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Comparative study of seaweed diversity indices in two different coastal areas in Veraval and Sikka coast, Gujarat, India

Shivani Pathak and Naresh Lavudya

Abstract
This study on seaweed diversity indices in two different coastal areas namely Veraval and Sikka coast was carried out from September 2019 to February 2020. Seaweed diversity at Veraval and Sikka coasts has been studied for six months the using belt transect random sampling method. A total of fifty seaweed species which comprise fourteen orders and nineteen families were recorded where thirty-nine of the species belong to the Veraval and fourty-one species were from Sikka. The best-represented family in both coastal areas of the Veraval and Sikka was Sargassaceae species, respectively. The Shannon-Wiener diversity index and Pielou's evenness index in the Veraval and Sikka coastal areas were counted as 2.83 and 1.80, and 0.62 and 0.40, respectively. For a healthy environment, the range of Shannon –Weiner species diversity index (*H*) values ranged from 1.5 to 3.5 in most ecological studies. During the diversity survey, economically important species like *Ulva lactuca, U. fasciata, Sargassum sp.,* and *Caulerpa sp.,* were reported.

Keywords: seaweed diversity, shannon-wiener diversity indices, Pielou's evenness index, diversity survey

Introduction

Seaweed Diversity in India

India (08˚04'-37˚06' N and 68˚07-97˚25'), a tropical South Asian country is rich in marine biodiversity resources, with a coastline of more than 8,120 km in length, and an Exclusive Economic Zone of 2.02 km^2 adjoining the continental regions and the offshore islands including those of the island of Andaman and Nicobar group and Lakshadweep harbors unique marine habitats which display a wide variety of marine biological diversity [1]. India has the highest record of seaweed species from the Indian Ocean region. Marine diversity is mostly studied in water along the coast and around the islands [2]. The latest diversity of Indian seaweed consisted of 1153 species from 271 genera [3]. Along the coastline of India, the littoral and sublittoral rocky areas support good growth of different seaweeds (agarophytes, alginophytes, and other edible seaweeds). There is a luxuriant growth of seaweeds along with the southeast coast of Tamil Nadu, from Mandapam to Kanyakumari; Gujarat coast; Lakshadweep Island, and the Andaman and Nicobar Islands. The current seaweed status of India showed 844 species distributed among 217 genera. The most abundant among them were Rhodophyta (434 species), followed by Chlorophyta (216 spp.), Phaeophyta (191 spp.), and Xanthophyta (3 spp.). Among these, the maximum number of species had been recorded from Tamil Nadu (302), followed by Gujarat (202), Maharashtra (159), Lakshadweep (89), Andhra Pradesh (79), and Goa (75) [4]. The coastal region of Tamil Nadu and Gujarat coasts has the richest diversity of seaweeds. The southwest coast of India that is Gujarat is situated on the north-western part of peninsular India (20˚1' to 24˚7' N and 68˚4' to 74˚4' E) which is a unique marine habitat infested with diverse macroalgae species. Gujarat has 1,600 km of coastline – the longest coastline of the country, the total area of 196,024 km^2, a continental shelf of 1,64,200 km^2, and an Exclusive economic zone (EEZ) is 2,14,000 km^2 [5].

What are Seaweeds

About 90% of the marine plants belong to one group of algae or the other. Many of these algal groups are now represented mainly as seaweeds. The term seaweed collectively denotes the group of a photosynthetic non-flowering plant with no distinguishable root, stems, and leaves;

those are lives either in marine or brackish water environments [5]. Seaweeds are generally known as multicellular benthic marine macroalgae that possessing chlorophyll and capable of photosynthesis. Seaweeds can reproduce sexually as well as asexually. Seaweeds form an important renewable resource in the marine environment and have been part of human civilization from time immemorial. Seaweeds are important in human food, health, and economic wellbeing. They are a fascinating and diverse group of organisms inhabiting the oceans. Seaweeds are found in the coastal region between high tide to low tide i.e. intertidal region and in the sub-tidal region up to a depth where photosynthetic light is available. They constitute one of the important living resources found mostly on a mudflat and rocky coastal wetlands, coral reefs and lagoons, estuaries, attached to the bottom on solid substrates such as rocks in the intertidal zones, washed up on beaches floating on the oceanic surface, and also in giant underwater forests, dead corals, pebbles, shells and plants [6].

Ecology of Seaweeds

In marine communities, seaweed plays very important ecological roles. They are a source of food for marine animals and make a significant contribution to the food of man. They also provide habitation and spawning sites for commercially important marine animals such as fishes, invertebrates, birds, and mammals. Large Seaweeds like *Ascophyllium*, *Macrocystis*, and *Laminaria*, etc. can form giant underwater forests, called kelp forests. These forests provide a physical structure that supports marine communities by providing animals with food and shelter. Kelp forests act as underwater nurseries for many marine animals, such as fish and snails. Seaweed also provides good home and tasty food for marine animals like invertebrates, fishes, birds, and whales. Sea slugs and kelp crabs can be seen on the blades and stipes of the seaweeds, while other small marine animals like worms find shelter in the holdfasts of the seaweeds. Kelp forests are a huge food source for sea urchins and other grazing invertebrates [7]. Devastations of seaweed beds through grazing by predators or invertebrates have been found to cause immense ecological imbalances which in turn have significant fisheries interactions.

Although a considerable amount of work has been done on marine algae of the Indian region, still we required for compilation of Marine Algal Flora of India, because of a large scale of species extinction. Thus to fulfill the notable lacunae from the present study locations about marine algal diversity are going to be done from the present study. Seaweed diversity information could also provide a baseline for future more complex ecological studies, planning the conservation and sustainable use of inshore marine resources, useful as an indicator of climatic change and coastal management as well as applied aspects of the uses of seaweed. Therefore present study conducted to define the temporal variations of the seaweed diversity indices at two different location areas of Saurashtra region of Veraval and Sikka coast of Gujarat.

Material and Methods

Study area

The present study was conducted at two places on the Western coast of Gujarat, India i.e. Veraval and Sikka coasts (20°54'34"N latitude 70°21'08"E longitudes) & (22°27'31"N latitude 69°48'17"E longitudes).The intertidal zone of Veraval coast is an inlet of the Arabian Sea in the state of Gujarat. Here the high diversity due to the availability of different types of habitats likes sandy and rocky shore. The Gulf of Kutchh is an inlet of the Arabian Sea in the state of Gujarat, India, and the Sikka coast is situated in Jamnagar. Here the high diversity due to the availability of different types of habitats likes sandy, muddy and rocky shores in the relatively sheltered waters of the Gulf.

Sampling period

The diversity survey was conducted at Veraval and Sikka sites for eight months but due to COVID-19 (Corona Virus Disease-19), two months sample was not able to collect. The study was conducted for six months and it was initiated from September-2019 and it continued up to February-2020. This sampling survey was selected to get an idea of seaweed diversity at the difference between two different locations and seasons.

Sampling method

The belts transect random sampling method was used for the quantitative assessment of seaweeds in the selected sites.

Qualitative and Quantitative assessment of seaweed

Sampling points along the rope were marked depending on the gradient and the expanse of the intertidal area. Whenever the intertidal area was small, sampling points were marked at 3 m intervals along the rope, and where the intertidal area was quite large the sampling point was marked at 8 or 10 m along the rope. A quadrant measuring 1 m^2 area was placed at the sampling points. All the species of seaweeds present within the quadrant were uprooted completely along with the holdfast, identified, and numbers of individuals were recorded for diversity. The species diversity which was available along the selected study locations were collected and at the laboratory identified by using standard references material [8].

Data analysis

As diversity indices are increasingly used to assess the health of the habitats, presently Shannon index of general diversity (H") and evenness index (E), measures were used to estimate the Algal species diversity of the intertidal area of selected stations.

Algal species diversity was calculated according to the Shannon's – Weiner index [9] formula.

$$H' = -\sum_{i=1}^{s} \left(\frac{ni}{n}\right) \times \ln\left(\frac{ni}{n}\right)$$

Where,

H'= the sample diversity

ni = Number of individuals of species in the sample

S= number of species

Apart from that species evenness index (J; Pielou) [10] was also studied to understand the distribution of the seaweed species.

Evenness Index (J')

$$J'' = \frac{H'}{\ln(s)}$$

Where

H'= the sample diversity

S= number of species

Results and Discussion

Species diversity at the Veraval coast

At Veraval coast, first thoroughly surveyed to get an idea of the coastal characteristics like climatic condition and to make a qualitative assessment of the seaweed flora inhabiting there, throughout the study period. A checklist of the different seaweed species recorded during the period of investigation is presented in Table classwise (Table-1). From this table, it is clear that a total of 39 seaweed species were observed throughout the study period. Out of those, 14 species were Chlorophyceae, 9 species were Phaeophyceae, and 16 species were Rhodophyceae. The ratio of Chlorophyceae: Phaeophyceae: Rhodophyceae was 14:9:16. In percentage, 34.50 % were Chlorophyceae, 30.28 % Phaeophyceae, and 35.21 % Rhodophyceae species were recorded (Figure-1). Thus species of red algae show more dominance in the seaweed flora at the Veraval coast.

From the Veraval survey, it is hypothesized that in general Green algae and Brown algae are observed during the initial months of the survey i.e. September to December while the majority of Red algae are found from January to February months.

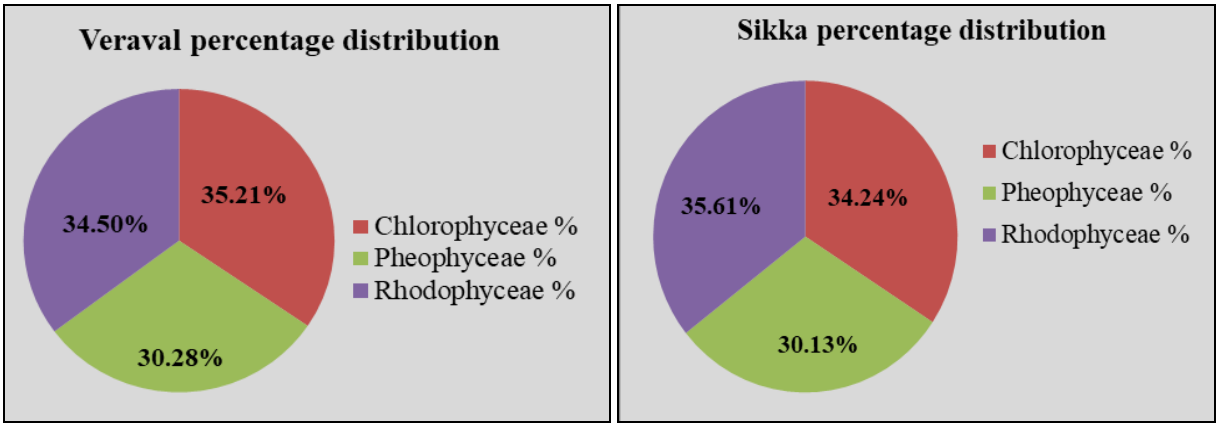

Fig 1: Class-wise percentage distribution of species diversity at veraval and sikka coasts

Table 1: Species diversity of seaweed present at the veraval coast

Sr.No.	Species	Sep' 19	Oct' 19	Nov' 19	Dec' 19	Jan' 20	Feb' 20
Chlorophyceae							
1	*Bryopsis plumosa* (Hudson) C. Agardh	0	0	3	5	5	0
2	*Caulerpa racemosa* (Forsskal) J.Agardh	11	3	6	10	0	12
3	*Caulerpa taxifolia* C. Agardh	0	0	2	0	0	3
4	*Caulerpa scalpelliformis* Var. Denticulata	4	0	2	2	0	0
5	*Chaetomorpha spiralis* Okamura	2	1	3	0	2	3
6	*Chaetomorpha antennina* (Bory de Saint- Vincent) Kuetzing	4	2	4	0	3	0
7	*Cladophora socialis* Kutzing	2	0	0	2	0	3
8	*Codium indicum* S.C Dixit	3	0	0	0	2	0
9	*Enteromorpha compressa* (Linn.) Grev.	0	4	0	0	2	0
10	*Valonia aegagrophila* C. Agardh	2	0	0	0	0	2
11	*Halimeda macroloba* Decaisne	0	2	2	3	4	3
12	*Halimeda tuna* C.Agardh	0	5	5	0	0	6
13	*Ulva fasciata* Linnaeus	9	10	8	13	9	0
14	*Ulva lactuca* Linnaeus	25	29	20	15	0	10
	Total number of Chlorophyceae species	9	8	10	7	7	8
	% of Chlorophyceae	52.94	42.10	37.03	28	28	27.58
Phaeophyceae							
15	*Ectocarpus confervoides* Le Jolis	0	3	2	1	2	3
16	*Cystoseira indica* (Thivy&Dhoshi) Mairh	4	0	3	1	0	7
17	*Iyengaria stellata* (Borgesen) Borgesen	1	3	2	0	6	4
18	*Padina gymnospora* (Kuetzing) Sonder	5	0	7	6	5	4
19	*Padinatetrastromatica* Hauck	2	6	2	15	2	11
20	*Sargassum plagiophyllum* C.Agardh	0	2	2	4	6	0
21	*Sargassum polycystum* C.Agardh	2	3	4	8	1	7
22	*Sargassum tenerrimum* J.G.Agardh	3	0	2	3	0	0
23	*Spatoglossum asperum* J. Agardh	0	2	2	2	4	3
	Total number of Phaeophyceae species	6	6	9	8	7	7
	% of Phaeophyceae	35.29	31.57	33.33	32	28	24.13
Rhodophyceae							
24	*Acanthophora spicifera* (Vahl) Boergesen	0	0	2	0	3	3
25	*Ceramium cruciatum* FS Collins & Hervey	0	0	0	2	3	3
26	*Ceramium rubram* (Huds.) Ag.	0	0	0	3	0	0
27	*Champia indica* Boergs.	0	3	2	1	2	3
28	*Chondria armata* (Kutzing) Okamura	2	0	3	2	3	2

29	*Gelidiella acerosa* (Forsskal) J.Feldmann & G.Hamel	2	2	2	3	0	6
30	*Gelidium pusillum* (Stackhouse) Le Jolis	0	3	2	0	2	2
31	*Gracilaria corticata*(J.Agardh) J.Agardh	0	2	2	4	3	7
32	*Gracilaria foliifera* (Forssk.)Boergs.	0	0	1	1	3	0
33	*Gracilaria salicornia*(C.Agardh) Dowson	0	0	2	0	2	3
34	*Halymenia venusta* Borgesen	0	0	0	0	2	4
35	*Halymeniaporphyraeformis* P.G.Parkinson	0	0	0	2	0	2
36	*Hypnea musciformis* (Wulf.) Lamour.	0	0	0	2	1	4
37	*Polysiphonia platycarpa* Borgesen	0	2	0	1	2	2
38	*Scinaia moniliformis* J.Agardh	0	0	0	2	0	1
39	*Scinaia hatei* Borgesen	0	0	0	0	1	2
	Total number of Rhodophyceae species	2	5	8	10	11	14
	% of Rhodophyceae species	11.76	26.31	29.62	40	44	48.27
	Total number of species	17	19	27	25	25	29

Species diversity at the Sikka coast

The entire intertidal area of the Gulf of Kutchh particularly Gujarat State Fertilizer Company's Jetty (GSFC Jetty), at Sikka has been first thoroughly surveyed to get an idea about the coast characteristics and to make a qualitative assessment of the seaweed flora inhabiting there, throughout the study period. Sikka coast is rich with a diverse group of seaweed species. Presence of suitable substratum especially the coral reefs and other rocks and thus form critical habitats for most of the algal species.

There were altogether 41 species were observed at the Sikka coast. A checklist of different seaweed species was recorded during the period of investigation which is presented in the following table. From the table (Table-2) it is cleared that 41 seaweed species were observed throughout the study period. Out of those, 14 species were Chlorophyceae, 11 species were Phaeophyceae, and 16 species were Rhodophyceae. The ratio of Chlorophyceae: Phaeophyceae: Rhodophyceae was 14:11:16. The major part of the stranded seaweed is represented by sixteen species of Rhodophyta accounting for 35.61 %, followed by 14 species of Chlorophyta with 34.24 % and 11 species of Phaeophyta with 30.13 % (Figure-1). Thus Rhodophyceae group was more preponderance in the seaweed flora at the Sikka site. The maximum number of seaweed species occurred during January 2020 and February 2020 with as many as 36 species, and a minimum of 13 was registered in October 2019 (Table-2).

Table 2: Species diversity of seaweed present at the sikka coast

Sr.no.	Species	Sep' 19	Oct' 19	Nov' 19	Dec' 19	Jan' 20	Feb' 20
	Chlorophyceae						
1	*Boodlea composita* (Harvey) Brand	3	0	0	3	0	1
2	*Caulerpa racemosa* (Forsskal) J.Agardh	0	0	0	4	5	4
3	*Caulerpa taxifolia* C. Agardh	0	0	3	3	0	3
4	*Caulerpa scalpelliformis* Var. Denticulata	0	0	0	0	2	1
5	*Chaetomorpha spiralis* Okamura	3	0	2	0	3	2
6	*Chaetomorpha antennina* (Bory de Saint- Vincent) Kuetzing	0	0	5	3	2	3
7	*Cladophora socialis* Kutzing	0	0	0	0	3	3
8	*Enteromorpha compressa* (Linn.) Grev.	0	0	3	2	1	0
9	*Vellonia species*	0	0	0	1	2	2
10	*Halimeda macroloba* Decaisne	0	3	6	3	2	1
11	*Halimeda tuna* C.Agardh	5	0	1	2	1	1
12	*Ulva fasciata* Linnaeus	0	18	10	4	7	5
13	*Ulva lactuca* Linnaeus	29	25	12	10	7	6
14	*Ulva reticulate* Forsskal	0	0	5	4	0	0
	Total number of Chlorophyceae species	4	3	9	11	11	12
	% of Chlorophyceae	25	23.07	47.36	42.30	30.55	33.33
	Phaeophyceae						
15	*Ectocarpus siliculosus* (Dillwyn) Lyngbye	1	2	2	0	0	0
16	*Cystoseira indica* (Thivy&Dhoshi) Mairh	4	0	0	0	3	2
17	*Iyengaria stellata* (Borgesen) Borgesen	3	3	3	2	3	2
18	*Padina boergesenii* Allender & Kraft	0	0	0	1	2	0
19	*Padina gymnospora* (Kuetzing) Sonder	2	3	2	3	4	0
20	*Padina tetrastromatica* Hauck	4	7	10	5	1	3
21	*Sargassum cinclum* J.Agardh	2	2	3	1	2	1
22	*Sargassum cinereum* J.Agardh	0	0	0	0	2	3
23	*Sargassum johnstonii* C.Agardh	6	6	10	4	2	3
24	*Sargassum tenerrimum* J.G.Agardh	0	0	0	3	2	1
25	*Spatoglossum asperum* J. Agardh	0	0	0	0	1	2
	Total number of Phaeophyceae species	7	6	6	7	10	8
	% of Phaeophyceae	43.75	46.15	31.57	26.92	27.77	22.22
	Rhodophyceae						
26	*Acanthophora spicifera* (Vahl) Boergesen	0	0	0	0	3	4
27	*Ceramium cruciatum* FS Collins & Hervey	0	0	0	2	3	1

28	*Ceramium rubram* (Huds.) Ag.	0	0	0	1	2	1
29	*Ceramium tenerrimum* (G.Martens) Okamura	0	0	0	0	2	2
30	*Champia indica* Boergs.	0	0	0	0	2	3
31	*Chondria armata* (Kutzing)Okamura	1	0	0	2	3	3
32	*Gelidiella acerosa* (Forsskal) J.Feldmann & G.Hamel	3	6	6	5	4	4
33	*Gelidium pusillum*(Stackhouse) Le Jolis	2	4	3	3	3	4
34	*Gracilaria corticata* (J.Agardh) J.Agardh	4	6	8	3	4	4
35	*Gracilaria foliifera* (Forssk.)Boergs.	0	0	0	1	2	1
36	*Gracilaria salicornia* (C.Agardh) Dowson	4	3	4	2	1	3
37	*Halymenia venusta* Borgesen	0	0	0	0	2	2
38	*Hypnea musciformis* (Wulf.) Lamour	0	0	0	0	3	4
39	*Platysiphonia delicate* (Clemente) Cremades	0	0	0	0	2	1
40	*Scinaia carnosa* (Kutzing) J.Agardh	0	0	0	0	0	3
41	*Scinaia hatei* Borgesen	0	0	0	0	1	2
	Total number of Rhodophyceae species	5	4	4	8	15	16
	% of Rhodophyceae species	31.25	30.76	21.05	30.76	41.66	44.44
	Total number of species	16	13	19	26	36	36

In the present study, Rhodophyceae algae showed maximum diversity with 19 species, followed by Chlorophyceae with 17 species. Phaeophyceae algae were comparatively less along the Veraval and Sikka coast with only 14 species. Thakur *et al*. [11] carried out a study on seaweeds; they reported a total of 62 seaweed species comprising 26 species of Rhodophyta, 22 species of Chlorophyta, and 14 species of Phaeophyta along Port Okha, northwest coast of India. Diversity-wise Rhodophyceaen algae were more in Port Okha, as was observed in the present study. During the diversity survey, economically important species like *Caulerpa, Ulva, Padina, Gracilaria, Polysiphonia, Cystoseira, and Sargassum* were reported during the present study. Among them, *Sargassum spp.* was highly dominated followed by *Gracilaria spp.* According to Naik *et al*. [12], the dominant species recorded were *Sargassum sp., Ulva fasciata, U. lactuca, Padina spp, Caulerpa spp.* along Karwar Bay.

Red algae grow better in the lower littoral zone and maybe more tolerant of the tropical environmental conditions. That may be the reason for the good growth of Rhodophyceae (red algae) as compared to Chlorophyceae of the Phaeophyceae. Joshi and Murthy [13] and Jha *et al.* [14] Observed more number of Rhodhophyceae compared to Phaeophyceae of the Chlorophyceae.

Results of the present study are satisfied with earlier reports of Rao *et al.* [15] in the Bhimili coast, east coast of India, Chakraborty and Bhattacharya [16] from Sikka and Vadinar, Gulf of Kutchh, India, Domettila *et al*. [17] along Muttom coastal waters of the southwest coast of India, Reddy *et al*. [18] in seaweed resources of India, Naik *et al.* [12] in Karwar Bay, and Rodde and Sable [19] from Malvan and Kunakeshwar in Sindhudurg District of Maharashtra. A similar observation was recorded in the present investigation also. Ishakani *et al*. [20] from the Veraval coast reported a total of 67 species comprises of 21 species of Chlorophyta, 14 species of Phaeophyta, and 32 species of Rhodophyta species which revealed that the results of the present study are much similar to earlier researchers.

Shannon's - Weiner Index (H) for Veraval and Sikka coast

The species diversity of seaweeds was estimated based on the Shannon –Weiner diversity index (*H*). At Veraval, Shannon – Weiner species diversity index (*H*) values ranged from 2.40-3.19 during the present study (Table-3). The maximum diversity index value was observed in February (Pre-monsoon) which is a winter month. While the minimum value was observed during September month (Post-monsoon (Figure-2). At Sikka, Shannon –Weiner species diversity index (*H*) values ranged from 1.46 -2.08 during the present study (Table-3). Maximum diversity indices were observed in November month (Post monsoon). While the minimum was during September month (Figure-2).

At Veraval, Species Evenness Index (E) varied in very narrow range i.e. 0.54- 0.71 (Table-3). Species Evenness was maximum during January month and lowest during September month, respectively (Figure 3). But at Sikka coast, Species Evenness Index (E) varied from 0.34-0.45 (Table-3). Species Evenness was maximum during November and December month and lowest during September month, respectively (Figure-3).

As diversity indices are increasingly used to assess the well-being of the health of the habitats (Ajamal Khan *et al.*) [21]. For a healthy environment, the range of Shannon –Weiner species diversity index (*H*) values ranged from 1.5 to 3.5 in most ecological studies (Magurran) [22] .The increase in the Shannon index shows the richness of diversity and the evenness of the community increases. According to Naik *et al.* [12] the Shannon index (H) value ranges from 1.941- 2.602 during southwest and post-monsoon in the Devagadh area whereas 1.452 – 2.467 during southwest and pre-monsoon in the Kurmagad area at Karwar Bay which was much similar to present investigation. Species Evenness Index (E) varied in very narrow range i.e. 0.34-0.71. However, low levels of species evenness possibly due to the flatness of the intertidal area, which is exposed during low tide as supported by the Shannon index (Misra and Kundu) [23]. The results revealed that the lower diversity during summer and higher diversity values in winter recorded in the present investigation.

Results of the present study are in agreement with earlier reports of Raghunathan *et al.* [24] at Veraval coast, Vaghela *et al.* [25] at Sikka and Vadinar coast of Gujarat.

Table 3: Shannon weiner diversity index for veraval and sikka coasts

Month	Number of species (S)		Pielous evenness (J')		Shannon index (H')	
	Veraval	Sikka	Veraval	Sikka	Veraval	Sikka
September	17	16	0.54	0.34	2.40	1.46
October	19	13	0.55	0.37	2.46	1.64
November	27	19	0.65	0.45	2.99	2.08
December	26	26	0.61	0.45	2.88	1.97
January	26	36	0.71	0.42	3.11	1.93
February	29	36	0.66	0.38	3.19	1.73

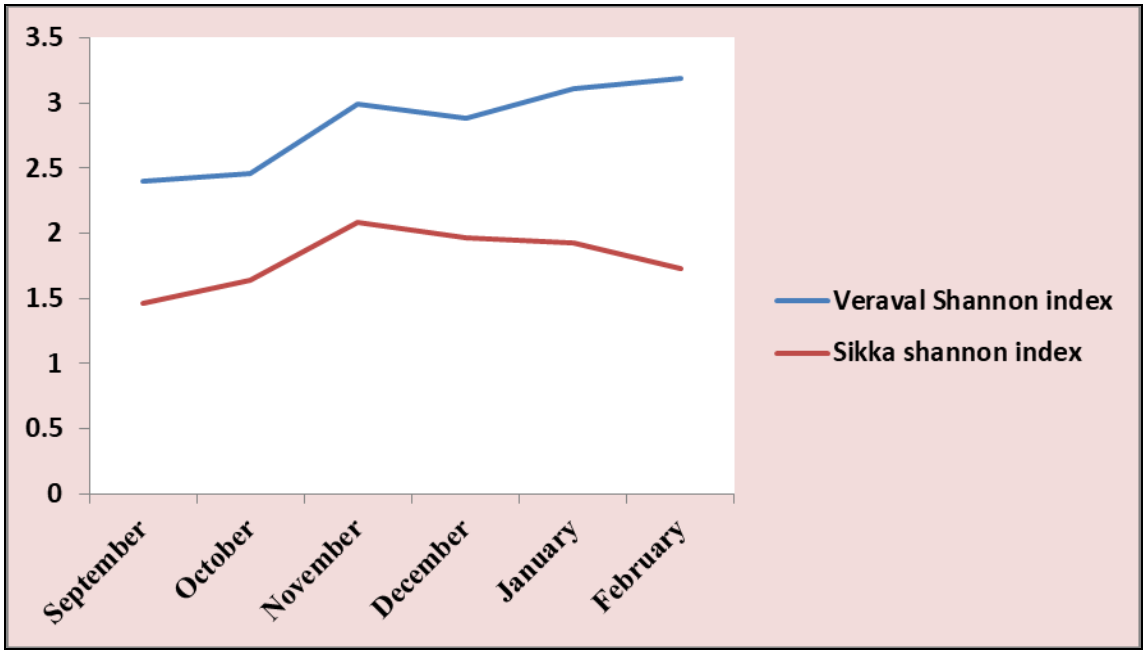

Fig 2: Variations in shannon weiner diversity index along veraval and sikka coasts

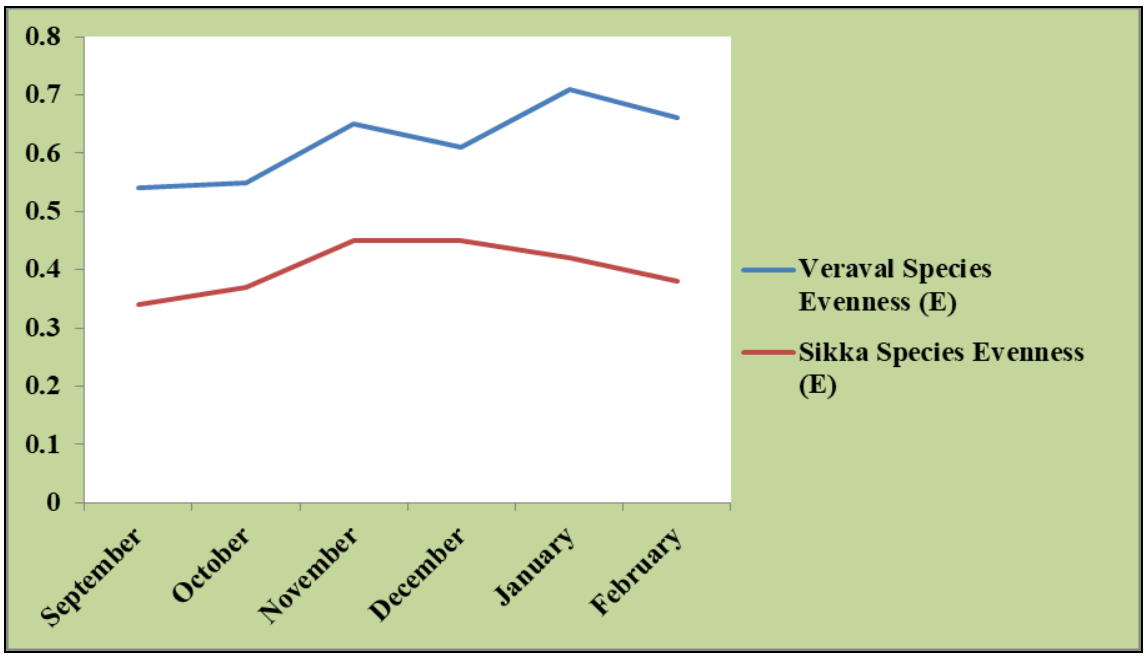

Fig 3: Variations in species evenness index (E) along veraval and sikka coasts

Conclusion

The present study concluded that Veraval has higher diversity of seaweeds compared to the Sikka coast. Because of the intertidal zone with maximum exposure to desiccation and direct sunlight, as a result considerable growth of seaweed diversity whereas at Sikka site, there are much illegal fishing, fish trade, goods transport, and many other activities reported from the area in question. The Sikka situation is going to worsen due to an increase in ship transportation. So, there is an urgent need to implement an effective environmental management plan to restore the seaweed diversity. Seaweed diversity information could also provide a baseline for future more complex ecological studies, planning the conservation and sustainable use of inshore marine resources, useful as an indicator of climatic change and coastal management as well as applied aspects of the uses of seaweed.

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