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*Short Note*

# Coastal Sand Dunes—Vegetation Structure, Diversity and Disturbance in Nallavadu Village, Puducherry, India

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**Abstract:** Tropical coastal sand dunes (CSD) are exposed to various disturbances. CSD vegetation in South East coast of India was sampled by belt transect and quadrate method at three gradients of disturbance—highly disturbed, moderately disturbed and slightly disturbed. Three clear zones could be identified—*Cyperus* sps. > *Ipomea pescapre* > *Spinifix litoreus* in the fore dune, *Ginisekia pharmacoeides* > *Glinus oppositifolius* along with few minor dune species in the mid zone, and *Bulbostylis barbata,* along with a few dune species in back dune. In moderately disturbed sites species diversity was higher, supporting intermediate disturbance hypothesis.

**Key words:** Coastal sand dunes, intermediate disturbance hypothesis, vegetation structure, diversity.

## Introduction

Coastal sand dunes, once distributed throughout the world except in Antarctica, are under higher human impacts and heavily degraded (Kumar et al., 1993; Mahmoud et al., 2007; Nordstrom et al., 2000; Varsha et al., 2001; Vandee, 1993). Wide range of sandy beaches was associated with sand dunes, while the spatial and temporal variations in the input of sediments and wind regimes, shape these dunes (Kurtbo et al., 2007; Hesp, 2000; Nordstrom, 1990; Pye, 1993). While several studies are available on coastal sand dunes (CSD) vegetation, restoration and stabilization in temperate regions (Koske et al., 1997; Sylvia, 1989; Sylvia et al., 1988), the tropical coastal dunes in general and Indian coastal dunes in particular are poorly studied (Sridhar et al., 2007; Kulkarni et al., 1997; Mohankumar et al., 1988).

Coastal dune formation ultimately depends on size and prevailing wind energy (Hesp, 2000; Kumar et al., 1993). Their heights differ in response to adequate sand supply, climate and local topographic features (Barbour, 1985; Brid, 1972; Ranwell, 1972). CSD constitute a variety of habitats of vital ecological and economic importance (Sridhar et al., 2007; Varsha et al., 2001; Martinez et al., 1996). Soil is the ultimate reservoir of plant nutrients and their availability decide the diversity, distribution and abundance of the native vegetation (Kurtbo et al., 2007; Zuo et al., 2007; Wilson, 1989; Kline, 1969).

CSD protect inland from various natural calamities like hurricanes, storm, and sea level rise. It also filter the rain water and recharge ground water, aquatic habitats, traps wind blown sand and prevent sand moving blown further inland, and provides critical habitats for both flora and fauna. Critical fragile coastal sand dunes were destroyed by various human interferences and infrastructure development activities like road, home construction etc., thus leading to disruption in dune process particularly in sand nourishment and development of dune and pioneer dunes (Vincent et al., 2008; Curr et al., 2000; Williams et al., 1997).

Quantitative surveys on the CSD provide information on the natural native flora and faunal species and their diversity. The most effective and durable methods in stabilizing/managing the dune is through re-vegetation,

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because it is least expensive, more durable, aesthetically appealing, and self regenerating technique (Spence et al., 2007; Mahmoud et al., 2007; Varsha et al., 2001; Grootjans et al., 1997). Dune plants stop and hold wind-borne sand effectively thus ultimately leading to dune stabilization, establishment and development.
The main objectives of this paper are:

- to estimate the distribution and abundance of native flora and
- to identify key threats/disturbance to sand dunes/flora.

## MATERIALS AND METHOD

### Study Sites

Puducherry is located on the Coramandal coast between 11° 52' 56" and 11° 59' 53" of North latitude and between 79° 45' 00" and 79° 52' 43" of East longitude. It is limited on the East by the Bay of Bengal and on the other three sides by the Cuddalore district of Tamil Nadu State. Nallavadu is a small coastal village present at a distance of about 14 kms towards South on the way to Cuddalore from Puducherry main town.

### Climate

Climate data for Puducherry available for 27 years (1980-2007) reveal a annual temperature of 31.1°C and mean annual rainfall about 1172-1311 mm. The mean number of annual rainy days is 55. The mean monthly temperature range from 21.3°-31.7°C for the same period. The climate is tropical dissymmetric with the bulk of the rainfall during northeast monsoon October-December (Indian Meteorological Department, Chennai).

### Method

Three sites namely TD - totally disturbed site (residential area), MD - moderately disturbed site (about 200 m from the settlement areas) and slightly disturbed site (about 300 m from the settlement areas) where human pressure can be in the form of cattle grazing and drying fishes were identified for the study.

Belt transect is the most common standard method, used for vegetation surveys on systems with less proportion of flora such as sand dunes and grasslands (Espejel, 1987). The plants along the belt transect and about 1 m on either sides of the line were surveyed. Belt transects were made on both horizontal and vertical directions (with reference to the shoreline) on coastal sand dunes. Each transect measured about 100 m (three sites). Each site covered by 2 × 100 m (horizontal and vertical). Vegetation was sub-sampled for abundance and density by square quadrates of about 1 $m^2$.

Human disturbance was estimated qualitatively and the sub-classes of disturbances were ranked into none (score 0), relatively low (1), medium (2), and high (3) (Veblen et al., 1992). The sum of all score for each site provides an overall ranking of anthropogenic disturbance in the sites. High rank denotes significantly higher level of anthropogenic disturbance and low ranks, lower levels of disturbance (Table 1).

**Table 1: Comparison of disturbance ranking in three study sites**

| *Disturbance* | *Site 1 (TD)* | *Site 2 (MD)* | *Site 3 (SD)* |
|---|---|---|---|
| 1. Site Encroachment | | | |
| i. For construction of roads | 3 | 1 | 0 |
| ii. For constructing houses, tanks etc | 3 | 0 | 0 |
| iii. For constructing factories | 3 | 1 | 0 |
| 2. Landing of boats by visitors | 3 | 1 | 0 |
| i. Vehicle parking | 3 | 1 | 0 |
| ii. Cooking | 3 | 1 | 0 |
| iii. Festival occasions | 3 | 1 | 0 |
| 3. Degree of cattle and goat browsing | 2 | 3 | 1 |
| 4. Drying of fishes and nets | 3 | 2 | 1 |
| 5. Using for sanitation | 3 | 2 | 1 |
| 6. Resource removal | | | |
| i. Firewood | 2 | 3 | 1 |
| ii. Fodder | 2 | 3 | 1 |
| iii. Soil | 0 | 2 | 1 |
| Total | 33 | 24 | 6 |
| Disturbance Index | 1.307 | 0.923 | 0.461 |

### Data Analysis

For species diversity and evenness, Shannon and Simpson indices were used (Vincent et al., 2007; Hiroaki Ikeda, 2003; Beena et al., 2000).

Simpson's index: $D' = 1/\Sigma(pi)^2$

Shannon index: $H = -\Sigma$ (Pi × ln Pi),

where *pi* is the proportion of individuals that species *I* contributes to the total.

The evenness (Oosting, 1942) is expressed by:

$J = H/H'_{max}$

$H'_{max}$ is the maximum value of diversity for the number of species present. Differences in Shannon's species diversity were statistically tested using ANOVA and Hutcheson's *t*-test (Vincent et al., 2008; Hutcheson, 1970). For disturbances, a synthetic disturbance index (DI) was also computed as follows: the values of the four factors of the "disturbances" data set were reduced to the [0–1.5] interval using the Gover's method [$X' = (X$

$-X_{min})/(X_{max}-X_{min})$] (Vincent et al., 2008; Legendre et al., 1998). The disturbance index was simply the average of these reduced values for each site.

## Results

The site 1 (TD) i.e., residential areas were disturbed due to various human activities. This study confirms that the native dunes species were found to be more in site 2 (MD) where disturbance were slight and limited (cattle and browsing, drying of fishes nets, resource removal e.g., firewood, fodder and soil), followed by site 3 (LD). Horizontal line transects parallel to shore does not show much variation as they are predominantly colonized by *Cyperus arenarus, Spinifex litoreus* and *Ipomoea pes-capre.*

The following results were reported from the present study which pertains to vertical transects only.

### Species Diversity

Diversity surveys on the three sites, along the coastal sand dunes for the present study, indicated a total of 36 species belonging to 35 genera and 25 families (Table 2). Only one species was found to be common in all three sites, whereas five species occur both in sites TD and MD, nine species only in MD and SD. Twenty-five families were recorded in all three sites, among this 17 families in TD, 13 in MD, and eight in SD were found.

**Table 2: List of families and species**

| *Family* | *Genera* | *Species* |
|---|---|---|
| Cyperaceae | 5 | 5 |
| Euphorbiaceae | 3 | 3 |
| Arecaceae | 2 | 2 |
| Rubiaceae | 2 | 3 |
| Poaceae | 2 | 2 |
| Verbenaceae | 2 | 2 |
| Aizoaceae | 1 | 1 |
| Molluginaceae | 1 | 1 |
| Convolvulaceae | 1 | 1 |
| Annonaceae | 1 | 1 |
| Cucurbitaceae | 1 | 1 |
| Meliaceae | 1 | 1 |
| Nyctaginaceae | 1 | 1 |
| Carricaceae | 1 | 1 |
| Casuarinaceae | 1 | 1 |
| Scrophulariaceae | 1 | 1 |
| Anacardiaceae | 1 | 1 |
| Moringaceae | 1 | 1 |
| Pedaliaceae | 1 | 1 |
| Onagraceae | 1 | 1 |
| Mimosaceae | 1 | 1 |
| Myrtaceae | 1 | 1 |
| Malvaceae | 1 | 1 |
| Zygophyllaceae | 1 | 1 |

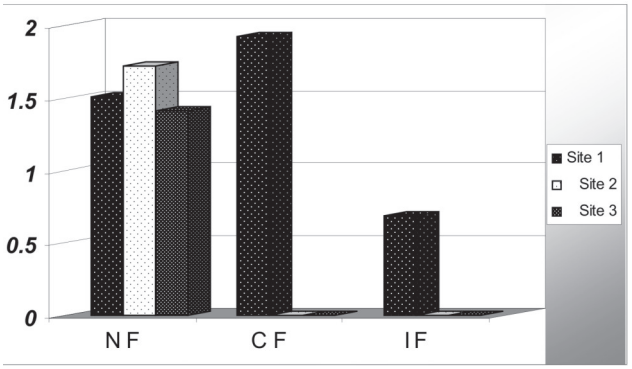


**Figure 1: Shannon indices in three study sites. TF - Total flora, NF - Native flora, CF - cultivated flora, IF - Invaded flora.**

Floras are classified into TF i.e. total flora, NF - native flora, CF - cultivated flora, and IF - invaded flora and their corresponding Shannon and Simpson indices value, evenness, families, genera, species in three sites are shown in Table 3 and Figure 1. Plants found in site 1 (TD) mostly comprise cultivated and invaded species. MD and SD sites consist of native dune plants mostly. The plants are listed in Table 4 with their respective sites. The overall species diversity values among the three sites were not significantly different ($P>0.5$) but when we compare them as native dune species ($P<0.5$), introduced/ cultivated species ($P<0.5$), invasive species ($P<0.5$), a significant difference among them was noted. While only one native dune species was found in site 1 (remaining are cultivated), it was more in MD and SD sites. The site MD species are higher than the species in site 3, supporting the intermediate disturbance hypothesis.

### Native Flora

The diversity and density ranking of native species are MD >SD>TD. When all the data for the three sites are pooled, the following results are obtained: $H' = 1.716>1.511>1.411$; $D' = 0.3519>0.2906>0.2953$; and $J' = 0.7768>0.60597> 0.5681$. ANOVA and *t* test (0.5 level of significance) confirming they are different significantly $F = 3.129644$; between $df = 1$; within $df = 69$; $P = 0.286915$). Three sites between themselves differed significantly, too; it is proved and confirmed by using ANOVA and *t* test ($P<0.5$). TD and MD $F = 2.744078 < 4.084746$; $P = 0.10544$. $t_{stat} = -1.90566$ $P$ ($0.0355 < 1.724$ - one tail, $0.0711 < 2.0859$ - two tails). MD and SD $F = 0.082885 < 4.098172$; $P = 0.774989$. $t_{stat}$ =

**Table 3: List of plants found along transects**

| *Botanical Name* | *Family Name* | *Site 1 - TD* | *Site 2 - MD* | *Site 3 – SD* |
|---|---|---|---|---|
| *Cyperus arenarius* Retz. | Cyperaceae | 39 | 257 | 362 |
| *Gisekia pharnaceoides* L. | Aizoaceae | 0 | 81 | 97 |
| *Glinus oppositifolius* (L.) A. DC. | Molluginaceae | 0 | 49 | 70 |
| *Bulbostylis barbata* (Rottb.) C.B. Clarke | Cyperaceae | 0 | 43 | 58 |
| *Spinifex littoreus* (Burm.f.) Merr. | Poaceae | 0 | 20 | 25 |
| *Ipomoea pes-caprae* L. R. Br. | Convolvulaceae | 0 | 19 | 24 |
| *Acalypha indica* L. | Euphorbiaceae | 13 | 0 | 0 |
| **Annona squamosa* L. | Annonaceae | 1 | 0 | 0 |
| *Azadirachta indica* Adr. Juss. | Meliaceae | 2 | 3 | 0 |
| *Boerhaevia diffusa* L. | Nyctaginaceae | 8 | 8 | 0 |
| **Carrica papaya* L. | Carricaceae | 2 | 0 | 0 |
| **Casuarina equisetifolia* Forster & Forster f. | Casuarinaceae | 7 | 0 | 0 |
| *Citrullus colocynthes* (L.) Schrader | Cucurbitaceae | 0 | 5 | 2 |
| **Cocos nucifera* L. | Arecaceae | 132 | 0 | 0 |
| *Croton bonplandianus* Baillon | Euphorbiaceae | 6 | 0 | 0 |
| *Dactyloctenium aegyptium* (L.) P. Beauv. | Poaceae | 0 | 1 | 3 |
| *Euphorbia rosea* Retz. | Euphorbiaceae | 0 | 8 | 0 |
| *Fuirena ciliaris* (L.) Roxb. | Cyperaceae | 0 | 0 | 1 |
| *Kyllinga triceps* Rottb. | Cyperaceae | 0 | 1 | 0 |
| ***Lantana camara* L. | Verbenaceae | 4 | 0 | 0 |
| *Lindernia oppositifolia* (Retz.) Mukerjee | Scrophulariaceae | 0 | 1 | 0 |
| *Ludwigia perennis* L. | Onagraceae | 0 | 1 | 0 |
| **Mangifera indica* L. | Anacardiaceae | 3 | 0 | 0 |
| **Moringa oleifera* Lam. | Moringaceae | 2 | 0 | 0 |
| **Musa paradisiaca* L. | Musaceae | 2 | 0 | 0 |
| *Oldenlandia stricta* L. | Rubiaceae | 0 | 3 | 3 |
| *Oldenlandia umbellata* L. | Rubiaceae | 0 | 16 | 0 |
| *Pedalium murex* L. | Pedaliaceae | 7 | 0 | 0 |
| *Phoenix sylvestris* (L.) Roxb. | Arecaceae | 0 | 0 | 1 |
| ***Prosopis juliflora* (Sw.) DC. | Mimosaceae | 3 | 2 | 0 |
| **Psidium guajava* L. | Myrtaceae | 2 | 0 | 0 |
| *Pycreus pumilus* (L.) Nees ex C.B. Clarke | Cyperaceae | 0 | 0 | 1 |
| *Spermococe ocymoides* Burm. f. | Rubiaceae | 0 | 1 | 0 |
| **Tectona grandis* L.f. | Verbenaceae | 2 | 0 | 0 |
| **Thespesia populnea* (L.) Sol. ex Corr. Serr. | Malvaceae | 6 | 0 | 0 |
| *Tribulus terrestris* L. | Zygophyllaceae | 3 | 0 | 0 |

* cultivated; ** invasive

**Table 4: Shannon index, Simpson index, evenness, number of families, genera and species in three study sites**

| | *Site 1 - TD* | | | | *Site 2 - MD* | | | | *Site 3 - SD* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *T F* | *N F* | *C F* | *I F* | *T F* | *N F* | *C F* | *I F* | *T F* | *N F* | *C F* | *I F* |
| Shannon index | 1.8 | 1.51 | 1.92 | 0.68 | 1.73 | 1.71 | 0 | 0 | 1.41 | 1.41 | 0 | 0 |
| Simpson index | 0.3 | 0.3 | 0.46 | 0.42 | 0.28 | 0.29 | 0 | 0 | 0.35 | 0.35 | 0 | 0 |
| Evenness | 0.6 | 0.78 | 0.86 | 0.98 | 0.6 | 5.90 | 0 | 0 | 0.57 | 0.56 | 0 | 0 |
| Number of families | 17 | 6 | 8 | 2 | 13 | 12 | 0 | 1 | 8 | 8 | 0 | 0 |
| Number of genera | 19 | 7 | 8 | 2 | 17 | 16 | 0 | 1 | 12 | 12 | 0 | 0 |
| Number of species | 19 | 7 | 8 | 2 | 18 | 17 | 0 | 1 | 12 | 12 | 0 | 0 |

TF - Total flora, NF - Native flora, CF - cultivated flora, IF - Invaded flora**.**

–1.17824 *P* (0.126625 < 1.729133 - one tail, 0.253249 < 2.093024 - two tails). TD and SD *F* = 2.385117 < 4.130018; *P* = 0.131754. $t_{stat}$ = –1.70187 *P* (0.053498 < 1.739607 - one tail, 0.106995 < 2.109816 - two tails).

**Cultivated Plants**

The diversity and density ranking of cultivated species are TD>MD>SD. They are found in TD site only. ANOVA and *t* test (0.5 level of significance) confirms they are different significantly *F* = 3.554557; between *df* = 2; within *df* = 18; *P* = 0.289619. Three sites between themselves differed significantly; it is proved and confirmed by using ANOVA and *t* test (0.5 level of significance). TD and MD *F* = 1.328553 < 4.747225; *P* = 0.271507. *t* stat = 1.152629 *P* (0.146454 < 1.94318 - one tail, 0.292907 < 2.446912 - two tails) . TD and SD *F* = 1.328553 < 4.747225; *P* = 0.271507. $t_{stat}$ = 1.152629 *P* (0.146454 < 1.94318 - one tail, 0.292907 < 2.446912 - two tails).

**Invasive Species**

The diversity and density ranking of invasive species are TD>MD>SD. They are found in TD and MD sites only. ANOVA and *t* test (0.5 level of significance) confirms they are different significantly. *F* = 9.552094; between *df* = 2; within *df* = 3; *P* = 0.064776. Three sites between themselves differed significantly; it is proved and confirmed by using ANOVA and *t* test (0.5 level of significance). TD and MD *F* = 5 < 18.51282; *P* = 0.154846. *t* stat = 1.666667 *P* (0.172021 < 6.313752 - one tail, 0.344042 < 12.7062 - two tails). MD and SD *F* = 1 < 18.51282; *P* = 0.42265]. $t_{stat}$ = 1*P* (0.25< 6.313752 - one tail, 0.5 < 12.7062 - two tails). TD and SD *F* = 1 < 18.51282; *P* = 0.019804]. $t_{stat}$ = 7 *P* (0.045167 < 6.313752 - one tail, 0.090334 < 12.7062 - two tails).

## Discussion

Plant survey among the three sites shows significant variation in the composition of native dune species. Site 2 i.e. MD is more diverse than other two sites, supporting intermediate disturbance hypothesis (Bonte et al., 2003; Wood, 2001; Anthony, 2001; Beena et al., 2000; Gordon, 2000). The edaphic factors like salt spray and meteorological (water) features dictate distinct zoning in coastal vegetation (Stubbs, 2004; Ayyad, 1976; Oosting, 1942) that perhaps explain the distinct zonation of the species found in the study area. Most tropics and warm temperate shores consist of *Ipomoea pes-caprae* (John, 1970). It is a stoloniferous perennial, pioneer, mat-forming creeping strand species confined to the tropical beaches (Devall, 1992) established along with 73 typical beach plant species in the Gulf of Mexico and tolerates sand erosion, accretion and inundation (Devall, 1992; Britton, 1989). It is well adapted to coastal habitats with disturbance, especially burial, erosion and inundation (Corkidi et al., 1997; Martinez et al., 1996; Devall, 1992). The earlier report that *I. pes-caprae* also supports the coexistence of many other dune plants in moderately disturbed or stabilized dunes, the flora associated with *I. pes-caprae* include *Canavalia cathartica* Thouras, *Spinifix littoreus* L. and *Cyperus* sps (Rao et al., 1987) is confirmed in our study.

Low soil moisture in open dune (near high tide region) was found to be critical factor affecting diversity, distribution, survival and dominance of the flora found spatially and temporally (Ranwell, 1972; Williams et al., 1997). Further, they are also reported to be influenced by environmental factors such as temperature, desertification, sand erosion, sand accretion, salinity and salt spray (Woodhouse, 1978; Magurran, 1988).

Our findings on density and diversity of CSD vegetation agree with that of other earlier workers—increasing from shore towards land wards (Figures 2 and 3) (Xiaoan et al., 2008; Munoz-Reinoso, 2005; Bossuyt et al., 2004; Sykes et al., 1991). The effect of salt spray, wind exposure, sand accretion, evaporation, and heat stress decreases gradually inland facilitating the establishment of more flora from shore to inland, with enhanced diversity and richness (Castillo et al., 1991; Breed et al., 1979; Ranwell, 1972).

Out of the psammophytic strand vegetation reported from the CSDs of the Indian subcontinent (Sridhar et al., 2007; Rao, 1985) e.g. mat-forming creepers, prostrate/

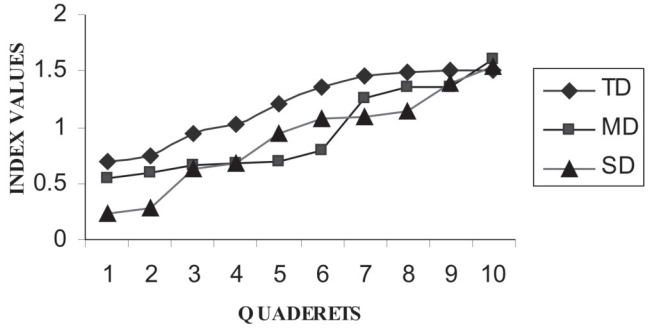


**Figure 2: Shannon wiener diversity index of the three study sites.**
**TD - Totally disturbed site; MD - Moderately disturbed site; SD - Slightly disturbed site.**

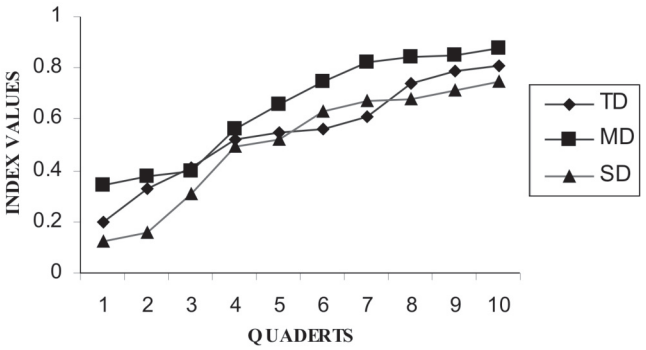


**Figure 3: Simpson dominance index of the three sites. TD - Totally disturbed site; MD - Moderately disturbed site; SD - Slightly disturbed site.**

erect herbs and sedges, climbers, plants with penetrating organs, scrubs and trees, consisting of 154 species belonging to 108 genera and 41 families (Williams, 1997), our surveys indicated a total of 36 species belonging to 35 genera and 25 families in the study area.

**Plant Families**

Cyperaceae was found to be a common family to all three sites. Cyperaceae, Aizoaceae, Mollugniaceae, Poaceae, Convolvulaceae, Cucurbitaceae, and Rubiaceae were common families for sites MD and LD. The most species-rich family was Verbinaceae with two species in site 1-TD. Cyperaceae with five species in SD and TD. The percentage of families represented by single species was higher in SD (38%) and LD in TD (25%). It comprises all three sites. Cyperaceae was found to be the common family with five species followed by Euphorbiaceae (3), and Rubiaceae (3), Poaceae (2) and Arecaceae (2); nearly 18 families were represented only by single species. Temperate CSDs comprise mainly the members of Poaceae, while tropics with Asteraceae, Cyperaceae, Fabaceae and Poaceae (Sridhar et al., 2007; Moreno-cosasola, 1989; Rao, 1985).

**Species Density, Dominance and Rarity**

The density of species varied considerably between the sites. Site 2 i.e. MD comprises native dune floral species of 88% and 12% of invaded exotic species (weeds). Site 3 had 100% of native dune floral species. Site 1 i.e. TD was dominated by *Cocous nucifera* (54%), MD and SD by *Cyperus arenarius* for about 50% and 56%. *Cocous nucifera* and *Cyperus arenarius* formed nearly 70% of dune cover in site 1-LD; while *Cyperus arenarius, Gisekia pharmacoeides, Glinus oppositifolius, Bulbostylis barbata, Spinifix litoreus, Ipomea pescapre* and *Oldenlandia umbellata* together formed 93% of dune cover in site 2-MD, whereas in site 3-LD 98% covered by *Cyperus arenarius, Ginisekia pharmacoeides, Glinus oppositifolius, Bulbostylis barbata, spinifix litoreus,* and *Ipomea pescapre*. Measuring biodiversity helps to understand the ecology of the habitat and to develop the conservation strategies (Beena, 2007).

Based on species density, dunes species were classified into very rare (those represent by 1), rare (2-5), common (5-15), dominant (15-30) and predominant (>30). TD site totally comprises cultivated ones and so native dune species does not occur in this region. In site 2 i.e. MD 27% of very rare, 22% of rare and 16% of common species. SD site 3 comprised 50% of very rare and rare species.

## Future Implications

If coastal dunes and their vegetation are cleared it leads to serious problems like storm erosion and potential sea level rise, prevent sand blowing further inland where agriculture is carried out. CSD provides nesting places of the sea turtles; several dune specific floral and faunal species filter the rainwater and ground water etc. Such ecologically important and sensitive dune has to be restored and protected (Vincent Comor et al., 2008; Frihy et al., 2004; Nordstrom, 2000; El Raey et al., 1999; Henriques et al., 1998).

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