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Competitive Interactions Between the Perennial Shrub *Ziziphus nummularia* and an Annual Herb *Rhynchosia minima*

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Abstract: The investigation focuses on competitive interactions between individuals of the perennial shrub *Ziziphus nummularia* and the annual herb *Rhychosia minima* with the aid of nearest-neighbour analysis in a sub-tropical desert region. Both intraspecific and interspecific competitive interactions were detected between nearest-neighbouring pairs. The cover as well as reproductive potential of *R. minima* were significantly reduced when it established in the close vicinity of *Z. nummularia*.

Key words: Interspecific competition, intraspecific competition, reproductive potential, desert region.

Introduction

Quantitative studies of plant distribution patterns suggest that biotic interactions are important in shaping the structure of arid and semi-arid vegetation (Fowler, 1986; Austin, 1990). The form and reproductive output of plants growing together are affected due to competition as compared to their growth in isolation (Harper, 1977; Ford and Sorrensen, 1992). Many empirical studies have shown the importance of local density on survival, growth and reproduction of individuals (Gottleib, 1977; Silander and Pacala, 1985; Miller and Weiner, 1999; Khan and Shaukat, 2000). However, density is a crude measure of competitive or interactive state of a population because an individual reacts to the effects of neighbours, not to the density of populations (Mack and Harper, 1977; Silander and Pacala, 1985). Competition among plants appears to be exclusively a neighbourhood phenomenon (Mack and Harper, 1977; Turkington and Harper, 1979) and interactions occur only among closely located individuals (Silander and Pacala, 1985; Ford and Sorrensen, 1992; Khan and Shaukat, 1997). Evidence of intraspecific and interspecific competition has been inferred from correlations between nearest-neighbour distances and plant sizes (Phillips and MacMahon, 1981; Welden *et al*., 1988; Cunliffe *et al*., 1990; Khan and Shaukat, 1997). Such results for low rainfall regions have been attributed in areas of low moisture regimes to competition between neighbouring plants for available moisture (Woodell *et al*., 1969; Khan and Shaukat, 1997). In many earlier studies, the experimental removal of all closely located neighbors, resulted in decreased negative xylem water potential of the focal plant, providing evidence that these patterns are the product of root competition for moisture (Fonteyn and Mahal, 1981; Ehleringer, 1984). Such studies have been mostly conducted on shrubs.

Annuals exploit the resources during the period of favourable environment, complete their life cycle and subsequently remain dormant as seed in soil under unfavourable conditions (Inouye *et al*., 1980; Gutierrez and Whitford, 1987). It has been argued by some that annuals are weaker competitors than perennial species because of former's greater sexual reproductive effort (Gadgill and Solberig, 1972). With a few exceptions (Pantastico-Cadas and Venable, 1993; Cheplick and Wickstrom, 1999; Bender *et al.,* 2002; Facelli and Temby, 2002), annuals have been largely ignored in competition studies under field conditions. However, interactions between perennials and annuals have been investigated in natural conditions with regard to possible allelopathic effects (Shaukat *et al*., 1983). Knowledge of the kind and degree of competitive interactions among species in the field is mandatory for appropriate population management decisions and the maintenance of biodiversity.

The objective of this study was to describe the competitive interactions between a perennial shrub, *Ziziphus nummularia* (Burm. f.) Wight. and Arn. (Rhamnaceae), and an annual herb, *Rhynchosia minima* (L.) DC. (Papilionaceae). Specifically, we investigated inter and intraspecific competition as well as the effect of interspecific competition on the reproductive potential of the annual herb.

Materials and Methods

Study area: The study was conducted at Pepri area, about 30 kilometers Northeast of Karachi city. The climate of the area has been designated as subtropical maritime desert. The average annual rainfall is about 20 cm, most of which is received during the monsoon season. A topographically uniform plain area was chosen within the study site. If the terrain is leveled, it ensures even

deposition of rainfall– a very important criterion in spacing and competition studies (Yeaton *et al.*, 1977).
The vegetation of the study area was dominated by the perennial shrub *Ziziphus nummularia.* Other co-occurring shrubs were *Prosopis cineraria* (L.) Druce, *Capparis decidua* (Forssk.) Edgew and *Indigofera oblongifolia* Forsk. Among the annuals, *Rhynchosia minima,* was most abundant. Other common annuals were: *Aristida adscensionis* L., *Indigofera cordifolia* Heyne ex Roth, *Cleome viscosa* L. and *Peristrophe bicalyculata* (Retz.) Nees. The soil of the study area was sandy loam with a pH of 8.1 and a maximum water holding capacity of 38%. Nitrogen and potassium content of the soil were low (N= .o8%, K=12 ppm).

Sampling: To estimate the density and cover of the major shrub species in the study area, sampling was performed using point-centered quarter method (Kent and Coker, 1994). A distance of four meters was kept between sampling points and measurements of distances and plant cover were made at forty sampling points. The cover of each individual shrub was based on diameter measured as the average of long axis and the maximum width of the canopy perpendicular to the length. From these data, relative and absolute density, and relative and absolute cover were computed. The density of *Rhynchosia minima* was estimated using fifty 1 m^2 quadrats.
The degree of intraspecific and interspecific interactions were assessed using the nearest neighbour technique (Pielou, 1977) and following the operational definition of Yeaton *et al.* (1977). In this method, the distance between randomly chosen individuals and their nearest neighbour is recorded as are the sums of the cover areas of each nearest neighbour pair. It is reasonable to assume that if these two variables (sum of cover and interplant distance) are positively correlated, then there exists interference between neighbouring individuals (Fonteyn and Mahal, 1981). It is mandatory that the data on pairs of individuals should be collected from a topographically homogeneous area and that the pair of plants should not be separated by a drainage line or a mound such as an ‘ant mound’ or a ‘mammal mound’. In addition, inter or intraspecific pair if individuals should not be intersected by the canopy of a third species.
Sets of measurements were made for sixty randomly chosen individuals of *Ziziphus nummularia* and *Rhynchosia minima.* Nearest neighbour distances were measured as the distance between the centers of the two canopies and the cover-area of each individual measured. For both the species cover was based on plant diameter measurement as described above. Though *Z. nummularia* had usually single main stem, occasionally clusters of stems were found. In some cases a little soil was excavated to see if there were any root connections between the stems. If this was the case, these were considered as one individual. Alternatively, if the canopy of one questionable plant extended over the center of the other questionable plant, they were regarded as one individual. Measurements of distance and sums of cover were made for sixty conspecific pairs of *Z. nummularia* and *R. minima* each. Interspecific interactions were measured for *R. minima* individuals located within 1.0 m radius from the center of each *Z. nummularia* shrub. *Z. nummularia* individuals were chosen randomly to serve as the focal plant. For the annual herb *R. minima*, in addition to cover-area of the plant and distance from the center of the shrub, the numbers of flowers (including developing fruits) were also counted as a measure of reproductive potential. Average values for cover, number of flowers and distance from the central *Z. nummularia* were calculated and were used in regression analysis. In addition, for randomly chosen *R. minima* individuals the nearest neighbour (either conspecific or heterospecifc viz., *Z. nummularia*) and flowering status were recorded. The combined cover was calculated for each nearest neighbour pair. These values were regressed against their corresponding separation distance to determine if there were significant linear relationships between them. The analysis of variance for regression was performed for both the species. (Zar, 1996). Additionally, the product moment correlation coefficient and the coefficient of determination were computed for combined cover versus distance for both *Z. nummularia* and *R. minima*.
The effect of distance on flowering status was determined by arbitrarily grouping *R. minima* individuals found at various distances from *Z. nummularia* into four classes as follows: 1-25, 26-50, 51-75 and 76-100 cm. A chi-square contingency test and a G-test (also known as log-likelihood-ratio test) were employed to determine the association between flowering designation and distance category of the annual and the shrub (Zar, 1996). Computer programs for statistical analyses were developed by one of us (S.S.S.) in FORTRAN 77, which are available on request from the authors.

Results

The results of vegetation analysis disclosed that *Z. nummularia* was the dominant species with a relative density of 62.3% and a relative cover of 50.35% (Table 1). *Prosopis cinerarea* and *Capparis decidua* were second and third dominants, respectively. The density of *Rhynchosia minima* was 1.21 plants per m^2.
A significant positive linear correlation ($r = 0.821$; $P<0.001$) was found between nearest neighbour distance (X) and

Table 1: Phytosociological attributes of the community investigated.

Species	Relative density (%)	Density ha^{-1}	Relative cover (%)	Cover m^2 ha^{-1}
Ziziphus nummularia	62.3	231.97	50.35	356.18
Prosopis cinerarea	16.1	59.94	32.74	231.67
Capparis decidua	9.5	35.36	9.85	69.65
Indigofera oblongifolia	8.8	32.76	5.92	41.93
Others	3.3	12.28	1.13	8.05

Table 2: The flowering status of *R. minima* individuals when their nearest neigbour was either conspecific or the shrub *Z. nummularia*

Nearest neighbour pair	Flowering	Non-flowering
Intraspecific	106	5
Interspecific	142	46

Table 3: The influence of distance of establishment from *Z. nummularia* on the flowering designation *of Rhynchosia minima*

Distance	Flowering	Non-flowering
1-25	17	12
26-50	87	36
51-75	72	17
76-100	63	12

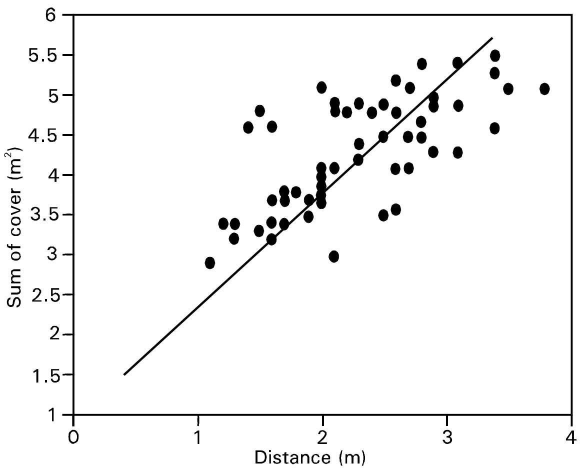

Fig. 1: Relationship for *Zizyphus numularia* at Pepri, of sum of cover for 60 pairs of a plant and its nearest neighbour

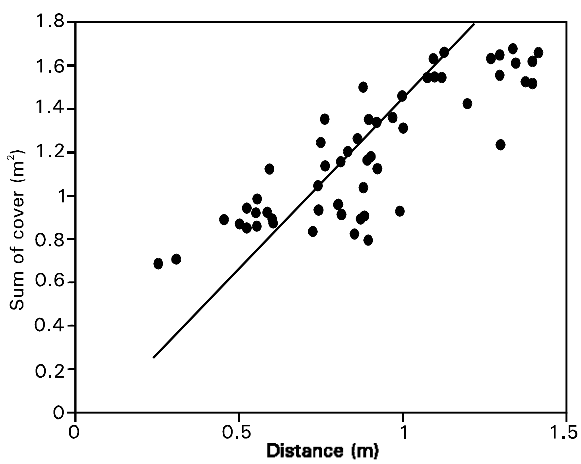

Fig. 2: Relationship for *Rhynchosia minima* at Pepri, of sum of cover for 60 pairs of a plant and its nearest neighbour

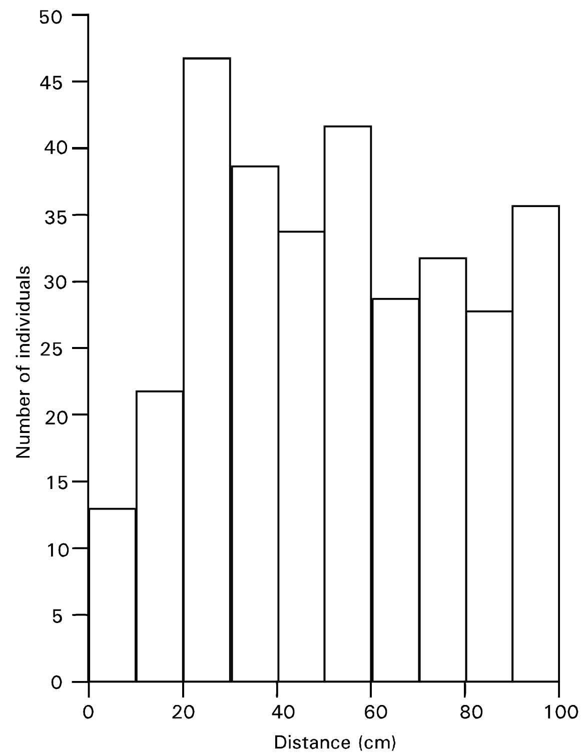

Fig. 3: The number of individuals of *Rhynchosia minima* plants recorded at 10 cm intervals from the center of the cover of *Zizyphus numularia*

sum of covers (Y) for pairs of *Z. nummularia* individuals. With the increase in interplant distance the combined cover also increased (Fig. 1). The following regression equation expresses this relationship:

$$Y=2.103+0.917X \quad \pm 0.395$$

The ANOVA for the simple regression showed a significant linear regression ($F = 120.15$; $P< 0.001$). The coefficient of determination ($R^2 = 0.674$) indicates that 67.4% of variation in the combined cover (of two nearest neighbours) is determined by the variation in the distance between nearest neighbour individuals of *Z. nummularia.* Similarly, the relationship between nearest neighbour distance (X) and sum of cover (Y) for pairs of *R. minina* (Fig. 2) was also significant ($r = 0.844$; $P<0.001$). The regression equation for this linear relationship is as follows:

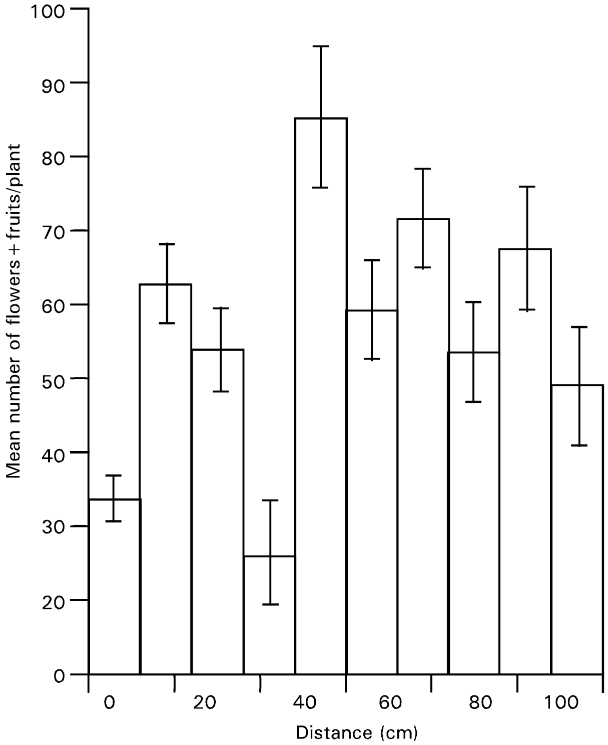

Fig. 4: Mean number of flowers plus fruits produces per plant of *Rhynchosia minima* at different distances from the cover of *Zizyphus numularia*

Y=-0.108 + 0.840X ± 0.159

The ANOVA for simple regression disclosed a significant linear regression (F = 143.61; P<0.001). The coefficient of determination (R^2 = 0.712) implies that 71.2% of variation in sum of cover is explained by the variation in distance between the neighbouring pairs.

In addition to intraspecific competition, negative interactions were also recorded between the perennial shrub *Z. nummularia* and the annual *R. minima*. Fig. 3 shows the number of individuals of *R. minima* establishing at 10-cm intervals from the center of *Z. nummularia* shrubs. Significantly (P<0.01) lesser number of individuals of *R. minima* established within 20 cm of *Z. nummularia* compared to the individuals establishing at >20 cm from the shrub. A significant positive linear correlation (r=0.548; P<0.001) was found between average distance of *R. minima* from *Z. nummularia* (X) and average cover of *R. minima* (Y). The relevant regression equation is as follows:

Y=1.379+0.424X ± 0.113

ANOVA for the regression analysis showed a significant linear regression (F=24.95, P<0.001). The corresponding coefficient of determination (R^2) was 0.300. The correlation coefficient between average distance (X) between *Z. nummularia* and *R. minima* and average number of flowers/plant (Y) of *R. minima* was significant (r=0.528; P<0.001). The regression equation for this relationship is given below:

Y=64.03+76.93X ± 21.84

ANOVA for the regression analysis disclosed a significant linear positive relationship (F=22.469; P<0.001) while the coefficient of determination (R^2) was 0.279. The reproductive output of *R. minima* was significantly influenced by the identity of the nearest neighbour (χ^2 =19.665; G=23.178; p<0.001). Overwhelming majority of individuals pairing intraspecifically, were flowering while 24.5% of the individuals pairing interspecifically failed to produce flowers (Table 2). Further analysis of the flowering status of the annual with respect to the nearness of the shrub (Table 3) showed a significant association between flowering status and distance category (χ^2 =10.37, G=10.13; P<0.001). Fig. 4 shows the average number of flowers and (developing) fruits produced by *R. minima* individuals at various distances from *Z. nummularia*. The mean number of flowers produced by the individuals of *R. minima* establishing up to 40 cm distance from the center of *Z. nummularia* were significantly (P<0.01) lower compared to those growing away from the shrub.

Discussion

The determination of the functional significance of negative species interactions in the assembly and maintenance of plant communities of arid regions has been the objective of numerous ecological investigations. One of the methods frequently employed in such studies is the nearest neighbour analysis. For the purpose of nearest neighbour analysis, most workers employ Pielou (1977) method wherein the distance between randomly chosen individuals and their nearest neighbour is recorded, as are the sums of the sizes of each nearest neighbour pair. It is postulated that if these two variates are positively correlated then there is interference between neighbouring individuals (Yeaton *et al.*, 1977; Phillips and MacMahon, 1981). The nearest neighbour analysis disclosed the existence of negative interactions between intraspecific nearest-neighbour pairs of *Z. nummularia* and *R. minima*. The intensity of competition as determined by the product-moment correlation coefficient (Yeaton *et al.*, 1985) was greater for the annual compared to that of perennial shrub. It is assumed that a higher correlation coefficient indicates stronger competitive interaction which limits more effectively the size attained by the smaller individual as a function of its distance from its nearest neighbour (Cunliffe *et al.*, 1990). Since larger plants may use more of a limiting resource than smaller plants, other individuals do not survive quite so close to a larger plant. Our results are contradictory to those of Cunliffe *et al.* (1990) who obtained greater correlation for the annual than that for the perennial shrub. Competition for a limited resource is the most likely form of interference. Presumably, light is not a limiting factor under desert conditions. Water is a plausible limiting factor (Welden *et al.,*1988; Harrington, 1991) but competition for nutrients (Gutierrez *et al.*, 1988) cannot be ruled out. In this situation we expect the root systems of perennials to be either sufficiently deep or extensive to the extent that they overlap. Since the root system of *Z. nummularia* excavated showed great lateral spread, and in case of closely situated individuals even overlapped, lending further credence to the role of competition in plant spacing (Phllips and MacMahon, 1981). Studies on desert plants (Campbell and Harris, 1977; Sturges, 1977) have shown that soil moisture depletion due to absorption by roots occurs more quickly in the immediate vicinity of plant axis, and gradually spreads outwards. Furthermore, the upper soil layer dries out more rapidly than the deeper horizon. Since root systems of annuals such as *Rhynchosia minima* are situated in the upper soil layer, these plants presumably face greater scarcity of moisture at later stages of growth (due to evaporation of moisture from the soil surface) compared to shrubs that possess deeper and extensive root systems. This could be the possible reason for the greater degree of intraspecific competition faced by the individuals of *R. minima*.

There were also negative interactions occurring between the shrub *Z. nummularia* and the annual *R. minima.* The interspecific competitive interaction resulted in a reduction in the size of *R. minima* and its reproductive potential. The adverse effect on reproductive potential is evidenced by the fact that a high percentage of the annual failed to flower when located close to the perennial shrub, *Z. nummularia*. Furthermore, the interspecific effect of *Z. nummularia* on *R. minima* was decidedly greater than that of *R. minima* upon its own individuals. The reproductive output as measured by the number of flowers plus fruits was considerably lesser in *R. minima* individuals that established close to the perennial shrub. This can easily be attributed to interspecific competition for moisture and also possibly for nutrients. For the individuals that established further away from the shrub, competitive pressure by the conspecific neighbours increased later in the season. From the studies utilizing nearest neighbour analysis and those of Woodell *et al.* (1969) and on distribution pattern of desert shrubs, it becomes evident that biotic interactions are potentially of major functional importance in the structuring of desert communities. Evidently, however, such studies are not definitive, because the conclusions drawn in them have been based primarily on ecological theory. After initial description of vegetation, there is generally a complete reliance on statistical inference both in the formulation of relevant hypotheses and in the 'measurement' of the biological interactions conjectured to be responsible for the observed community structure. These descriptions and inferences although useful do not test for controlling mechanisms or directly measure the degree of biological interactions. Conclusive evidence of such biological interactions can be obtained only by controlled field experiments (Connell, 1990).

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