Indicator species for the natural regeneration of *Shorea robusta* Gaertn. f. (sal)

Species interactions are considered important in the process of understanding the overall ecology of a species. In any given habitat there are a number of biotic and abiotic factors which may influence the distribution, abundance and interactions among species. In general, an association between two species exists because: (i) both species select or avoid the same habitat or habitat factors; (ii) they have the same general abiotic and biotic environmental requirements; or (iii) one or both of the species has an affinity for the other, either attraction or repulsion[1]. Knowledge of these interspecific associations may help us resolve various dilemmas, especially regeneration of *Shorea robusta* Gaertn. f. (sal).

In this correspondence chi-square and association indices[2–4] were used for detecting the existence of association and assessing the degree of association between sal and its associates at tree, shrub and herb layers, separately for the moist sal forests. Hubalek[1], and Janson and Vegelius[5] have recommended these three indices as they generally perform well. These indices are equal to 0 at 'no association' and 1 at 'maximum association'. The objectives of the present study were: (i) To find the positive and negative associates/indicators for sal regeneration in different strata using chi-square and various association indices. (ii) To correlate soil parameters, viz. temperature (°C), moisture (%) and pH with sal regeneration.

The geographical area of Doon Valley is estimated[6] to be approximately 2100 sq. km, out of which 56.84% (1193.75 sq. km) is occupied by moist sal forests[7]. The present study was carried out in 36 points spread in four forest ranges of the Doon Valley[8,9], covering an approximate area of 432.41 sq. km, and lying between 30°02′–30°21′N long. and 77°52′–78°20′E lat., with average altitude of 600 m asl.

A total of 36 points were selected randomly from different parts of the Doon Valley to cover all the variations. At each point ten quadrats were laid along a transect line from northeast to southwest direction. The sizes of quadrats were 10 m × 10 m, 3 m × 3 m and 1 m × 1 m for tree, shrub and herb layers respectively. Therefore, for each stratum 360 quadrats were sampled. The saplings of tree species were considered in the shrub layer and seedlings of both tree and shrub species in the herb layer.

From every quadrat, data on abundance of species were collected. These numerical abundances were then converted to presence/absence data; the presence of species was indicated by 1 and absence by 0. The transformed data were then computed using SPASSOC.BAS[10], a computer package in BASIC language, to calculate chi-square values, Ochiai index $\{S_1 = a/[(a+b)(a+c)]^{0.5}\}$, the Dice index $\{S_2 = 2a/(2a+b+c)\}$ and the Jaccard index $\{S_3 = a/(a+b+c)\}$ for all pair-wise combinations of species as well as the variance ratio (VR) test for multiple species association. All species with less than 10% presence were not taken for final analysis.

Soil parameters, viz. temperature, moisture and pH were also studied simultaneously for all the 360 quadrats. Three samples from 0 to 10 cm depth were taken in a moisture box and brought to the laboratory. Soil moisture was then determined in the laboratory with the help of moisture meter. Soil pH was analysed according to the standard method[11]. Soil temperature was recorded with the help of soil thermometer in the field. The readings were taken at 0 to 10 cm depth from each quadrat (three replicates).

Pearson's correlation coefficient was also calculated between the abundance values of sal at tree, shrub (sapling) and herb (seedling) layers, and the soil parameters (temperature, moisture and pH) to find out any possible relationship among these constraints.

An overall positive association is suggested by the fact that the variance ratio (1.72) is greater than unity. Furthermore, the value of the test statistic (W) is 558.17. This lies outside of the 90% probability limits given by the chi-square distribution ($404.18_{0.05}$ and $316.09_{0.95}$) for 359 degrees of freedom. Therefore, null hypothesis of no association among the 36 species is rejected.

Results on the basis of significant χ^2 values ($>3.84_{0.05,1}$), show that true negative association exists between 11 species pairs (1 and 6, 1 and 21, 2 and 6, 2 and 8, 2 and 11, 2 and 24, 2 and 32, 2 and 35, 2 and 36, 3 and 28, and 3 and 35), and positive association between 26 species pairs (1 and 9, 1 and 10, 1 and 12, 1 and 19, 1 and 23, 1 and 24, 1 and 26, 2 and 4, 2 and 5, 2 and 7, 2 and 9, 2 and 14, 2 and 15, 2 and 16, 2 and 17, 2 and 18, 2 and 20, 2 and 21, 2 and 22, 2 and 26, 2 and 33, 2 and 34, 3 and 4, 3 and 11, 3 and 16, and 3 and 32; for species codes see Table 1).

If species affinities are analysed using only the association indices (Ochiai, Dice and Jaccard), the highly associated species pairs were 1 and 3, 1 and 4, 1 and 9, 1 and 10, 1 and 11, and 1 and 28 for tree layer; 2 and 4, 2 and 7, and 2 and 20 for shrub layer; 3 and 9, 3 and 10, 3 and 11 for herb layer (Figure 1).

Pearson's correlation with one-tailed significance test was performed between sal tree, saplings and seedlings, and soil parameters (moisture, pH and temperature). Sal was positively correlated (r = 0.127 and $P < 0.01$) to soil moisture at seedling stage. At sapling stage this correlation was positive but not significant, and finally in the mature stage it was negatively correlated ($r = -0.102$ and $P < 0.05$) to soil moisture (Table 2). Similar results were evident in the case of soil pH, where the values were positively correlated at seedling stage, slightly negative at sapling stage and strongly negative at mature stage. Soil temperature was however negatively related with sal at seedling and sapling stages at $P < 0.01$ and positively (non-significant) related at mature stage.

Statistically significant correlation between different stages of sal, viz. tree, sapling, seedling and soil parameters has clearly shown that the requirements of the species changes from one stratum to another, and so does the association with various species. Sal at maturity (i.e. tree layer) was negatively associated with *Mallotus philippensis* and *Terminalia alata*. Seth and Bhatnagar[12] have also reported these species as unfavourable for sal regeneration in most of the communities. They also stated that presence of *T. alata* indicates a clayey and water-logged situation, which is unfavourable for sal reproduction. *M. philippensis* indicates the prevalence of dry conditions especially in the surface layer, which is not good for sal regeneration. It occurs in

Table 1. Species code and information of species present in tree, shrub and herb layers

Species code	Species name	Family	Habit	Consistency (%)*
Tree layer				
1	*Shorea robusta* Gaertn. f.	Dipterocarpaceae	Tree	90.42
4	*Mallotus philippensis* Muell. Arg.	Euphorbiaceae	Tree	59.15
5	*Terminalia alata* Heyne *ex* Roth.	Combretaceae	Tree	27.32
6	*Syzygium cumini* (Linn.) Skeels	Myrtaceae	Tree	23.94
7	*Ehretia laevis* Roxb.	Boraginaceae	Tree	23.94
Shrub layer (shrubs and saplings)				
2	*S. robusta* Gaertn. f.	Dipterocarpaceae	Sapling	21.67
8	*Adhatoda vasica* Nees.	Acanthaceae	Shrub	17.78
9	*Clerodendrum viscosum* Vent.	Verbenaceae	Shrub	84.72
10	*M. philippensis* Muell. Arg.	Euphorbiaceae	Sapling	83.33
11	*Murraya koenigii* Spreng.	Rutaceae	Shrub	73.61
12	*Millettia auriculata* Baker.	Papilionaceae	Climber	35.00
13	*Casearia tomentosa* Roxb.	Samydaceae	Sapling	11.39
14	*Flacourtia indica* (Burm. f.) Merr.	Bixaceae	Shrub	18.33
15	*E. laevis* Roxb.	Boraginaceae	Sapling	23.33
16	*Holorrhena antidysentrica* Wall.	Apocynaceae	Sapling	10.28
17	*Randia dumentorum* Lamk.	Rubiaceae	Shrub	13.06
18	*Flemingia chappar* Ham.	Papilionaceae	Shrub	11.39
19	*Litsea monoptela* (Roxb.) Pers.	Lauraceae	Sapling	26.94
20	*Coffea bengalensis* Roxb.	Rubiaceae	Shrub	18.61
21	*Lantana camara* Linn.	Verbenaceae	Shrub	25.56
22	*Syzygium cumini* (Linn.) Skeels	Myrtaceae	Sapling	11.94
23	*Desmodium gangeticum* DC.	Papilionaceae	Shrub	16.39
24	*Pogostemon plectranthoides* Desf.	Lamiaceae	Shrub	17.22
25	*Ardisia solanacea* Roxb.	Myrsinaceae	Shrub	24.72
26	*Jasminum multiflorum* (Burm. f.) Ander.	Oleaceae	Shrub	17.22
27	*Litsea glutinosa* (Lour.) C.B. Robinson	Lauraceae	Sapling	12.78
Herb layer (herbs and seedlings)				
3	*S. robusta* Gaertn. f.	Dipterocarpaceae	Seedling	45.56
28	*Oplismenus compositus* (Linn.) O. Kuntze	Poaceae	Herb	39.44
29	*M. koenigii* Spreng.	Rutaceae	Seedling	24.17
30	*Jasminum multiflorum* (Burm. f.) Ander.	Oleaceae	Seedling	18.61
31	*C. viscosum* Vent.	Verbenaceae	Seedling	23.06
32	*Sida cordifolia* Linn.	Malvaceae	Herb	12.50
33	*Digitaria longiflora* (Retz.) Koel.	Poaceae	Herb	11.11
34	*Cyperus rotundus* Linn.	Cyperaceae	Herb	10.83
35	*Ageratum conyzoides* Linn.	Asteraceae	Herb	10.83
36	*Achyranthes aspera* Linn.	Amarantaceae	Herb	10.56

*Consistency percentage = [(Number of quadrats of occurrence of a species)/(Total number of quadrat studied)] × 100.

gregarious masses and both its excessive moisture requirements and the dense shade cast by its shrubby form prove inimical to sal regeneration. In the shrub and herb layers, however, *M. philippensis* is a strong and significant positive indicator of sal regeneration. This may be because in these stages sal requires shade and soil moisture, and *M. philippensis* conserves the soil moisture due to its dense shrubby form.

Syzygium cumini is a moisture-loving evergreen species. Competition for soil moisture between sal and *S. cumini* (both have almost similar height and growth) may be responsible for their negative association in all the three strata. *S. cumini* occurs and regenerates better in localities where the ground moisture supply is comparatively high.

Ehretia laevis was the only tree species having significant positive association with sal. Unlike all the other trees, it is a moderate-sized deciduous tree found in damp and shady places. Its requirements are limited and much lesser than sal.

Shrubs and herbs are thought to be better indicators for sal regeneration. In the shrub layer, most of the species (nearly 62%) were positively associated with sal saplings. The association between both sal sapling and seedlings and *Clerodendron viscosum* is worth mentioning. While most researchers have reported[13–17] negative effects of *C. viscosum* on sal regeneration, only Seth and Bhatnagar[12] have reported their positive association. In the present study we found a strong and significant positive association between the sal and *C. viscosum* in both sapling and seedling stages. An undergrowth of *C. viscosum* indicates fertile soil below which sal seedlings are usually found to occur in plenty[12], as shown by the positive correlation between soil pH and sal seedlings.

Significant negative association was found between sal saplings and *Adhatoda vasica*, *Pogostemon plectranthoides*, *Murraya koenigii* and *Jasminum multiflorum*. *A. vasica*, *P. plectranthoides* and *J. mul-*

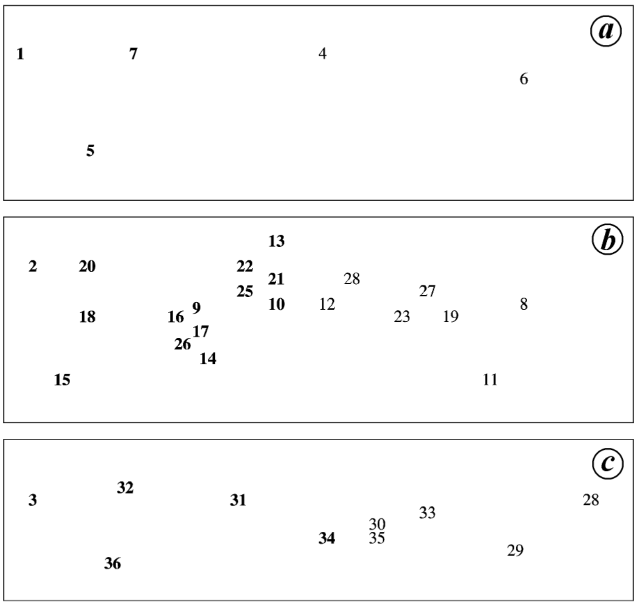

Figure 1. Plexus diagram for tree (***a***), shrub (***b***) and herb (***c***) layers based on values of association indices. Species codes in bold font are positively and in normal font are negatively related to various stages (tree, sapling and seedling) of sal.

Table 2. Matrix showing Pearson correlation (*r*) and significance test (one-tailed *t*-test) for sal tree, saplings, seedlings and soil parameters

Stage of sal	Soil temperature (°C)	Soil moisture (%)	Soil pH
Mature	0.012	–0.102*	–0.190***
Saplings	–0.143**	0.055	–0.046
Seedlings	–0.134**	0.127**	0.109*

*,**,***Correlation is significant at the 0.05, 0.01 and 0.001 probability levels respectively.

tiflorum inhabit moist and shady places and compete with sal saplings for soil moisture and shade. *M. koenigii* on the other hand, populates dry and open areas, which are not good for sal regeneration.

Sal seedlings were significantly associated with *Oplismenus compositus* and *Sida cordifolia*. Negative association with *O. compositus* maybe due to competition for resources, as both species have the same requirements of soil moisture and shade. *O. compositus* being a grass is a hardy species and can survive under drought conditions, but sal seedlings cannot. *S. cordifolia*, however, has low soil moisture demand and is a slow grower and hence it was positively associated with sal seedlings.

Champion[18] compiled the findings of regeneration and management of sal compressively in a monograph. Various methods of soil working and other field techniques were suggested by him to overcome the problem of regeneration. Management of middle-storey, shrub and herb layer species was one of his main suggestions. To achieve this, adequate knowledge of associates of sal is required. Care must be taken during the management of sal that the right species is maintained and the negative associate removed. To do so, a complete inventory of associates and competitor species is a prime requisite. We have tried to do so in order that these associations will be taken into consideration during the management of sal forests and to boost its natural regeneration. Various requirements of sal, especially soil moisture, must also be taken into consideration during various stages (seedling, sapling and maturity) of development.

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Received 15 December 2006; revised accepted 25 September 2007

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