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ASSESSMENT OF HALOPHYTE SPECIES DIVERSITY AT DIFFERENT COASTAL HABITATS ALONG THE SOUTHWEST PART OF GUJARAT COAST, INDIA

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ABSTRACT

Species diversity studies on coastal flora carry a lot of importance because approximately 60 % of the global populations live in coastal areas, rising up to 80 – 90 % in some countries, which are of high ecological and economic significance and value. Halophytes 'salt-tolerant plants' constitute one of the important groups of flora occurring in marshy wetlands. As halophytes grow in highly saline conditions, they possess diversified morphological, phenological, physiological, biochemical, anatomical, and ultra-structural adaptations. The compositional component of diversity is usually quantified by using alpha (species diversity within a community) and beta (between communities) diversity indices. In the present investigation reveals diversity measures like Shannon's diversity (H'), Simpson's reciprocal (1/D) and Pielou's evenness (J) indices were computed for assessing alpha diversity and similarity coefficients viz., Jaccard's (SCj) and Sorensen's (SCs) indices were calculated for beta diversity of 12 halophyte species growing at 8 locations along the Gujarat coast. Consolidated findings of this study interestingly show that halophyte vegetation growing along half of the Gujarat coast from Amreli to Valsad districts is characterized by quite a low species diversity, and low to moderate level of species richness as well as of species evenness.

INTRODUCTION

Gujarat is located in the north-western parts of India (20° 2′ - 24° 4′ N latitude. and 68° 8′ - 74° 2′ E longitude) and it has a 1663-km-long coastline occupying an area of 1,96,024 sq.Km. It represents a unique terrain consisting of naked tidal mud flats transacted by several dead and live creeks, also having various marshes with aquatic plants and varying types of lakes are characteristic features of this region.

Biological diversity in the coastal ecosystem differs from terrestrial ecosystem both in respect to pattern of diversity and to the functional application of those patterns. In general, coastal ecosystems have not only high diversity at respect to species level but also higher at taxonomic level. They show greater diversity of types of organisms and types of adaptive specialities than the terrestrial system. However, salt marsh ecosystems have significant importance as they are sheltering and nursing grounds for several species. Therefore, amongst various biodiversity regions, marine and coastal ecosystems are extremely important for their role in eco-physiological studies as well as economic utility to the human livelihood (Dijekema 1984).

Salt marshes are dominated by high salt tolerant halophytic species such as succulent, non-succulent, grasses, facultative halophytes and strand species. They complete their lifecycle in adverse conditions such as tidal inundations high salinity and anthropogenic activities. Halophytes not only tolerate very high salt concentration in habitats, but are also served as important sink for metal pollutants. Therefore, halophytes are not only good sources for food, fodder, but also useful for biofuel, chemicals, landscaping, dune stabilization, and phytoremediation (Lieth and Moshenko 1998; Williams *et al* 1994). They also serve as i) a model to study salt tolerance, ii) a source for 'salt tolerant gene' and iii) a source of crops themselves (Gallagher 1985). Because of such a fascinating

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combination of salt tolerance and economic potential, halophytes have been considered as cash crops for growing on saline wastelands (Lieth and Lohmann 2000).

Exhaustive details of geographical distribution, ecology, zonation and succession, adaptation and physiological aspects of the world's mangroves are available in Chapman (1974) and Walsh (1974). Likewise, many workers have studied distribution and ecology of Indian mangroves. Singh (2000), and Bhosle (2005) described the mangroves on the west coast of India; Kathiresan (2000) studied those on the east coast. Detailed compilation of important studies on Indian coastal flora by Banerjee *et al* (2002) indicated that limited studies on halophytes had been made. Later on, attention was paid to listing, distribution and eco-physiological aspects of this group (Sen and Rajpurohit 1982).

According to Magurran (2004) biodiversity has become an important measure to evaluate the ecosystems, the role of species diversity in ecosystem functioning needs to be investigated thoroughly and deeply (Patrick 1997; Schulze and Mooney 1994). Moreover, description of patterns in species assemblages and diversity is an essential step before generating hypotheses in functional ecology (Jonsson and Moen 1998), and analysing relations between plant communities and ecological processes (Decocq 2002; Schluter 1984).

The objective of the present investigation was to assess diversity of halophytes growing along ~ 800 km-long-coast of Saurashtra, the Gulf of Khambhat and South Gujarat coast nearing the Maharashtra state. Distribution of halophytes diversity of eight selected locations have been carried out by important diversity indices *viz*., Shannon index (*H'*), Simpson reciprocal index (1/D) and Pielou's index (*J*) were worked out, as they provide vital information about diversity, rarity and commonness of the species in a community. These measures also elucidate richness and evenness of halophyte communities growing at selected habitats. Similarity coefficients, often called coefficients of community, are the simplest approaches to comparing community structure. They are based solely on presence and absence of species. The Jaccard's index (SCj) is based on the presence-absence relationship between the common numbers of species at two vegetational groups. The Sorenson's index (SCs) differs from the Jaccard's index by measuring the ratio of the common to the average number of species in the two samples. Its formula gives greater weight to species common at both areas and less to species unique to either area.

MATERIAL AND METHODS

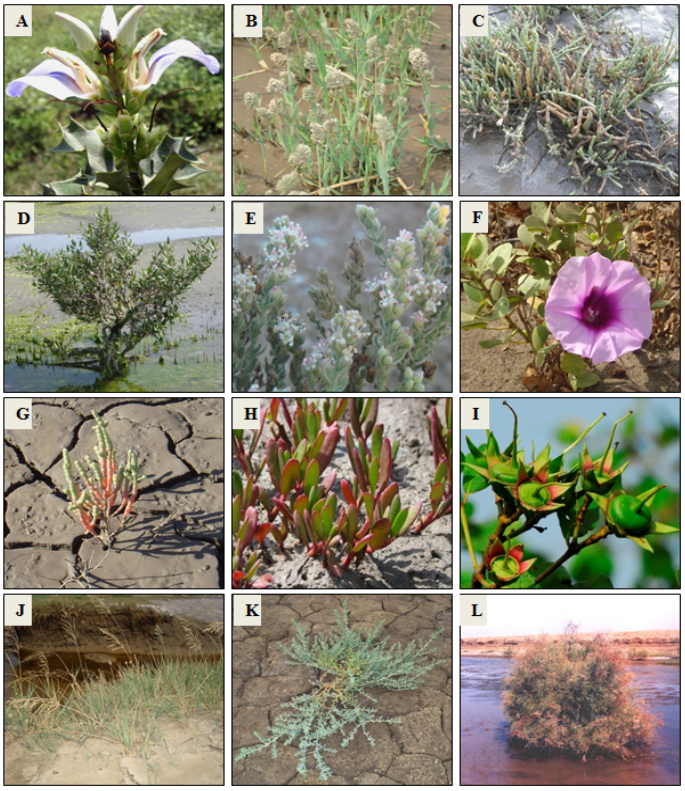
Study area

The present investigation was restricted to 8 maritime districts, namely Amreli, Bhavnagar, Ahmedabad, Anand, Bharuch, Surat, Navsari and Valsad on Saurastra and South Gujarat coast. One (Surat) of these habitats was sandy-muddy, whereas remaining all habitats were marshy (figure 1). As major objective of the present investigation was to examine diversity of halophytes alonglower half of (~ 800 km) Gujarat coast (Amreli to Valsad districts), standard and well established field procedures were followed.

Figure 1 The selected locations alongsouth-west part of Gujarat coast.

H1 = Victor Port, H2 = Sartanpar, H3 = Navagam, H4 = Machhipura, H5 = Mooler, H6 = Sunwali (Sandy-Muddy), H7 = Matwad and H8 = Umargam. (Source:https://earth.google.com/web/@21.23991516,72.13292135,0.80698889a,409220.9453326d,35y,0h,0t,0r/data=MicKJQojCiExVm01TmVQSWNoUFJMaEMxUHpjYnZja0E1QjdRYnNlYng)

Plate 1



A - *Acanthus ilicifolius*; **B** - *Aeluropus lagopoides*; **C** - *Arthrocnemum indicum*; **D** - *Avicennia marina*; **E** - *Cressa cretica*; **F** - *Ipomoea pes-caprae*; **G** - *Salicornia brachiata*; **H** - *Sesuvium portulacastrum*; **I** - *Sonneratia apetala*; **J** - *Sporobolus maderaspatanus*; **K** - *Suaeda nudiflora*; **L** - *Tamarix troupii*

METHODOLOGY

For an assessment of halophyte diversity we randomly surveyed 7 locations per maritime districts, eight (one for each district) were selected for present study. The selection criteria were maximum number of species as well as density of the species considered. For data collection twin belt transect was laid down at right angle to or parallel with sea coast or creeks at all selected locations. Halophyte species were counted in five alternative quadrats (5 x 5 m) of either of the belts.

In each location the total number of halophyte species and the total number of individuals occurred in sampled area were noted in the field note book as per the standard procedure followed for field study (Kent and Coker 1994). Floristic data recorded in data sheet for twenty alternate sample units (20 × 25m^2) admeasuring 500 m^2 in all selected habitats were used for computing alpha and beta diversity indices **(**Smith and Smith 2001).

Floristic identifications

The halophyte specimens were collected and preserved as Herbarium and few were dissected for identification. They were identified and confirmed using the identification manuals and standard Floras (Cooke 1958; Joshi 2011; Shah 1978).

Diversity Indices (Smith and Smith 2001)

Alpha diversity

1. Shannon index for diversity = $H' = -\sum_{i=1}^{S} (pi)(\log_{10} pi)$

Where, S =Number of species, pi = is the number of individuals of ithspecies (ni) divided by the total number of individuals of all species (N) in sampled area = (ni/N). log10 = log base10

2. Simpson's reciprocal index = $1/D = \frac{1}{\sum (ni/N)^2}$

Where, D = Simpson's index.ni = the total number of individuals of ith species. N = the total number of individuals of all species.

3. pielou'sindex for evenness = $J = \frac{H'}{H_{\max}}$ $\frac{-\sum_{i=1} pi \log_{10} pi}{\log_{10} S}$

Where, S = the number of species. pi = is the number of individuals of ith species divided by the total number of individuals of all species in sampled area log10 = log base 10

Beta diversity or Similarity coefficient

1. Jaccard's index (SCj) = $SCj = \frac{C}{A+B-C} \times 100$

Where, C = total number of species common at both the sites. A = total number of species in stand A. B = total number of species in stand B.

2. Sorensen index (SCs) = $SCs = \frac{C}{\frac{1}{2}A + B} \times 100$

Where, A = total number of species in community A. B = total number of species in community B. C = total number of species common at both the sites.

RESULTS

In present investigation 12 species from 6 different halophyte groups have been listed in Table 1, (Plate - 1). Comparative information of their presence and absence in different locations indicated dominance of grass *A. lagopoides*, and two succulent halophytes *viz*., *S. portulacastrum* and *S. nudiflora* were observed in study area. The maximum number of species (5) was recorded for locations H2, H6 and H7.

Alpha Diversity

Species diversity **-** The present study on diversity of halophytes indicated that all selected eight habitats exhibiting remarkable low diversity calculated by the Shannon index (Table 2). Among these, quite low diversity index was noted for location Machhipura (H4 = 0.04) and Matwad (H7 = 0.05). Marginal increase in the index was observed for halophyte vegetation at H1 (0.14), H3 (0.14), H5 (0.17) H6 (0.16) respectively and comparatively higher diversity was recorded for two locations *viz*., Umargam (H8 = 0.25) and Sartanpar (H2 = 0.34, Table 2). Obviously, all these values are extremely low in context with usually accepted range (1.5 to 3.5) of the Shannon index for halophytic flora.

Species richness **-** The Simpson's reciprocal index (1/D) calculated for halophytic flora was low in Navagam (H3 = 1.18), Sunwali (H6 = 1.19) and Matwad (H7 = 1.05), while its values slightly increased for the marshy vegetation at Umargam (H8 = 1.48) and Mooler H5 = 1.29, Table 2). These index values obviously indicated low to moderate species diversity of halophyte flora along the lower half of Gujarat coast.

Species evenness **-** Table 2 include results of the Pielou's index, fluctuating from 0.08 to 0.55 for halophyte flora at eight sampled sites. Low values of the Pielou's index were noted for four locations namely, Matwad (H7 = 0.08) and Machhipura (H4 = 0.12), whereas evenness of species in halophyte vegetation at Sartanpar (H2 = 0.490) was moderate. Furthermore, maximum values of this study showed moderately high even distribution of component species at Umargam (H8 = 0.53, Table 2) sites. The Pielou's index values lie between 0 to 1 and when the value is getting closer to 1,it means that the individuals are distributed equally in sampled area and thereby the plant community has high degree of species evenness or in that sense high degree of the diversity. Consolidated results of this study interestingly show that halophyte vegetation growing in study are a is characterised by quite low species diversity, and low to moderate level of species richness as well as of species evenness (Table 2).

Table 1 Halophyte species occurred at different locations.

Name of species	Halophyte Group	Selected locations							
		H 1	H 2	H 3	H 4	H 5	H 6	H 7	H 8
Arthrocnemum indicum (Willd.) Moq.	Succulent	√	×	×	×	×	×	√	×
Salicornia brachiata Roxb.	Succulent	√	√	×	×	×	×	×	×
Sesuvium portulacastrum (L.) Linn.	Succulent	×	√	×	×	×	√	×	√
Suaeda nudiflora (Willd.) Moq.	Succulent	√	√	√	√	√	√	√	×
Aeluropus lagopoides (L.) Trin. Ex Thw.	Non-succulent	√	√	√	√	√	√	√	√
Sporobolus maderaspatanus Bor.	Non-succulent	×	×	√	×	×	×	×	×
Tamarix troupii Hole.	Shrubby	×	×	√	×	×	×	×	×
Cressa cretica Linn.	Facultative	×	×	×	×	×	√	×	×
Ipomoea pes-caprae Linn.	Strand species	×	×	×	×	×	√	×	×
Acanthus illicifolius Linn.	Mangrove	×	×	×	×	×	×	√	×
Avicennia marina (Forsk.) Vierh. var. *acutissima*, Stapf.	Mangrove	×	√	×	×	×	×	×	√
Sonneratia apetala Buch.-Ham.	Mangrove	×	×	×	×	×	×	√	×

H1= Victor Port, **H2** = Sartanpar **H3** = Navagam, **H4** = Machhipura, **H5** = Mooler, **H6** = Sunwali, **H7**= Matwad, **H8** = Umargam; √ = presence, × = absence

Table 2 Alpha - diversity measures for halophyte vegetation at 8 different habitats along half of Gujarat coast. Values of the respective diversity index are mentioned in parenthesis.

Districts	Selected locations	*H	*S	Shannon's index (*H'*)		Simpson's index (1/D)		Pielou's index (*J*)	
				*L	*M	L	M	L	M
Amreli	Victor Port	H1	4	(0.14)	-	-	(1.18)	-	(0.24)
Bhavnagar	Sartanpar	H2	5	(0.34)	-	-	(1.77)	-	(0.49)
Ahmedabad	Navagam	H3	4	(0.14)	-	(1.18)	-	(0.24)	-
Anand	Machhipura	H4	2	(0.04)	-	-	(1.03)	(0.12)	-
Bharuch	Mooler	H5	2	(0.17)	-	-	(1.29)	-	(0.55)
Surat	Sunwali	H6	5	(0.16)	-	(1.19)	-	(0.23)	-
Navsari	Matwad	H7	5	(0.05)	-	(1.05)	-	(0.08)	-

Valsad	Umargam	H8	3	(0.25)	-	-	(1.48)	-	(0.53)

***H** = Habitat number; ***S** = Total number of species; ***L** = low; ***M** = moderate.

Beta diversity (Similarity coefficients)

Similarity indices often called as coefficients of community, are the simplest approach for comparing community structure. It also gives an idea about diversity, because similarity is invers todiversity. The Jaccard's index expresses the ratio of the common species to all species present in the two vegetational groups, while the Sorenson's index gives greater weight to species common to both the sites and less to species unique to either area. Consequently, the number of the Sorenson's index is always greater than that of the Jaccard's index, whereas meaning and interpretation of the diversity changes only marginally.

Table 3. Comparative presentation of Jaccard's (SCj) and Sorensen's index (SCs) computed for halophyte communities occurring at 8 different habitats.

*SCj *SCs	H1	H2	H3	H4	H5	H6	H7	H8
H1	--	50	33	50	50	28	50	16
H2	66	__	28	40	40	43	25	60
H3	50	44	__	50	50	28	28	16.7
H4	66	57	66	__	100	40	40	25
H5	66	57	66	100	__	40	40	25
H6	44	60	44	57	57	__	25	33
H7	66	40	44	57	57	40	__	14
H8	28	75	28	40	40	50	25	--

***SCj=** Jaccard's, ***SCs** = Sorensen's

***Jaccard's index* -** The present investigation yielded following major observations. Diversity of halophyte flora found at seven habitats matched with moderate magnitude (40 to 75 %) with regard to remaining five to six of the studied sites (Table 3, Row 2). Occurrence and number of individuals of two species (*Suaeda nudiflora and Aeluropus lagopoides*) at as many as seven to eight habitats reduced the diversity to the moderate level. One location (Umargam), which had unique halophyte composition (*Sesuvium portulacastrum, Aeluropus lagopoides* and *Avicennia marina*) not found elsewhere, showed very high diversity (50 to 83 %) with respect to five other selected habitats (Table 3, Row 1). Moreover, high level of floristic diversity was noted between vegetation of one or two possible coinciding habitats (Table 3, Row 1). A pair of locations Sartanpar (H2) and Umargam (H8) had flora marked by low level of species diversity (40 %), whereas another combination of sites supported halophyte communities having zero % diversity between the two, because of similar species composition at both the locations.

***Sorenson's index* -** As expected, results (Table 3) showed different magnitude of halophyte diversity. For instance, high degree of diversity (34 to 72 % - column 1 in Table 3) was noted merely for halophyte flora occurring at two habitats (Matwad and Umargam). Thus, as compared to the Jaccard's index, matching number of highly diversified sites declined here. The major shift reducing this number of paring locations from five to one, with respect to Umargam (H8) was most remarkable.

Furthermore, (Table 3, column 2) pairing number of habitats with moderate range of diversity of species (25 to 60 %) also declined here, because some sites moved to the next category of low diversity (Table 3, column 3).

Table 4 Assessed values of different diversity indices for halophyte species occurred in salt marshes of India and other countries.

Study area	Total No. of species	Shannon 's index	Species richness	Species evenness	References
Southern part of Gujarat coast, India	12	0.04 - 0.34	1.03-1.77	0.08-0.55	Present Study
Gulf of Kachchh Gujarat, India	27	1.63-1.86	1.08-1.52	0.36-0.53	Salvi *et al*,. 2017
Saurashtra coast Gujarat, India	21	0.12-0.50	1.13-2.61	0.18-0.88	Gohel *et al*., 2015
Bhal eco-region Gujarat, India	3	0.18-0.47	1.35-2.88	0.60-0.98	Vyas and Joshi, 2013
Georgia salt marshes in the U. S	43	0.15-0.41	*NA	0.80-0.92	Kunza and Pennings, 2008
Northern coast of Kuwait	6 vegetation groups	0.02-0.35	1.04-1.25	0.04-0.76	El-Ghareeb *et al*.. 2006
JalAz-Zor National Park, Kuwait	57-89	0.70-0.78	3.1-3.70	0.40-0.56	El-Sheikh and Abbadi, 2004

*NA – not available

One more major change indicated by the Sorenson's index, was an increase in number of (Table 3, column 3) coinciding habitats characterised by low (34 to 72 %) level of diversity. Halophyte communities growing at each site had such low magnitude of dissimilarity with those found at three to five other locations. However, no shifting was observed for a combination of habitats (Machhipura (H4) and Mooler (H5) having zero % diversity, between them.

DISCUSSION

Results of alpha diversity in terms of Shannon's, Simpson's and Pielou's indices recorded during this study are very low to moderate diversity. Couple of recent investigations on salt marshes of India also reported low diversity of halophyte flora. For instance, Vyas and Joshi (2009) reported low species diversity for vegetation at the in 'Bhal' ecoregion in Gujarat, while Gohel *et al* (2013) too, recorded low index values for marshy vegetation at Saurashtra coast (Table 4). Low species diversity of coastal habitats may also depend on hydrology, type of vegetation, salinity, edaphic factors. Similarly, dominance of particular species also affects species diversity.

Low values of diversity indices indicate less to moderate richness as well as low relative dominance of species in the selected location in present study. Furthermore, present results are in agreement with previous work of Kunza and Pennings (2008) on diversity of Georgia salt marshes in the U. S., who reported the Shannon index. Similarly, El-Ghareeb *et al*. (2006) also reported low species diversity of five halophytic vegetational groups in salt marshes of the northern coast of Kuwait. On the other hand Salvi *et al*. (2017) reported high value of Shannon index for halophyte vegetation in Gulg of Kachchh (Table 4). The values less than 1 suggest that habitat structure is being strongly damaged by climatic changes, anthropogenic activities. Whereas, values of indices compared with other studies are advisable because of sample size, species dominance and environmental conditions.

During their study on coastal plant communities in JalAz-Zor National Park in Kuwait, El-Sheikh and Abbadi (2004) found very high diversity of three halophyte habitats in terms of the Simpson index. Apparently, greater values of the index for the Kuwait flora were, perhaps because of occurrence of large number (57 to 89) of species in their study area. In contrast, El-Ghareeb *et al*. (2006) recorded low to moderate diversity of

coastal plant communities in marshy habitats in Kuwait (Table 4).

The results show variations in halophyte species diversity, richness and evenness among the different habitats. These variations may be attributed to the climatic differences, edaphic factors and anthropogenic activities.

It may be further added here that Talekar (2009), who worked out the Jaccard's index for diversity of six marshy and freshwater-marshy communities in 'Bhal' wetland in Gujarat, reported that each habitat differed with moderate diversity (51 to 75 %) from the vegetation found at one, two, three, or four matching habitats. The number of similar sites having low plant diversity between 26 to 50 %.also varied between one to four. However, two freshwater marshy sites had two coinciding habitats having quite low diversity (0 %), obviously because of all common species present at both the locations.

Recalculation of his data of the Sorenson's index values in terms of diversity, showed that there was a major shift towards the lower categories of dissimilarity or diversity and as a result, there was increase in number of matching habitats under the category of low and quite low diversity. Therefore, forgoing discussion supports a conclusion that halophyte communities occurring in the lower half of Gujarat coast are mostly characterised by high to low level of diversity, when evaluated jointly by values of Jaccard's and Sorenson's indices. It needs to be mention here that the unavailability of data for similarity coefficients of halophytes species diversity, we unable to discuss with present investigated.

CONCLUSION

In conclusion, it can be said that this case study indicated noticeably very low diversity, slightly high species richness and moderately even distribution of species in terms of Shannon's, Simpson's and Pielou's indices as well as similarity coefficients. Exceptionally high impact of salt concentration in habitats edaphic factors, climatic conditions, tidal inundation, anthropogenic activities may influence the halophyte flora. Remarkably low values of diversity indices of present investigation alarming fast destruction of salt marsh habitats indicated more attention to be paid towards conservation of such interesting and fascinating group of plants before it gets damaged irreparably.

Conflict of Interest: The authors declare that there is no conflict of interest.

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