

## Fire-induced invasion of an endemic plant species alters forest structure and diversity: a study from north-east India

Invasive alien species are regarded as principal threats to global biodiversity<sup>1,2</sup>. In this paper, we describe a situation where an endemic plant species, the dwarf bamboo '*Sinarundinaria rollaona* (Gamble) Chao & Renv.', invades the surrounding forested areas following a fire and becomes the dominant component suppressing other native species. The dwarf bamboo is endemic to eastern Himalayas and also grows in the Dzukou valley and surrounding hills of north-east India (Figure 1 *a* and *b*). The scenic beauty of the area attracts thousands of tourists to the valley throughout the year. The valley can be called as the 'valley of flowers' during the flowering season, i.e. April to September. It may also be called the 'valley of bamboo' as the open valley and surrounding hillocks devoid of forests trees are fully covered by the dwarf bamboo which appears like an open grassland from a distance (Figure 1 *a*).

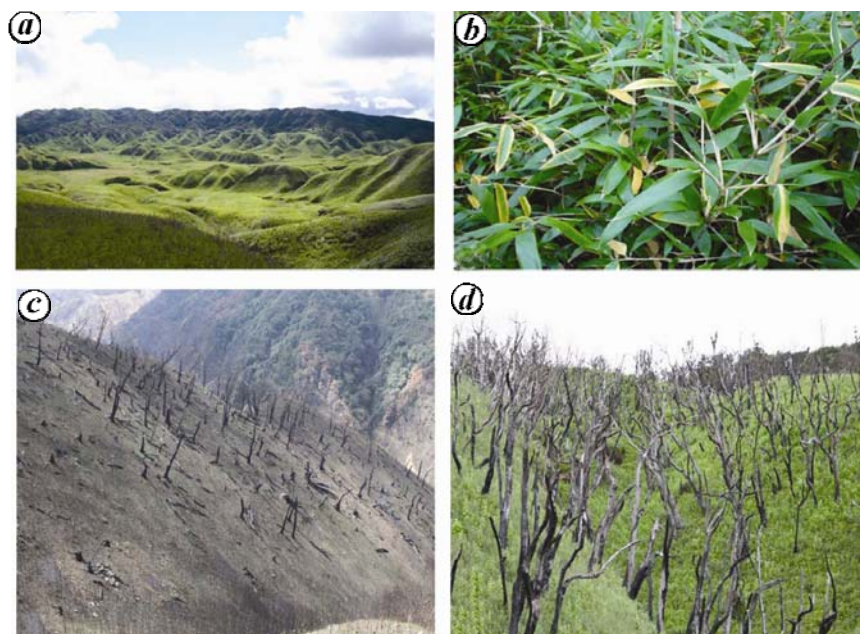
Over the past several years we have observed that the pristine forests of Dzukou valley and the surrounding hills are being destroyed extensively by frequent annual forest fires due to anthropogenic activities, causing a serious threat to biodiversity. The main cause of the fires is the thick growth of native dwarf bamboo in the valley and open spaces in the hills that gets burnt easily during the dry season. The dwarf bamboo grows more vigorously after the fire resulting in rapid colonization and invasion of the open spaces created by the forest fire. The fire-dwarf bamboo cycle has become an annual affair due to the heavy influx of tourists to the valley. The magnitude of destruction can be imagined from the devastating fire in January 2006 which lasted for over a week. The State Forest Department, Government of Nagaland with the help of Indian Air Force conducted aerial surveys to gauge the extent of damage using GPS to map the area of devastation, which spread over 70 sq. km of Dzukou hills and valley and the adjacent Japfu hill ranges (Figure 1 *c* and *d*).

We undertook a study in 2006–08 on three sites in Dzukou valley and surrounding hills with the objective to determine the status of regeneration of dwarf bamboo in relation to other native species following the forest fire.

The Dzukou valley is situated at the border of Nagaland and Manipur states (Figure 2). The valley and the hills surrounding it have an area of about 27 sq. km. The elevation ranges from 2400 m in the valley to 2994 m above the mean sea level in the surrounding hills. Geologically the area is of recent origin. The soil is black in colour indicating that it is rich in humus. The natural drainage system is maintained by a number of streams which have their origin in the hills and later join in the valley to form the main Dzukou river. The river flows down the valley criss cross towards the west to Paren district of Nagaland and down to Assam plains. The climate is warm temperate monsoon with an annual rainfall of more or less 2000–2500 mm. The vegetation of the area can be briefly described as temperate to sub-alpine (2400–2994 m). The hills surrounding Dzukou valley have rich temperate forest vegetation besides the thick dwarf bamboo vegetation on the hill-slopes. The dominant tree species found in this forest are *Betula utilis*, *Rhododendron* spp., *Gaultheria* spp., *Peiris formosa*, *Lyonia ovalifolia*, *Lithocarpus pachyphylla*,

*Quercus lamellosa*, *Ilex* spp., *Taxus wallichiana*, *Juniperus recurva*, *Symplocos* spp., etc. The main valley (c. 2400 m) is devoid of big trees but rich in herbaceous plant species with few small shrubs here and there. The dominant species are *Lilium mackliniae*, *Euphorbia sikkimensis*, *Rhodiola heterodonta*, *Polygonatum verticillatum*, *Satyrrium nepalensis*, *Primula* spp., *Caltha palustris*, grasses, *Sinarundinaria rolloana*, *Anemone* spp., *Aconitum nagarum*, *A. elswii*, *Thalictrum* spp., *Selinium* spp., *Oenanthe* spp., *Ligularia* spp., *Carex* spp., *Juncus* spp., *Osmunda claytonia* subsp. *vestita*, *Potentilla* spp., etc.

Three sites which differed from each other with respect to fire incidence were selected for the study. Site-1, the valley (c. 2400 m) gets burnt by mild fire almost every year during the dry season, i.e. November to March; site-2 (c. 2550 m), gets burnt by a devastating forest fire in January 2006; and site-3 (c. 2600 m) is situated in a forest area on the hills surrounding the valley. The phytosociological analysis of dwarf bamboo and associated plant species was carried out by using five, 3 × 3 m randomly dis-



**Figure 1.** *a*, A view of Dzukou valley – the green grassland-like appearance of the valley and hill-slopes is due to dense cover of the dwarf bamboo. *b*, A closer view of *Sinarundinaria rollaona* – the invasive dwarf bamboo. *c*, Photograph taken in April 2006 after the forest fire in January 2006. *d*, Dense dwarf bamboo forest formed after one year of forest fire.



Figure 2. The location of Dzukou valley in north-east India.

tributed quadrates on each site according to Misra<sup>3</sup>. In each quadrate, each species were individually counted and in the case of dwarf bamboo, each individual culm was counted. Frequency, relative frequency, density, relative density, abundance, relative dominance<sup>4</sup>; abundance frequency ratio<sup>5</sup> and importance value index (IVI) of each species were calculated<sup>6</sup>.

The study revealed that dwarf bamboo showed the highest IVI on site-2 followed by site-1. On site-3, *Gaultheria hookeri* showed the highest IVI. The dwarf bamboo thus dominated the burnt sites and exhibited excellent power of regeneration following the fire. Other species with low IVI are of little significance to the community and are not able to compete with dwarf bamboo in the prevailing environment. If such a condition (repeated fire) prevails for long time, dwarf bamboo will eliminate other species. The relative density of dwarf bamboo in the three study sites especially in site-2 indicates that the species grows more vigorously after forest fire contributing to its success in invasion. On site-3, apart from dwarf bamboo, all the other plant species found were trees and shrubs. The population of dwarf bamboo in the valley is so thick now that it grows like the grasses with an average

height of about 30 cm. However, in the forested area not affected by fire in the recent past, the understorey population of dwarf bamboo is sparse and height of the culms varies from 2 to 3 m. If such a forested area is burnt, the dwarf bamboo assumes dominance through rapid regeneration and suppresses the regeneration of other species.

The dwarf bamboo embodies several of the advantageous characteristics of fire-adapted invasive species, such as: (i) it resprouts readily on being burnt. In fact, the present study has shown that it grows more densely in response to burning as reported in *Lantana*<sup>7</sup>. This bamboo forms dense impenetrable thickets and it severely restricts the regeneration of other species. Like in *Lantana*, dwarf bamboo once established, fuels further fires, setting up self-feeding fire-dwarf bamboo cycle. This dwarf bamboo flowers sporadically and not gregariously (usually the bamboo species dies after flowering) which is another advantageous characteristic of dwarf bamboo. Thus, forests once colonized by the dwarf bamboo will fall victim to fire-dwarf bamboo cycle. (ii) A second mechanism underlying the success of dwarf bamboo is its ability to compete for scarce nutrients. It can grow even on rock crevices where it is devoid of soil and nutrients

which is an indication that it is exceedingly efficient at nutrient uptake and use, enabling it to grow on highly impoverished soils as does *Lantana*<sup>8</sup>. Such an ability to extract and use nutrients efficiently would give it a competitive advantage over other species. (iii) Finally, a third mechanism underlying the success of dwarf bamboo is its colonizing ability. The rhizomes grow deep in the soil, solid and strong, so physical removal is very difficult. Thus, a complete eradication of dwarf bamboo requires repeated uprooting of sprouts for several consecutive years.

The phenomenon of the invasive grass-fire cycle has been especially well-documented for the Americas, and on the Hawaiian Island<sup>9-11</sup>. Historical record on fire regimes in the Dzukou valley and surrounding hills is not available. However, there is good reason to infer that forest fires have been more frequent in recent years than before. Burnt stumps of tree trunks standing on the hill-slopes speak of the ferocity of recent forest fires (Figure 1 c and d). The alteration in fire regimes is thus causing wide-ranging consequences for the forest structure, composition and functioning. The altered fire regimes have probably made the ecosystem susceptible to invasion by the fire-tolerant or fire-resistant dwarf bamboo.

According to Ewel<sup>12</sup>, the ecological traits of invasive species alone do not necessarily determine invasions. The presence of invasive species may merely be a 'symptom', the underlying cause being ecosystem invasibility. There are reports of increasing ecosystem invasibility due to disturbance: more disturbed ecosystems are more vulnerable to invasion than less disturbed ones<sup>13-15</sup>. In the present case also, the area is greatly disturbed by the influx of thousands of tourists throughout the year and their careless behaviour that results in forest fires.

In our view, the biggest threat to the biodiversity of the area is the fire induced invasion by the dwarf bamboo which is rapidly colonizing and altering the forest structure and diversity of the Dzukou valley and the surrounding hills. There are still patches of pristine forests in the surrounding hills with its unique flora and fauna. The populations of several species are facing survival threats to their natural habitats, whereas a few are already on the verge of extinction<sup>16,17</sup>. If the present trend of annual forest fires

and consequent dwarf bamboo invasion is not controlled, the entire valley and the surrounding hills will be covered by the dwarf bamboo. There is an urgent need to put in place large-scale monitoring of fires and spread of dwarf bamboo to better gauge the spatial and temporal patterns of one, and the spatial extent of the other. The task requires active participation of stakeholders, viz. the local communities, wildlife conservationists, forest managers, government agencies and the civil society at large. Also, well-planned ecotourism will certainly be a solution for protection of these hill ranges which will conserve the unique biodiversity of the area in general and endemic ones in particular *in situ*.

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ACKNOWLEDGEMENTS. We are grateful to the Director, Botanical Survey of India, Kolkata and Joint Directors, Botanical Survey of India, Eastern Circle, Shillong and Arunachal Pradesh Circle, Itanagar for providing the facilities that made this work possible. Also, we thank Prof. J. S. Singh, Emeritus Professor, Banaras Hindu University, Varanasi, for the critical comments and suggestions during the preparation of this paper.

Received 2 March 2009; revised accepted 18 January 2010

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## Land–ocean tectonic signatures of the Krishna–Godavari Basin, a qualitative evaluation

The Krishna–Godavari (K–G) Basin extends approximately from Nellore in the south to Kakinada in the north and forms one of the most promising petroliferous basins of the East Coast of India. The basin has a unique half crescent shape and the onland part consists of 28,000 sq. km and offshore basinal area covers 24,000 sq. km up to the isobath of 200 m. On the basis of geophysical surveys carried out by ONGC, the onshore basin is divided into three sub-basins, viz. Krishna, West and East Godavari sub-basins by two prominent NE–SW basement ridges called Bapatla and Bhimavaram–Tanuku Horsts<sup>1</sup>.

The preliminary analysis of the bathymetry and total field magnetic data collected over the eastern continental margin of India (ECMI) between 17°N and 14°N lat. covering the area of K–G Basin and the available coastal geological and geophysical data brought out new

information on land–ocean tectonic lineaments (LOTL).

The bathymetry data reveal that the water depths in the area vary from 40 m (near shore) to 3000 m (offshore). It indicates high gradient tightly packed contours over offshore Krishna Basin between 40 and 1000 m water depth whereas between Krishna and Godavari rivers, the pattern shows relatively wider shelf from 40 m to slope regions up to 2500 m water depth. The band of depth contours ranging from 1000 to 2400 m (shown as shaded portion) appears to be sheared and bounded by fault lineaments F1 and F2 (Figure 1).

Single beam bathymetry (Figure 1) contour map is overlain by the multi-beam bathymetry contours. The NW–SE trending topographic rise of 500 m from the adjacent seafloor of 1750 m observed in multibeam bathymetry study<sup>2</sup> falls in the area where the shearing was observed

in the present bathymetry data. The landward extension of this topographic rise, well depicted in the multibeam bathymetry contours probably abuts the trend of the Bhimavaram–Tanuku Ridge at the coast. Deep seismic sounding studies of Narasapur–Paloncha DSS profile<sup>3</sup> nearer to the coast also indicate a basement rise at a depth of 4.0 km corresponding to the Bhimavaram–Tanuku Ridge.

The total intensity magnetic anomaly map (Figure 2) exhibits two major trends in NE–SW and NW–SE direction. The amplitude of magnetic anomaly varies from –280 to +240 nT. On the basis of the anomaly signatures, the area is divided into three zones namely A, B and C. The zone A is characterized by NE–SW trending anomalies whereas the zone C is characterized by NW–SE trending anomalies. The NE–SW trending wide curvilinear anomaly zone A, approximately runs parallel to the coast within the