Population structure of Scotch broom (*Cytisus scoparius*) and its invasion impacts on the resident plant community in the grasslands of Nilgiris, India

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We investigated age and size class structures of Scotch broom stands, and the effects of invasion on the native plant community, in the high-altitude grasslands of the Nilgiris, South India. Girth, height and age of broom stems were recorded. Native vegetation cover was assessed under broom and in the surrounding grasslands. Age was positively correlated with girth and height of broom. Middle-age classes were better represented than the younger classes. Species richness and diversity of native plants were affected by invasion intensity, but not duration.

Keywords: Age and size structures, diversity, exotics, native species loss.

GRASSLANDS and savannas worldwide are undergoing phenomenal transformations in structure, composition and ecosystem function due to expansion of woody invasive plants[1,2]. Changes in relative proportion of woody and herbaceous biomass bring about structural modifications, while displacement of original species or release of new species can alter the composition of the plant community[3–5]. Dramatic shifts in patterns of dominance and distribution in native plant communities can not only lead to the extinction of less common plant species[6], but can also impact the populations of native fauna, directly through availability of food resources and habitat, and indirectly through competitive interactions[7]. Establishment of exotic plants is often facilitated by disturbances in the landscape[3]. As soon as a self-sustaining population is established, most species, by altering the community composition and structure, modify existing disturbance regimes or create new disturbances and transitional states that affect ecosystem structure and function[8].

The grasslands of the upper Nilgiris are home to several endemic flora and fauna[9]. The grasslands are being fast closed in by various woody exotic species[9] (M. P. Srinivasan, pers. obs.). Invasion by *Chromolaena odorata* (L.) King & Robinson, *Cytisus scoparius* (L.) Link and *Ulex europaeus* (L.) was first reported[10] in the late 1930s. Wattle (*Acacia mearnsii* (de Wild)), planted in the later half of the nineteenth century, has naturalized and is now fast encroaching the grasslands. *C. scoparius* (Scotch broom or broom) appears to be dominating vast areas of the grasslands in the Nilgiris[9] (M. P. Srinivasan, pers. obs.). Though concern over expansion of Scotch broom has initiated attempts to test the efficacy of various chemical and mechanical methods[9], little has been done to understand the mechanism of invasion and its impact on the native flora.

A majority of the weed control programmes are discontinued after initial trials, as the potential threats posed by exotics are not well perceived. Other reasons are the high costs of weed eradication, and doubts regarding the effectiveness of control methods[11]. Scientific documentation of negative effects of exotic invasion is essential to provide impetus to any eradication programme. Similarly, it is imperative to understand the population ecology, including factors responsible for establishment and persistence, not only to determine types and levels of control, but also to target the life-stage of the weed that might be most vulnerable to a given control method.

Age and size class structures are good indicators of the health of plant populations, specifically regeneration patterns[12]. In stable populations, there is highest representation of smaller and younger individuals, while the larger and older individuals are poorly represented. The age and size class distribution of such a population produces a characteristic reverse J-shaped curve[12], or an exponential decline. We hypothesized that the above described pattern will be seen in the Scotch broom population sampled in upper Nilgiris if they are stable, assuming age and girth are positively related.

Invasion of woody exotic plants is often associated with decline in species diversity and biomass of herbaceous native plants[7]. We hypothesized that there will be a negative relationship between species diversity and biomass of native plants, and invasion intensity. Further, this pattern may also be influenced by the duration for which the infestation

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has been present at a particular site. A survey was carried out in sites invaded by broom in the high altitude shola-grasslands of Nilgiris, to test the above hypotheses.

Methods

Study area

The Nilgiri Hills, an integral part of the Western Ghats complex, is located between 11°10′–10°30′N lat. and 76°25′–77°00′E long., at the junction of the Eastern and Western Ghats. The altitude in the upper areas of the Nilgiris ranges from 1800 to 2500 m amsl. May is the warmest month with a mean maximum temperature of 20°C, while January is the coolest month with a mean maximum temperature of 7°C. The Nilgiris experiences two wet periods, the first receiving rain from the southwest monsoon between June and September, and a second post-monsoon period between October and December. The western regions of the plateau receive about 3000 mm of rainfall which exceeds 5000 mm in certain sites. The bedrock of the Nilgiris consists of Precambrian rocks, chiefly gneisses, charnokites and schist[13]. The soils are classified as non-allophanic andisols[14]. The natural vegetation of the upper regions is classified as Southern montane wet temperate forests and montane grasslands[15]. The montane vegetation consists of patches of stunted evergreen forests (locally referred to as sholas) surrounded by grasslands. There is a sharp ecotone between the sholas and grasslands, and this ‘dual climax’[16] has been attributed to the prevalence of frost, fire and grazing[10,16].

This study was restricted to the area around Upper Bhavani Reservoir, specifically the Lakkadi area (Nilgiri South Division) in the southwest corner of the Nilgiri plateau. This region fringes with the Mukurthi National Park, which is a prime habitat of the endangered and endemic Nilgiri tahr (*Hemitragus hylocrius*). These regions are well protected relative to other parts of the Nilgiris. However, invasion by the exotic shrubs, Scotch broom and Grouse (*Ulex europaeus*) is prevalent here. *Acacia* plantations occur scattered throughout the landscape. A typical view presents *Acacia* saplings climbing down the hills in Lakkadi and Scotch broom climbing up, thereby sandwiching the grassy stretches.

Study plant

Scotch broom is a polycarpic perennial plant, native to parts of central and western Europe[17]. This leguminous shrub grows to nearly 3 m height in the study site. Plants exhibit plasticity in traits; in the Nilgiris, it is seen in a range of habitats from open high-altitude grasslands (ca. 2200 m) to *Eucalyptus* plantations at slightly lower elevations, and leaves are broader in plants growing under tree cover than in open grasslands. Scotch broom seeds and seedlings germinate and survive better in disturbed sites[18]; seeds remain viable in seed banks for decades[19,20]. Plants were in flowering and fruiting condition during our visits to the site from May through July 2005. The earliest published reports[10] of Scotch broom invasion in the Nilgiris date back to 1938. It is believed to have been introduced as an ornamental by British settlers in the region[9].

Vegetation sampling

The study was carried out between June and July 2005, and plots were set up in the Lakkadi grasslands, large areas of which were occupied by Scotch broom thickets. Eighteen 25 sq. m (5 m × 5 m) plots were set up in or around randomly selected Scotch broom thickets of similar topographic position, such that the centre of the plot roughly coincided with the centre of the thicket. The girth at the base of all the broom shrubs in the plot was measured. Subplots (1 m × 1 m) were placed at three randomly selected points by casting a 1 m × 1 m frame over the shoulder, while standing at the corners of the plot. Broom individuals encountered within the 1 m × 1 m subplots were cut at the base to count the growth rings to determine the age[21], girth at the base, and height from the base to the tip of the longest branch, which was measured prior to harvest of these individuals. The cover of native grasses and forbs was assessed within each of these subplots by visually estimating the relative contribution to cover of each species. Estimates were made by placing a 1 m × 1 m frame (divided into ten grids of equal size) on the ground over the herbaceous vegetation. If species *X* covered half the area of one grid (10 cm × 10 cm), its cover was estimated at 5%; the per cent cover for various species was averaged among the three subplots to arrive at an estimate for the 25 sq. m plots in which they were nested. Aboveground biomass of the native herbaceous plants was measured by harvesting 0.1 sq. of biomass by clipping at ground level from the centre of each subplot. Biomass samples were brought back to the field station, oven-dried at 80°C until constant weight, and their weights were obtained. Similarly, eight 5 m × 5 m plots were set up in uninvaded grassland patches adjacent to Scotch broom stands. Measurements of species richness, species cover and aboveground biomass were made in these plots. We were unable to sample more plots due to time constraints.

Analyses

Histograms of age and size of Scotch broom were constructed to describe patterns in population structure and regeneration dynamics of broom stands. Correlations were used to examine the strength of the relationships between age and girth, and age and height of Scotch broom plants; also, regression analyses were performed to examine the nature of these relationships. Basal area of broom within a

25 sq. m plot was considered as a measure of the invasion intensity. This was regressed against species richness, diversity and biomass of native plant species to understand the nature of the change in native plant structure and community in relation to Scotch broom invasion. Average age of broom within each plot was regressed against native species parameters to test if duration of infestation at any particular site influenced the native species. Diversity was calculated using the Shannon–Weaver index as $H' = \sum pi\ln(pi)$, where *pi* represents the mean (averaged among the three subplots) proportional contribution of the *i*th species to the canopy[22].

Two sample *t*-tests were used to test for significant differences in species richness, diversity and biomass of native plant species between the uninvaded grassland plots ($n = 8$) and Scotch broom sites ($n = 18$). Native species were classified into two functional groups, namely grasses and forbs to examine the response of each of these groups to broom invasion.

Results

Age and size structure

Age of the Scotch broom plants ranged from less than a year to a maximum of 13 years (mean ± SD = 4.8 ± 0.23, n = 157). Age was positively correlated with girth ($r = 0.69$, $P < 0.001$) and height ($r = 0.64$, $P < 0.001$) linearly (Figure 1). Age explained 47% of the variance in girth and 39% in height. The trends from the regression suggest that girth could be a better indicator of the age of a plant rather than height. The characteristic reverse J-shaped curve was not observed in the age and girth class structures of the Scotch broom plants in the study area (Figure 2).

Recorded girths of sampled individuals started from as low as 0.5 cm, but since few of these individuals were encountered, they were excluded from the analyses; only datapoints above 4.0 cm girth were plotted. Regeneration appears to have been interrupted in the past couple of years, as suggested by the low numbers of seedlings and individuals aged less than 3 years encountered during the study. It may be premature to assume a declining trend in the population, as seeds in the seed bank may not germinate for several years[19,20].

Effect of broom invasion on native plants

The *t*-test for mean species richness (grassland = 13.75 g, broom = 8.0 g, $P = 0.004$) of native vegetation in Scotch broom stands and the adjacent uninvaded grasslands showed a significant difference at the 5% significance level, while biomass was different (grassland = 13.34 g, broom = 6.18 g, $P = 0.096$) at the 10% significance level. However, diversity did not significantly decrease due to the presence of Scotch broom (grassland = 1.52, broom = 1.15, $P = 0.145$).

Within the broom stands, a significant quadratic fit was observed for species richness ($R^2 = 0.25$, $P = 0.12$) and

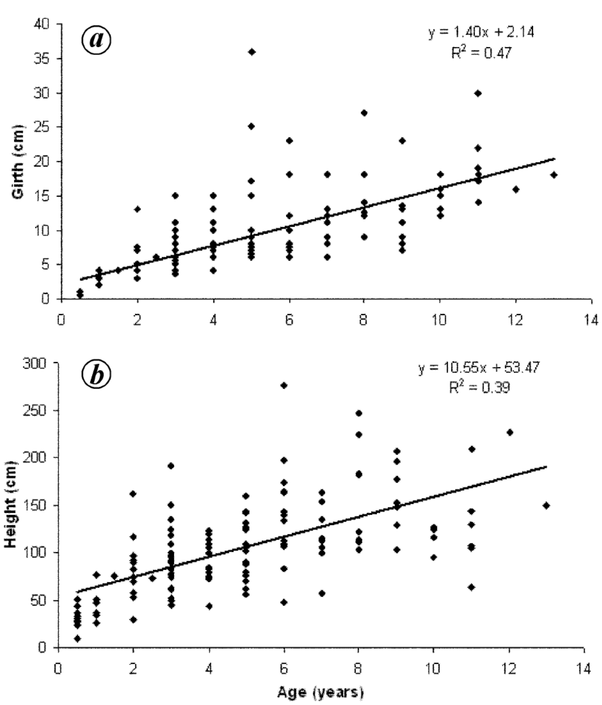

Figure 1. Relationship between (***a***) girth (cm), and (***b***) height (cm) and age (years) of Scotch broom plants in the population.

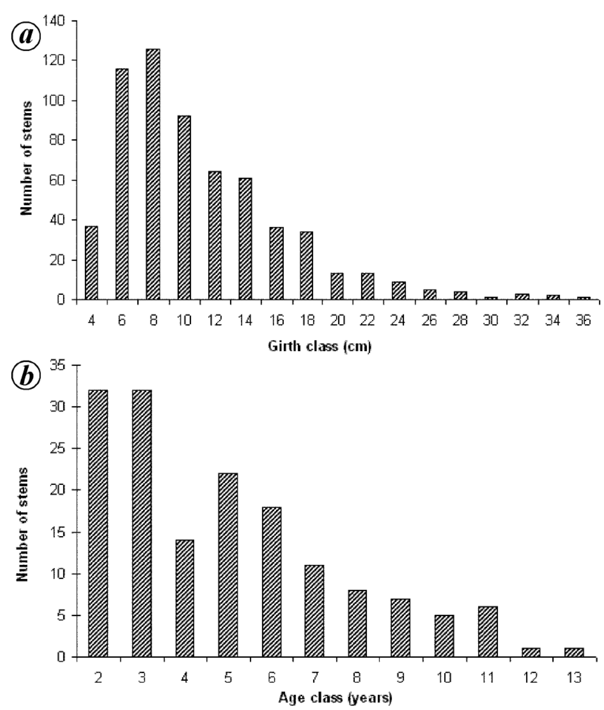

Figure 2. Girth class (***a***) and age class (***b***) structures of sampled plants in the Scotch broom population.

diversity ($R^2 = 0.46$, $P = 0.001$), with invasion intensity as measured by basal area of Scotch broom in the 25 sq. m plots (Figure 3). Species richness and diversity of native plants were least at intermediate intensities of invasion (300–525 sq. cm, $n = 8$ plots) compared to low (<300 sq. cm, $n = 5$ plots) and high levels (>525 sq. cm, $n = 4$ plots) of invasion. However, there was no significant relationship between herbaceous native biomass and invasion intensity. The average residence time of Scotch broom, in other words, the mean duration for which broom stands were present in the 25 sq. m plots, did not influence any of the native plant community parameters mentioned above.

Though over 60% of the native plant species encountered were forbs, they accounted for only 11% of the total cover across all the plots sampled, while grasses and sedges constituted 88% of the total native plant cover. Among the grasses and sedges, *Isachne kunthiana* (Wight & Arn. ex Steud.) Miq. was dominant under broom stands, while *Andropogon polyptychus* Steud. and *Chrysopogon zeylanicus* Thw. dominated the grassland sites (Figure 4 *a*). Among forbs, *Hypochaeris glabra* L. was found in comparable numbers in both broom and grassland plots. Certain species such as *Leucas hirta* Spreng. and *Fragaria nilgerrensis* Schlecht. were found only under broom stands, while *Iphigenia* sp. and *Leucas suffruticosa* Benth. were more common in grasslands than in broom plots (Figure 4 *b*). However, nearly all of these differences were not statistically significant. Per cent cover of *L. suffruticosa* was significantly more ($P = 0.029$) in grassland sites than under broom stands. Graminoids and forbs that were recorded under broom and not in the sampled grassland plots were common in the grasslands in general, suggesting that the grassland was under-sampled.

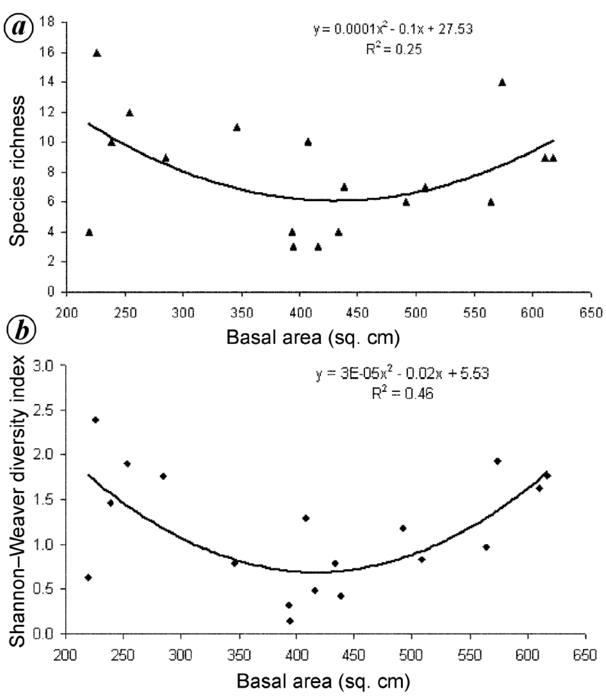

Figure 3. Regression of (***a***) species richness and (***b***) diversity, expressed as a Shannon–Weaver index, with basal area of Scotch broom as a measure of invasion intensity within the 25 sq. m plots.

Discussion

Strong correlations between age, girth and height of Scotch broom plants as reported from this site, have been well documented in New Zealand, Australia and France[21]. These trends can be interpreted as the growth of Scotch broom being uniform over time. Paynter *et al.*[21] found that age explained 88% of variance in stem diameter, and 66% of variance in height. We found that age explained only 47% and 39% of variance in girth and height respectively, and these were statistically significant. The aforementioned age structure studies were conducted in temperate parts of the world where there are stark differences between summer and winter temperatures relative to the Nilgiris. The moderate differences between summer and winter temperatures possibly resulted in growth-ring patterns that are not as

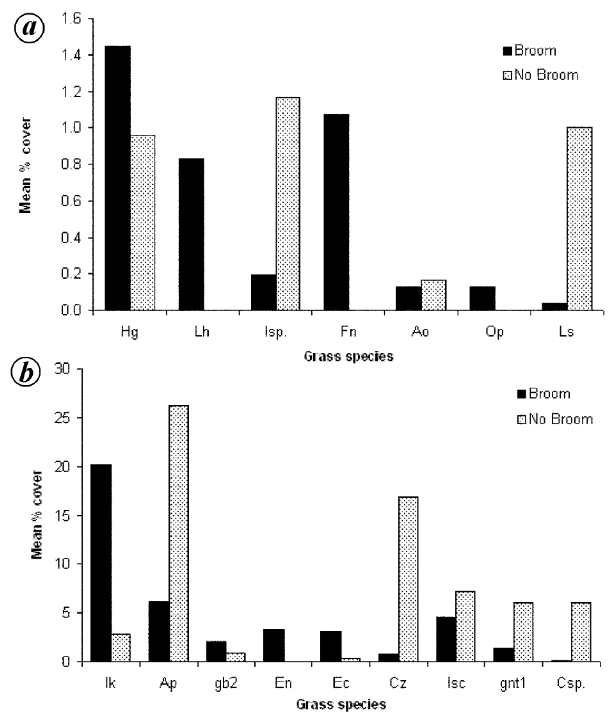

Figure 4. Comparison of cover of common species of (***a***) forbs and (***b***) grasses and sedges in Scotch broom and grassland plots. Forbs (from left to right) are *Hypochaeris glabra, Leucas hirta, Iphigenia* sp., *Fragaria nilgerrensis, Anaphalis oblonga* DC., *Oxalis pubescens* and *Leucas suffruticosa* (significant, $P = 0.029$). Grasses and sedges (from left to right), are *Isachne kunthiana, Andropogon polyptychus,* unidentified grass 1, *Eragrostis nigra* Nees ex. Steud., *Elaeocharis congesta* Don, *Chrysopogon zeylanicus, Ischaemum ciliare* Retz., unidentified grass 2 and *Cymbopogon* sp.

discrete as might be seen in temperate regions. The indistinct patterns may have led to the subjective estimation of age in a few cases, which in turn reduced the explanatory power of our model. Additionally, sambar (deer) browsing of Scotch broom[9] (M. P. Srinivasan, pers. obs.), which is common in the region, would have affected the model. Thus, girth was considered to be a better predictor of age than height.

Paynter *et al.*[21] observed that open sites had a slight tendency to exhibit the reverse J-shaped curve in age structure of Scotch broom stands. Similar patterns occurred in our grassland sites. The recruitment decline observed in our site, as evidenced by the relatively lower number of young individuals, could be speculated as a result of an undocumented increase in seed predation or seedling mortality, or conditions inhibiting germination of seeds, for example, lack of dormancy-breaking factors.

It was interesting to observe that sites with intermediate levels of broom invasion showed maximum loss in native species richness and diversity. We believe the following process might explain the low diversity at intermediate invasion intensities seen in our study: the herbaceous plant community in the shola-grasslands consists of light-demanding grassland species, and shade-specialist shola species. As Scotch broom invades the grasslands, light-demanding species are steadily eliminated, however, as the thickets increase in density, shade-specialist species, dispersed from the adjacent sholas, establish themselves and predominate. For example, *I. kunthiana*, *F. nilgerrensis*, *Oxalis pubescens* H.B. & K. and an unidentified grass (gb2) that were observed in shade conditions in the study area were also found growing under broom thickets. Average age of the broom stands was not correlated with density of the stand, and did not control species richness, diversity and biomass of native plants. It would be worth testing whether different trends emerge when sampled across a larger landscape.

Though the species richness and biomass of native plants did not show a clear decline with broom densities, presence of broom itself affected the plant community parameters. Although the species diversity values were not very different ($P = 0.145$) between broom stands and grassland plots, the composition of native plants differed in patterns of dominance, suggestive of species replacement rather than loss. *I. kunthiana*, a broadleaved, shade-tolerant grass, contributed to much of the biomass under broom stands, while *A. polyptychus* and *C. zeylanicus*, which are among the dominant species in these grasslands, were almost completely eliminated under broom. Dramatic loss in native species richness and cover has been reported in a recent study in a subalpine habitat in Australia[23]. Exotic plants are often implicated in modifying soil properties that might affect the success of native plants[24]. Other mechanisms of displacement of native plants by exotics include allelopathy and shading effects, competition for resources, and alteration of disturbance regimes among others[3]. Wearne and Morgan[23] have attributed reduced light levels and accumulation of a thick litter layer under Scotch broom as a barrier for germination of native forbs. There may be several mechanisms by which Scotch broom displaces native vegetation depending on the affected species.

Parker[25] has reported that disturbances such as fire reduced seedling establishment of Scotch broom. Since fire has been a part of this landscape for several centuries, it may be considered as an efficient and inexpensive management tool in the Nilgiris. Some researchers[17,26] have achieved reasonable success in broom removal with bio-control agents. However, such trials must be adopted with caution in ecosensitive regions such as the Nilgiris. Chemical control has been attempted in the Nilgiris[9] and elsewhere[27], and the success of this might be evaluated for future decisions. Mechanical removal has been attempted in this site[9] (A. C. Soundarajan, pers. commun.); additional removal and monitoring of succession in eradicated sites will provide useful insights into the regeneration potential of native plants.

More research needs to be directed towards understanding the factors controlling establishment of Scotch broom in the Nilgiris. Researchers have listed several factors for the same, such as life-history strategies of the species in conjunction with dispersal, disturbances and competing vegetation[3,25]. These factors need to be examined in the context of the Nilgiris.

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