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Biogeography and distribution of bacillariophyceae in the highland rivers of India

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Abstract
Fifty one, fifty and forty three genera are recorded from the West Himalaya (Garhwal region), Central Highlands and Western Ghats, respectively. Thirty six genera are common to these three biogeographic regions of the Indian subcontinent. Currently, the Indo-Gangetic Plains separate the Himalaya and the Central Highlands but are connected by the Gangetic drainage. The Western Ghats and the Central Highlands are connected like 'elbow' at northern and western extremity, respectively and extend to south and east located perpendicular to each other. These two regions constitute the Deccan Peninsula the oldest part of the Indian subcontinent, a historical reason for high similarity between these two biogeographic regions. However, similarity with the Himalaya (part of the sub continent) created historically by recent upheavals, other geological activities in the Deccan and glaciations and current geography account for this high similarity.
Preliminary investigations show presence of fifty eight genera from three biogeographic regions the Central Highland, West Himalaya and Western Ghats of the Indian subcontinent. Fifty one taxa were recorded from the Himalaya (Garhwal region), fifty from Central Highlands and forty three from Western Ghats. Thirty six genera were common to these three regions. Historical rather than geographical factors appear to have played a greater role, due to movement of landmasses and upheavals, which not only led to changes in the drainage patterns but also climatic conditions. The recently deglaciated high altitude locations in the Himalaya have not been geologically stable while the Central Highlands and the Western Ghats in the peninsula has been geologically stable.

Keywords: Diatom, Highland Rivers, India

1. Introduction
Many diatom species are known to have world-wide distributions; others appear limited to certain climatic zones or geographical regions, or are endemic to particular water bodies. Most of the factors found to be important for distribution of benthic river diatoms like water chemistry (pH, ionic strength and nutrient concentrations), substrate, current velocity, light and grazing (Patrick and Reimer, 1966; Round, 1981) [11, 12] depend strongly on climate, geology, topography, land-use and other landscape characteristics, and hence are similar within ecological regions defined by these characteristics (Stevenson 1997) [13]. The apparently global distributions of unicellular organisms have been suggested to result from huge population sizes and efficient passive dispersal over large areas, facilitated by small cell size. Kociolek and Spaulding (2000) [4] argue that the proportion of geographically restricted diatom species is much higher than formerly thought, and because of that, the importance of geographical factors in explaining patterns in diatom flora has been underestimated. This is based on the knowledge of diatom distribution across the northern hemisphere, primarily from the continents of Europe and North America. However, there is still ignorance about the distribution of diatoms in the Indian subcontinent, especially in view of its past geology; the drift which accounts for its present position in the globe and collision with the Asian plate leading to the Himalayan orogeny. Presently, the terrain consists of plateau, plains and mountains.
Though the climate is governed by monsoon, both hot and cold wet to arid conditions prevail across the subcontinent resulting in varied ecoregions. This study examines distribution of the diatom genera, especially the taxa specific and those common to the West Himalaya, Central Highlands, and Western Ghats ecoregions, in the northern, central and southern regions of India, respectively. The study also examines the possible role of geographic and historical factors to explain the current state of distribution in these biogeographic regions.

2. Study-area

The study is based on diatom collections from the Chalakudy River in Western Ghats, the Ken, Paisuni and Tons in Central Highland, Yamuna, Alaknanda, Bhagirathi, Mandakini and Ganga in the West Himalaya. The geographicallocationofthestudyareapresentedinTable1.

Table 1: Geographical coordinates of the Rivers of North-Western Himalaya, Central Highland and Western Ghats.

Region	Rivers	Latitude (N)	Longitude (E)	Elevation (m)
North-WesternHimalaya	Yamuna, Bhagirathi, Ganga,Alaknanda	30°8′15″ - 31°45′2″N	78°10′29″- 78°48′32″E	375-2200m
Central Highland	Ganga, Yamuna	23°59′28.92″-25°46′15.49″N	80°0′41.16″ -80°54′26.34″E	86-365m
Western Ghats	Chalakudy River	10°05′-10°35′N	76°15′-76°55′E	0-1250m

3. Materials & Methods

3.1 Rationale for sampling benthic (epilithic) diatoms: Since distributional patterns of species are a function of dispersal mechanism, environmental tolerances and historical factors (Carter and Watts 1981) [1], the likelihood of a species being present throughout a large geographical area is low. To analyze the distributional patterns, the samples are taken on the assumption that difference in distributional patterns reflects real difference among the sites and not seasonal trends (Corkum 1989) [2]. Hence, one time intensive sampling during stable flow (November to May) was deemed suitable for present study as the rivers are in floods during monsoon (mid June to mid September) when flora is poorly represented on the substrate. Besides, the purpose was to obtain a composite sample to explore the total flora and diversity, not the seasonal trends.

3.2 Sampling: Diatom samples were collected by scraping an area of 3 x 3 cm^2 from the cobble surface and preserved in 4% formalin. Samples were treated with hydrochloric acid-peroxide, washed repeatedly and mounted in Naphrax and stored at Aquatic Biodiversity Unit. Each sample was examined under brightfield in a BX-40 Olympus microscope (x1500 oil immersion) for its flora using standard literature. The diatom genera were identified using standard literature (Hustedt and Jensen 1985; Krammer and Lange-Bertalot 1986-1991; Krammer 2002; 2003; Lange-Bertalot 2001; Werum and Lange Bertalot 2004; Metzeltin *et al*. 2005) [3, 7, 5, 6, 8, 14, 9].

4. Results

Fifty eight genera occur in three biogeographic regions of India (Table 2). Of these 51 genera occur in the West Himalaya, 50 genera in the Central Highland and 43 genera in the Western Ghats. Thirty six genera are common to all three regions, of which 42 genera are common to the Vindhya and Himalaya, 39 are common to the west Himalaya and Western Ghats while only 38 are intriguingly common to closely located Vindhya and Western Ghats. Nine genera (*Ceratoneis* Grunow, *Encyonopsis* Krammer, *Reimeria* Kociolek & Stoermer, *Rhoicosphenia* Grunow, *Melosira*Agardh, *Meridion* Agardh, *Fragilariforma* Williams & Round, *Peronia* Brèbisson & Arnott, *Nupela* Vyverman & Compère) are specific to the Himalaya while five (*Anomoeoneis* Pfitzer, *Gomphocymbelopsis* Krammer, *Mastogloia* Thwaites, *Aneumastus* Mann & Stickle, *Scoliopleura* Grunow) arespecific to the Vindhya. Almost all these genera have either one or few species in respective ecoregions. Further investigations on other parts of the Western Ghats may yield some specific and endemic genera.

Table 2: Distribution of diatom genera in three highland regions of the Indian subcontinent.

GENERA	H	CH	WG
1.*Cyclotella* Kützing	+	+	+
2.*Diatoma* Bory	+	+	+
3.*Fragilaria* Lyngbye	+	+	+
4.*Staurosira* Ehrenberg	+	+	+
5.*Synedra* Ehrenberg	+	+	+
6.*Eunotia* Ehrenberg	+	+	+
7.*Achnanthes* Bory	+	+	+
8.*Achnanthidium* Zhakovschikovii	+	+	+
9. *Planothidium* Round & Bukhtiyarova	+	+	+
10.*Cocconeis* Ehrenberg	+	+	+
11. *Amphora* Ehrenberg	+	+	+
12. *Brachysira* Brèbisson	+	+	+
13.*Caloneis* Cleve	+	+	+
14.*Cymbella* Agardh	+	+	+
15.*Cymbopleura* Krammer	+	+	+
16.*Encyonema* Kützing	+	+	+
17.*Frustulia* Rabenhorst	+	+	+
18.*Gyrosigma* Hassall	+	+	+
19.*Gomphonema* Ehrenberg	+	+	+
20.*Navicula* Bory	+	+	+
21.*Navicula sensu lato*	+	+	+
22.*Adlafia* Moser	+	+	+
23.*Luticola* Mann	+	+	+
24.*Geissleria* Lange-Bertalot & Metzeltin	+	+	+
25.*Sellaphora* Mereschkowsky	+	+	+
26.*Pinnularia* Ehrenberg	+	+	+
27.*Stauroneis* Ehrenberg	+	+	+
28.*Hantzschia* Grunow	+	+	+
29.*Nitzschia* Hassall	+	+	+
30.*Surirella* Turpin	+	+	+
31.*Cymatopleura* W.Smith	+	+	+
32.*Epithemia* Brèbisson	+	+	+
33.*Rhopalodia* O.Müller	+	+	+
34.*Neidium* Pfitzer	+	+	+
35.*Amphipleura* Kützing	+	+	
36.*Diploneis* Ehrenberg	+	+	
37.*Craticula* Grunow			
38. *Fallacia* Stickle & D.G.Mann	+	+	
39.*Hippodonta* Lange-Bertalot	+	+	
40.*Placoneis* Mereschkowsky	+	+	
41. *Denticula* Ehrenberg	+	+	
42. *Tabellaria* Ehrenberg	+	+	
43.*Aulacoseira* Thwaites		+	+
44. *Diadesmis* Kützing		+	+
45.*Bacillaria* Gmelin		+	+
46. *Ceratoneis* Grunow	+		+
47.*Encyonopsis* Krammer	+		+
48.*Reimeria* Kociolek & Stoermer	+		+
49.*Rhoicosphenia* Grunow	+		+
50.*Melosira* Agardh	+		
51.*Meridion* Agardh	+		
52.*Fragilariforma*D.M.Williams & Round	+		
53.*Peronia* Brèbisson & Arnott	+		
54.*Nupela*Vyverman & Compère	+		
55.*Anomoeoneis* Pfitzer		+	
56.*Gomphocymbelopsis* Krammer		+	
57.*Mastogloia* Thwaites		+	
58.*Aneumastus* Mann & Stickle		+	
59.*Scoliopleura* Grunow		+	

5. Discussion

There is considerable similarity (Sorensen) among these regions; 0.83, 0.82 and 0.81 among Central Highland -West Himalaya, West Himalaya-Western Ghats and Central Highland -Western Ghats, respectively. Nautiyal and Singh (2009) observed similar distribution for freshwater fish fauna from these biogeographic regions i.e. low similarity among the Central Highlands and Western Ghats. It appears logical that Central Highland -West Himalaya are most similar as they are close to each other in past and recent times. The Central Highland and Western Ghats do not exhibit higher similarity in genera-richness though they lie close to each other at their respective western and northern extremities in 'elbow' like fashion. Historically, the Central Highlands and Western Ghats constitute the Deccan Peninsula the oldest (geological age) part of the Indian subcontinent another strong reason for high similarity. Lack of connection between their drainages (that flow in opposite directions), may facilitate speciation through isolation only in recent times. On the contrary, relatively higher similarity among the West Himalaya and Western Ghats is intriguing. These regions are separated by the Gangetic Plains and Central Highlands. They differ in monsoon patterns and ambient temperatures (Western Ghats, tropical latitudes; subtropical to temperate and tundra latitudes in the West Himalaya).

In the current geographic perspective, the mountain terrain is the only geographical similarity among the West Himalaya and Western Ghats. This builds up an interesting case about the distributional patterns for diatoms in the Indian subcontinent and look for possible reasons that explain the present levels of richness among the above said biogeographical regions. The, geographical factors such as terrain and climate show enough variation to support potential differences in the flora and hence genera-richness in these ecoregions. Despite these differences high similarity across the Indian subcontinent and relative difference among the biogeographic regions are attributable to historical (geological) past of the subcontinent.

The Himalayan orogeny and consequent events are other convincing reasons for looking at the geological past of the subcontinent, because Himalaya is a landmass (extra Peninsula) that has been added to the subcontinent after the Indian Plate began to slide under the Asian Plate. The Himalayan streams and rivers were virgin areas for colonization by the biota from adjacent or distant regions. Even the Western Ghats that are of recent origin in the period similar to the Himalaya were also colonised. Only the Central Highlands are ancient (Pre Cambrian). Obviously, the Western Ghats and Himalaya were colonized by elements from adjoining areas i.e. the old Peninsula. The genera were distributed through drainages in the then newer habitats, the Western Ghats and Himalaya. Over a period of time the regions became isolated from adjoining areas. The Himalaya became isolated from the Central Highlands as the Himalayan rivers eroded the mountains and deposited the alluvium to form the Gangetic Plains. However, the northern part of the Central Highlands i.e. the Vindhya drain into the Ganga river system and thus are connected till recent times.

The present similarity indicates that certain geological mechanisms led exchange of elements over a large period to recent times after the Himalayan orogeny, despite the presence of physical barriers in the form of mountains in these biogeographic regions. Glaciations appear to be the major geological agents that facilitated these exchanges.

The diatom distribution in the Himalaya, the Central Highlands and the Western Ghats may have taken the following course after Himalayan orogeny; a) initial invasion of the Himalayan rivers and the Western Ghats by peninsular elements, b) speciation in respective regions prior to the glaciations, c) downward movement of floral elements into the Peninsula through the Himalayan drainages during glaciations, d) retreat during inter-glaciations, e) the similarity may have decreased in post glaciations, as the climate became hot and taxa unable to withstand desiccation may have perished and those which modified or adapted to sub tropical climate became new species, varieties and forms, f) similar exchanges, though to a lesser degree are expected among Central Highland and the Western Ghats, where the historical factors like Himalayan orogeny have no role, while the glaciations are likely to influence southward movement of the elements.

Besides, glaciations there seem to be no geological events in the peninsula that are likely to influence diatom floral exchanges because the Peninsula has been geologically stable for over long periods except volcanic activity that may have reduced similarity among these regions. Here, the existing similarity among these two regions may be due to passive dispersal, disturbance, chance introductions as environmental factors differ among the Central Highlands (120-170 mm) and Western Ghats (200 mm) by virtue of climate.

6. Conclusion

Historical rather than geographical factors appear to have played a greater role, due to movement of landmasses and upheavals, which led to changes in the drainage patterns and later in the climatic conditions. Further, creation of the Himalaya effected glaciations when the global climate was cooling. The recently de-glaciated high altitude locations in the Himalaya have not been geologically stable while the Central Highlands and the Western Ghats in the Peninsula has been geologically stable, a factor of consequence to diatom distribution in the Indian subcontinent.

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