precise information on species' distributions and ecology is important for assessing conservation status of endangered and rare species, and developing effective *in situ* and *ex situ* conservation and reintroduction strategies. All of these benefits can be leveraged still further using novel, GIS-based ecological niche modeling techniques that can assist in locating new populations as well as identifying suitable areas for reintroduction (Soberón and Peterson, 2005; Siqueira *et al.*, 2009).

We used ecological niche modeling (ENM), which combines known species' occurrence records with relevant environmental data layers to estimate species' ecological requirements and potential geographic distributions (Guisan and Zimmermann 2000; Soberón and Peterson, 2005). ENM provides a predictive framework for targeting areas for field surveys to locate additional population of rare and endangered species. We have already prototyped ENM applications to plants in this region in a recent study that resulted in discovery of several previously-unknown populations of the highly endangered tree species *Gymnocladus assamicus* (Menon *et al.*, 2010). An application of ecological niche model predictions to *R. arboreum* ssp. *nilagiricum*, an endemic tree species in the Nilgiri, Anamalai, Palni, and Meghamalai regions of the Western Ghats, India, found the species' distribution primarily influenced by mean diurnal temperature and number of dry months, and identified priority areas for *in situ* conservation of that species (Giriraj *et al.* 2008).

Specific objectives of this study were to: (1) prepare known-distribution maps of selected endemic, rare, threatened, or endangered *Rhododendron* species in the Eastern Himalayan region of Arunachal Pradesh, (2) identify ecological factors limiting species' distributions, and (3) assess threats to the species and analyze management practices at sites not presently under conservation. These steps would allow us to identify possible areas for reintroduction and examine new sites for as-yet unknown populations. The results of this study will enhance ongoing efforts for *in situ* conservation of such *Rhododendron* species in the Eastern Himalayas and contribute to building a broader conservation action plan.

Materials and Methods

Priority areas for field surveys within the state of Arunachal Pradesh (Figure 2) were determined based on prior knowledge about the likely distribution of pure to mixed *Rhododendron* forest. Such priority areas were in West Kameng, East Kameng, Tawang, West Siang, Upper Siang, Lower Subansiri, Upper Subansiri, Dibang Valley, and Anjaw districts (Figure 2).

The following 12 *Rhododendron* species were selected for study: *R. arboreum* ssp. *delavayi* var. *peramoenum*, *R. coxianum, R. dalhousiae* var. *rhabdotum*, *R. edgeworthii*, *R. falconeri* ssp. *eximium*, *R. hookeri*, *R. kendrickii*, *R. keysii*, *R. maddenii*, *R. megeratum*, *R. neriiflorum* ssp. *phaedropum*, and *R. tanastylum.* The species were selected on the basis of conservation status (Sastry and Hajra, 1983; Mao *et al.*, 2001) to include large and small trees, shrubs, and epiphytes that are endemic, endangered, rare, or threatened.

The distribution of selected *Rhododendron* species was investigated in initial exploratory field surveys. A set of parameters including geographic coordinates, biogeophysical characteristics of the area, and prevailing local threats to the species was recorded. Samples were collected and preserved in the herbarium after proper identification and labeling (Jain and Rao, 1977). Species were identified by consulting available references, including *The Rhododendrons of Sikkim-Himalaya* (Hooker, 1849), *Sikkim-Himalayan Rhododendrons* (Pradhan and Lachungpa, 1990), *Encyclopedia of Rhododendron Species* (Cox and Cox, 1997), *The Rhododendrons of Nepal* (de Milleville, 2002), *Flowers of the Himalaya* (Polunin and Staninton, 2006), *Materials for the Flora of Arunachal Pradesh* (Giri *et al.*, 2008) and *Flora of Assam* (Kanjilal, *et al.* 1939). Several herbaria, such as the State Forest Research Institute (SFRI), Itanagar; Botanical Survey of India (BSI), Itanagar and Shillong; and Central National Herbarium (CNH), Kolkata, were also consulted for validation of identifications, and further validation was achieved

Table 1. Habit, status, and occurrence data for 12 selected *Rhododendron* species.

Species	Habit	Status	Georeferenced occurrence points*
R. edgeworthii	Epiphytic shrub	Rare	42
R. maddenii	Shrub	Rare	34
R. arboreum ssp. *delavayi* var. *peramoenum*	Large tree	Endemic	26
R. neriiflorum ssp. *phaedropum*	Large shrub/tree	Threatened	23
R. kendrickii	Large shrub/tree	Rare	12
R. tanastylum	Shrub/small tree	Rare	16
R. keysii	Shrub/small tree	Rare	10
R. falconeri ssp. *eximium*	Large tree	Endangered	4
R. dalhousiae var. *rhabdotum*	Epiphytic shrub	Rare	3
R. hookeri	Shrub/small tree	Rare	3
R. megeratum	Dwarf shrub	Rare	2
R. coxianum	Epiphytic shrub	Endemic	1

by consultation with *Rhododendron* taxonomists Mr. Kenneth Cox (Managing Director, Glendoick Gardens Ltd., Perth, Scotland) and Dr. D. Bhattacharjee (*Rhododendron* revisioner, Botanical Survey of India, Kolkata).

Geographic coordinates of known occurrence sites, for the selected species were compiled from the exploratory field surveys; additional occurrences were obtained from electronic sources (www.gbif.org). Five of the 12 species had very few available occurrence points (n = 1 to 4), whereas seven species had ten or more occurrence points available (Table 1). We report here on preliminary analyses for four of the latter species: *R. edgeworthii*, *R. kendrickii*, *R. keysii*, and *R. maddenii*.

The occurrence data were used as input points to train an initial set of niche models for each of the four species. We used remotely-sensed layers from the NASA-MODIS/Terra data set (spatial resolution 500 x 500 m) to characterize environments across the region. Six of the layers were 16-day composite images of the Enhanced Vegetation Index (EVI) from every second month in 2005 and five of the layers summarized differences between consecutive pairs of the six EVI layers. We used two evolutionary-computing approaches to develop ecological niche models and associated geographic predictions: the Genetic Algorithm for Rule-set Prediction (GARP; Stockwell and Peters, 1999) and Maxent (Phillips *et al.*, 2006).

We generated a second set of niche model predictions by combining previously available occurrence data with new locations obtained from field surveys conducted in October-November 2009. Based on the second set of model predictions, we identified sites for targeted field surveys to explicitly validate and test the accuracy of the models and discover new populations in a systematic way. Sites were chosen for field surveys based on

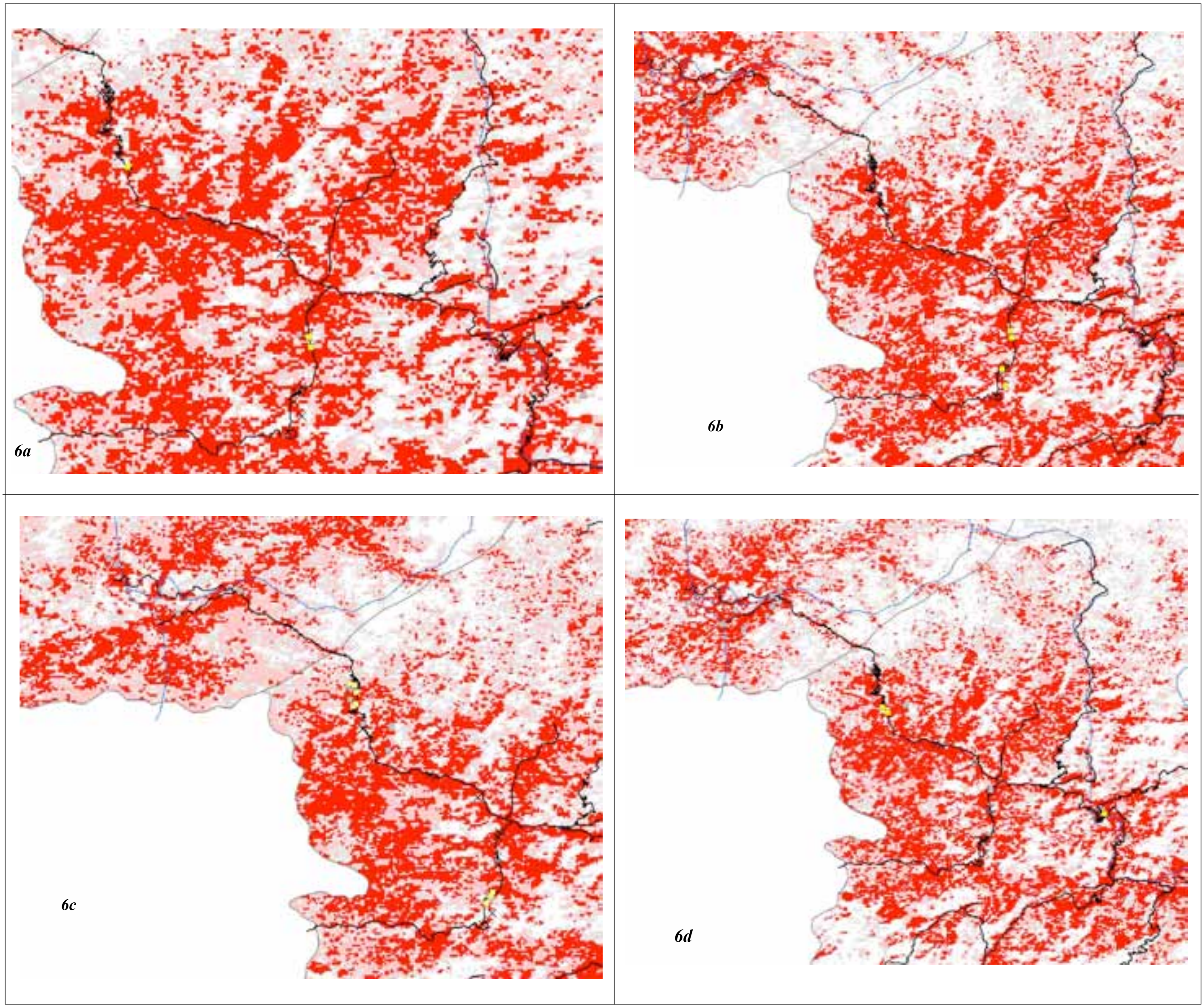

Figure 6. Niche model predictions and field validation for *Rhododendron* species: (*a*) *R. edgeworthii*, (*b*) *R. kendrickii*, (*c*) *R. keysii*, and (*d*) *R. maddenii*. Red areas are predicted potential presence, gray squares are previously known occurrences, and yellow squares are new occurrences located during field surveys to validate the niche model predictions.

niche model predictions and accessibility of predicted locations. These sites included those identified as highly probable for occurrence of particular species and sites identified as unsuitable for individual species: the field crew was unaware of the prediction (suitable versus unsuitable) for any given species, so that the tests of the model would be objective. Field surveys were carried out in February-March 2010 to validate the niche model predictions.

Results

The basic plan of the study was to generate an initial suite of models from data already available, and to visit a series of sites based on the initial models. Predictions from these initial models could then be tested in a second round of field surveys. A summary of areas thus identified as "of interest" based on the initial suite of niche model predictions is shown in Figure 3.

An example of an individual species' prediction is shown in Figure 4. Indeed, this initial suite of predictions and tests of predictions was quite successful. That is, the area remote from known occurrences of *R. kendrickii* in the north-eastern corner of Figure 4 indeed was confirmed to hold populations of the species in our initial field surveys. As a consequence, we had considerable confidence in further predictive efforts. Figure 5 shows a large number of sites identified for further study based on the initial success, and combining the initially available occurrence data with the new data from the first set of surveys.

The field survey team located seven previously unknown populations of the four study species as a result of the niche model predictions. All of the new detections of species during validation field surveys were either in or quite close to areas of predicted presence (Figure 6 a-d). Newly located populations consisted of one to two individuals; no large patches or populations were located. Individuals occurred at elevations of 2000-3800 m, and were observed growing along roadsides, forest edges, and in mixed forest with other rhododendrons. Individuals were found in flower bud formation or flowering phenophase. Individuals were recorded in adult and seedling stages; saplings were rarely observed. Pressures resulting from anthropogenic and developmental activities were noted at each of the new locations. While all the new detections closely matched areas of predicted presence, other surveyed areas of predicted presence did not contain individuals of these species, at least to the extent that our rapid surveys could establish.

Discussion

This study illustrates how a little knowledge can be turned into a lot more knowledge, using ecological niche modeling techniques. The niche model predictions allowed us to target field surveys, and facilitated the discovery of new locations of populations for *in situ* conservation of the species. The field validation demonstrated that the niche modeling did a better job at predicting presence *versus* absence. In other words, new individuals located in field surveys were found in areas closely matching model predictions; however, some areas predicted as suitable by the model did not appear to contain any individuals. Many reasons exist why a species might not be present in an otherwise suitable location, including local extirpation owing to overexploitation by humans, dispersal limitations, or presence of a competitor. Ecological conditions at these locations are suitable for *Rhododendron* species, but reintroduction efforts might only be successful, for example, if anthropogenic pressures at such locations were reduced by involving the local people in conservation efforts.

A majority of the region's human population lives in rural areas, where fuel-wood is the prime source of energy for cooking, boiling water, and heating homes during chilly winters. Ongoing land-use changes and exploitation of forest resources exert tremendous pressure on *Rhododendron* survival in the Eastern Himalayan region. Reduced availability of other plant species results in even greater anthropogenic pressure on *Rhododendron* species. The increased pressure in turn affects natural regeneration in a taxon comprising species that are generally slow growing. As a result, many *Rhododendron* species in the region have been categorized as threatened or endangered. Although, the Sikkim government has established two sanctuaries, Shingba and Barsey, as "*Rhododendron* sanctuaries" for conservation of rhododendrons (Singh *et al.*, 2003; Tiwari *et al.*, 2006, Singh, 2009), to date no conservation measures (such as sanctuaries, parks, or reserve forests) have been initiated for rhododendrons in Arunachal Pradesh.

Conservation efforts are more effective and economical if species are protected *in situ*. Vulnerable *Rhododendron* species are likely to become extinct in the Eastern Himalayas in the absence of adequate financial, technical, and extension efforts. Moreover, the region's biodiversity is under pressure from limited or alternative sources of income for the indigenous people. More than 50% of the reported *Rhododendron* taxa of Arunachal Pradesh occur in western (Tawang and West Kameng district) Arunachal Pradesh, which should be brought into the region's protected area network to conserve the endangered, endemic, rare, and threatened species occurring there from various anthropogenic disturbances. Various *in situ* as well as *ex situ* management practices such as the establishment of arboreta, sanctuaries, parks and reserve forests, protected areas through community management, botanical gardens, and in vitro research are imperative for conservation of keystone taxa.

Ecological niche modeling also plays an important role in identifying suitable locations for introductions or reintroductions of species. Reintroductions of the species could be initiated in suitable areas by introducing seedlings or saplings from areas where the species is more abundant. This step could also be achieved by introducing nursery-raised seedlings or by multiplication through tissue culture of species that are under threat. Like other germplasm, seeds of endemic, endangered, rare, and threatened *Rhododendron* species can be deposited in gene banks such as the National Bureau of Plant Genetic Resources (NBPGR) for future conservation and reintroduction. Reintroductions can eventually be carried out in deforested, degraded, and wasteland areas that once held *Rhododendron* forests, which not only conserves the species but also help to re-establish the species' habitat.

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[*] Source: Previous field surveys and www.gbif.org (georeferenced locations were from the Harvard University Herbaria)

See page 92 for Instructions on submitting photographs for the Photo Contest