CJBAS Vol. (01) - August - Issue 01 (2013) 33-43

CANADIAN JOURNAL OF BASIC AND APPLIED SCIENCES

CJBAS

WWW.CJBAS.COM

Signature Of Warmer Late Holocene Around Vestfold Hills, East Antarctica

Abhijit Mazumder[a] ∗ and Pawan Govil[a]

[a]Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow – 226 007, India

Keywords:

Vestfold Hills,

Diatom,

Cluster Analysis,

Holocene,

alaeoclimate

Abstract

To interpret palaeoclimatology of Vestfold Hills region, an inland lake sediment core of 47 cm length was studied with respect to its diatom population. A total of 13 diatom species was identified and used for the Q-mode cluster analysis. Cluster analysis delineates five major clusters, including two sub-clusters. These clusters and sub-clusters are represented by typical diatom assemblages, arranged along the length of the core. Increasing trend of Diploneis crabro and decreasing trend of Fragilariopsis curta and Achnanthes taylorensis towards the top of the core reveals colder climatic condition during early to mid-Holocene which changed to warmer climatic condition and nutrient-rich lacustrine environment during late Holocene. It also implies the ice cover of the lake was melt not less than late Holocene. However, the continuous presence of marine diatom reveals that the lake was constantly in contact with the marine water inlet.

1. Introduction

Antarctica plays a crucial role in the global climate system. Therefore, it is important to access the reliable records of natural climate change patterns from this region, particularly on time scales for a decade, century and even over the last 10,000 yr or the Holocene, in order to conclude whether current climate changes are natural or a result of anthropogenic manipulation. In such case, palaeolimnological record is one of the best ways to decipher the natural changes of climate in Antarctica. Palaeolimnological researches from continental East Antarctica and maritime and subantarctic islands have been addressed the issue of natural variability of the Antarctic climate (e.g., Vestfold Hills: [1,2]; Larsemann Hills: [3,4]; Bunger Hills: [5,6]; Rauer Islands: [7]; and Maritime and subantarctic islands: [8]).

Local climate changes around the Antarctic lake instigate the hydrological characters of the lake [2]. These changes are documented as palaeolimnological indicators, including diatom abundance [9]. Diatoms are being one of the most sensitive proxies using to reconstruct the palaeoclimate of the Antarctic region, especially for change of lake salinity [10,11]. In high

[*] Corresponding author [(-mail: *abhijit.mazumder.email@gmail.com*)

latitudinal area, other palaeoclimatic proxies, e.g. palynology have their limitation for use due to low concentrations of those proxies [12]. On the other hand, diatoms are quite abundant and diverse in the Antarctic lakes. Their opaline silica skeleton, being well preserved in Antarctic lake sediments, is a store house for paleoenvironmental information. In the present study, the subsurface lake sediment data signify an important database from interpreting the palaeoclimatic changes around the Vestfold Hills region.

2. Study Area

The present study was concentrated the Vestfold Hills region, Princess Elizabeth Land, East Antarctica. This region is considered as one of the rocky, ice-free 'oases' part along the margin of the East Antarctic ice-sheet. The retreat of the continental ice-sheet from this region happened approximately 8000 yr BP [13], this was followed by an isostatic rebound of the land mass, which led to the gradual upliftment of the land from beneath the surrounding ocean. By this process, seawater became trapped in many depressions presently occurring across the Hills [14]. Some of these trapped water bodies form small lakes, flushing out of the relict seawater by glacial meltwaters [15].

The Vestfold Hills covers an area of 410 km2 [15] situated 157 m above sea level on the eastern edge of Prydz Bay on the coast of Princess Elizabeth Land, East Antarctica (68°25' to 68°40's; 77°50' to 78°35'E). The East Antarctic Ice Sheet bordered the eastern side of this region, while the Sørsdal Glacier, an outlet glacier of the ice sheet flanked the southern side. The region is considered the third largest ice-free region in Antarctica. This region is characterized by long peninsulas, fjords, low hills, raised beaches, saline and freshwater lakes.

Summer sea surface temperature in Prydz Bay observes varies from -1.1 to -0.6°C [16,17], but sometimes increases up to 1.39°C near Vestfold Hills [18]. Vestfold Hills exhibits polar lowland periglacial climate with an average annual temperature of -10.2°C [19] which is slightly warmer than Antarctic regions of the same latitude [20]. Rainfall is scarce; total precipitation is recorded < 250 mm per year. During the short summer (December to February) snow and ice get melted. Due to limited melting, the rates of ice melt and hence, sediment accumulation rate is relatively less. The meltwater from ice and snow is the primary agent for sedimentation.

3. Materials and Method

A 47 cm long sediment core collected from Antarctic lake CD-1 in Vestfold Hills area during 24th Indian Antarctic Expedition was studied for its diatom content (Figure 1). Entire core was sub-sampled at an interval of 1 cm.

The methodology for processing the samples and making the diatom slides was followed as described by [21]. Diatoms were counted 300-500 valves, among which thirteen diatom species were identified. Finally, the relative abundance of all species in every interval was tabulated. The slides are properly numbered and stored in the repository of National Centre for Antarctic and Ocean Research, Goa, India.

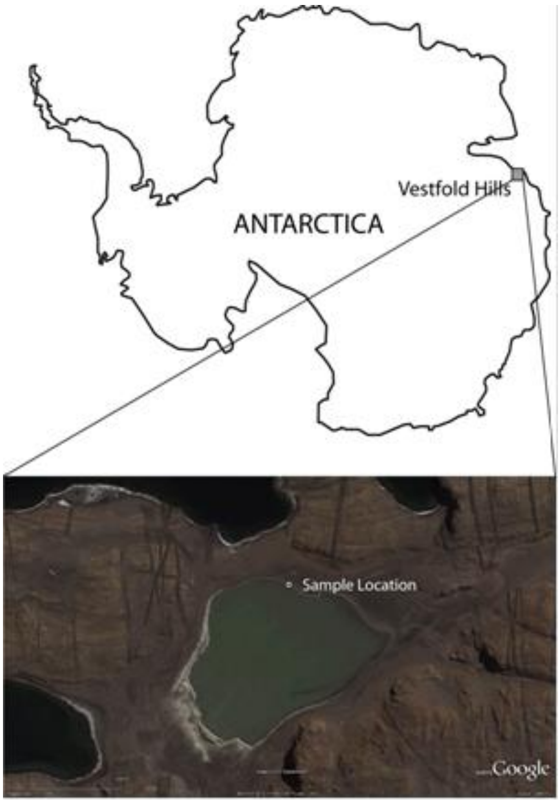

Figure 1: Location of the core analyzed for the present study

This data were subjected to Q-mode cluster analysis. The analysis was performed using the unweighted pair group averaging method (Figure 2). The relative abundance of thirteen diatom species has been chosen as the variables against the core intervals. The results of cluster analysis are plotted in the form of a two-dimensional hierarchy dendrogram wherein intervals of core sample are presented along X-axis and similarity level is plotted on Y-axis.

4. Results

The relative percentages of thirteen diatom species from entire core were used for the Q-mode cluster analysis. The Q-mode cluster analysis classified the samples into five distinct clusters (A, B, C, D, E; Fig.2) under the linkage distance 15. Cluster C was in turn further subdivided into sub-clusters C1 and C2 under the linkage distance 13. Each cluster and sub-cluster is characterized by a particular association of diatom species. The following are the relations of clusters and sub-clusters with diatom species (relationship with the presence of >10% at least in one interval).

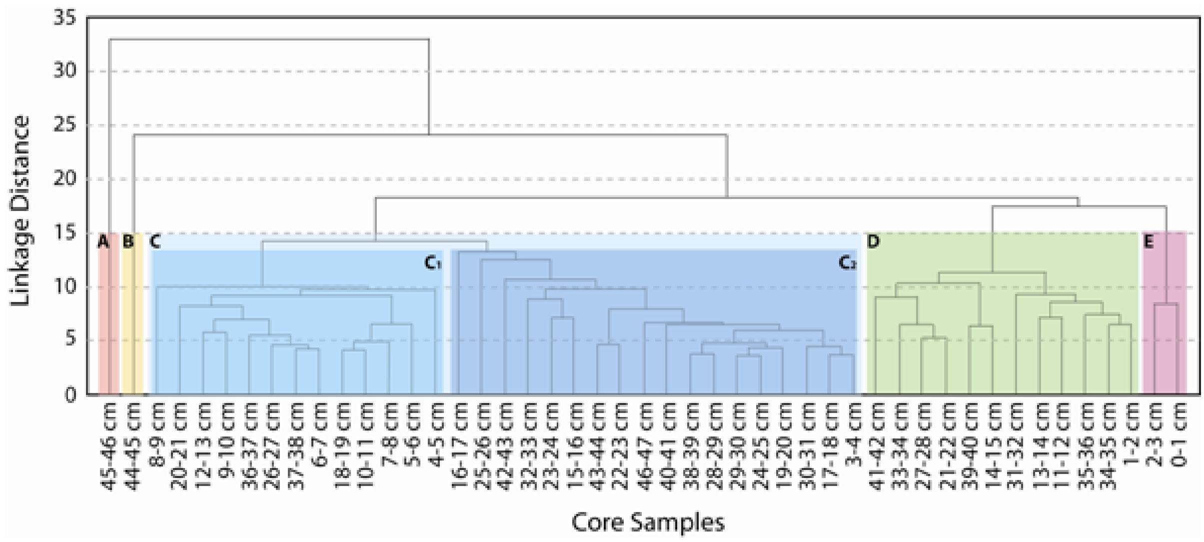

Figure 2: Cluster analysis of abundance of diatom found in core samples

Cluster A comprises single sample of 45-46 cm. It is near the lowermost part of the present core. This cluster is characterized by the presence of abundant Achnanthes taylorensis and Fragilariopsis curta with a percentage of 18.33% and 21.67%, respectively.

Cluster B also comprises single sample of 44-45 cm. Stratigraphically it is just above the Cluster A. This cluster is characterized by the presence of five diatom species; namely Amphora ovalis, Cocconeis costata, Diploneis crabro, Fragilariopsis curta and F. ritscheri with the a percentage of 15.60d%, 20.20%, 10.00%, 19.80% and 19.00%, respectively.

Cluster C comprises a maximum number (thirty one) of samples from core interval and it spreads all over the core. This cluster is characterized by the presence of mainly four diatom species (Amphora ovalis, Cocconeis costata, Diploneis crabro and Fragilariopsis ritscheri with the average percentage of 24.82%, 18.21%, 27.02% and 15.53%, respectively) along with a lesser abundance of Fragilariopsis curta (average percentage of 5.69%). This cluster is further subdivided into two major sub-clusters.

Sub-cluster C_1 consists of thirteen samples, concentrated within the upper part of the core. This sub-cluster is characterized by the abundance of four diatom species, namely Amphora ovalis, Cocconeis costata, Diploneis crabro and Fragilariopsis ritscheri with their average percentage of 24.96%, 17.01%, 25.99% and 17.28%, respectively.

Sub-cluster C_2, represented by eighteen samples, scattered within middle and lower parts of the core. This sub-cluster is characterized by a higher abundance of Amphora ovalis, Cocconeis costata, Diploneis crabro and Fragilariopsis ritscheri (average percentage of 24.71%, 19.07%, 15.72% and 18.13%, respectively) with a minor abundance of Fragilariopsis curta (average percentage of 6.63%).

These two sub-clusters within cluster C differ from each other on the basis of the minor abundance of Fragilariopsis curta in sub-clusters C_2 over C_1, and higher abundance of Diploneis crabro in sub-cluster C_1 than in C_2.

Cluster D is represented by twelve samples, scattered mostly in the bottom parts of the core mixed with some top components. This cluster is characterized by the higher abundance of Amphora ovalis, Cocconeis costata and Diploneis crabro (average percentage of 26.93%18.76% and 21.54%, respectively) with the minor abundance of Achnanthes taylorensis and Fragilariopsis curta (average percentage of 8.96% and 5.48%, respectively).

Cluster E comprises of two samples (0-1 cm and 2-3 cm), concentrated in the topmost part of the core. This cluster is represented by the higher abundance of Amphora ovalis, Cocconeis costata and Diploneis crabro with the average percentage of 19.50%, 18.83% and 34.87%, respectively.

To establish chronological control, the core was dated at 3 different levels using AMS 14C dating method. At 9-10 cm, 18-19 cm and 28-29 cm, the dates exhibit 3820±113 yr BP, 5050±98 yr BP and 5560±96 yr BP, respectively.

5. Discussion

From the cluster analysis, it can be easily understood that the different levels of core contain different major assemblages of diatom. The core represents the samples from each cluster according to their core length (Figure 3).

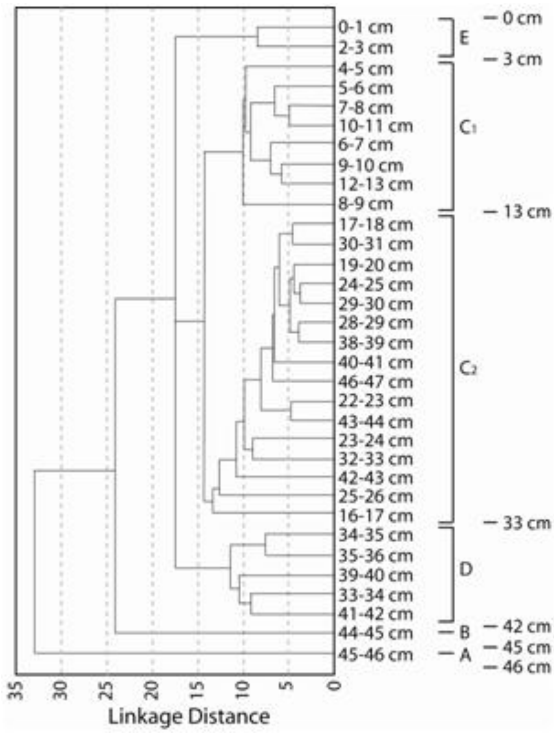

Figure 3: Arrangement of clusters along the core length

Low tire of the core (represented by Cluster A) contains an abundance of two species, namely F. curta and A. taylorensis; whereas the highest tire (represented by Cluster E) shows the abundance of three species, namely D. crabro, A. ovalis and C. costata. Overall, the percentage of F. curta and A. taylorensis shows its decrease towards the top of the core (from 21.67% to 1.97% and from 18.33% to 6.34%, respectively); whereas D. crabro increases towards the top of the core (from 0.33% to 34.87%). On the other hand, A. ovalis and C. costata remain more or less continuous throughout the core (Figure 4).

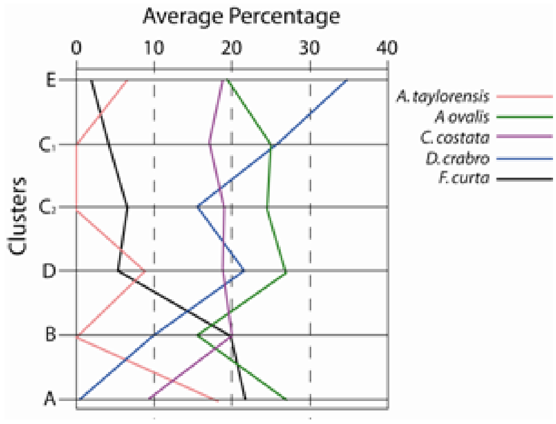

Figure 4: Variation of abundance of five major species of diatom along the clusters

There are several reports where F. curta is described as one of the dominating sea-ice-related taxa [22-24], as well as marine (coastal) diatom flora within the Polar Front [25-27]. F. curta has also been used to delineate the colder climatic condition during early to mid-Holocene in Vestfold Hills [28]. In the Rauer Islands and Vestfold Hills A. taylorensis is relatively rare in brackish lakes [1,3]. This diatom grew well in both freshwater and brackish water cultures, but does not appear to tolerate higher (> 20‰) salinities [29]. The salinity optima and tolerance for this species was calculated as 4.65‰ and 4.49‰, respectively [30].

The presence of the bloom of diatom, including Diploneis crabro indicates the richness of nutrients during the summer and monsoon periods in coastal areas of Uttara Kannada district, West Coast of India [31]. This species was reported from various tropical to sub-tropical regions; such as Nigeria [32,33], Brazil [34], Singapore [35], Spain [36] and other Adriatic Sea region [37,38]. A. ovalis was reported from Spain [36,39], Romania [40], Brazil [34] and many other places as freshwater species. Whereas C. costata was reported from Brazil [34], Canary Islands [41] and around Antarctica [42,43] as marine species.

In present study, the continuous present of freshwater species A. ovalis and marine species C. costata throughout the core indicates the core had an influence of both marine and freshwater all along its deposition. The increasing trend of fresh water to rarely brackish water species A. taylorensis towards lower tire of the core indicates the more marine water influence during early Holocene. The presence of F. curta indicates the colder to a warmer climate from early to late Holocene. On the other hand, the increasing trend of D. crabro towards the top of the core also indicates increasing temperature as well as nutrient towards the late Holocene. This palaeo-ecological data derived from diatom study can be utilized to explain the palaeo-environmental scenario of the region. During early to mid Holocene, the lake was frozen due to low temperature. By late Holocene, due to warmer climate the ice cover of the lake melts and the lake became nutrient rich. But during the entire Holocene, the lake was somehow continuously in contact with marine inlet, though in the previous study it was shown that during late Holocene the connection with the sea became less [44].

Our result is in accordance with other previous study in and around our study area. Sea ice diatom assemblage documented retreat of ice shelves at the head of the fjord in the Prydz Bay region during early Holocene i.e. 10580–7890 years BP [27]. Depending upon the total organic carbon value extensive sea ice cover was reported between 7310 and 5390 years BP in Lallemand Fjord region [45]. In another study from Winmill Islands, the early and early mid-Holocene (~10,500 to ~4000 yrs BP) was demarcated by the retreat of Antarctic glaciers [46]. In the southern Windmill Islands and Vestfold Hills, several studies were done to show glacial retreat with relatively cool temperatures and low bioproductivity during the early and early mid-Holocene [47,48]. Late Holocene was designated by warmer and wetter condition as compared to early to mid-Holocene colder events in Vestfold Hills region [49,50].

6. Conclusion

Q-mode cluster analysis of relative abundance of diatom species of a 47 cm sediment core from an inland lake in Vestfold Hills region unveils a brief palaeoclimatic history of the region during Holocene. The five major clusters, namely A, B, C, D and E, and two minor clusters, namely C1 and C2 are divided the entire core into several parts based on its diatom assemblage. These clusters are represented by typical diatom assemblages and changing patterns of relative percentage of few ecologically sensitive diatoms. The increase of temperature and nutrient sensitive species Diploneis crabro towards the top of the core indicates the increase of temperature and increase the scope of producing more nutrients. On the other hand, decrease of sea-ice indicator species Fragilariopsis curta towards the top of the core signifies that the lake was ice free during late Holocene. Therefore, it can be concluded that the lake was frozen during early to mid-Holocene, and during late Holocene ice was melted and lake became nutrient rich.

Acknowledgements: The authors would like to express their thanks to Director, Birbal Sahni Institute of Palaeobotany, Lucknow, India for giving permission to publish this paper and Director, National Centre for Antarctic and Ocean Research, Goa, India for using the samples and laboratory facilities. The authors would also like to thanks Ms. Rosyta Afonso for sample processing.

References:

[1] Roberts D., McMinn A.: Diatoms of the saline lakes of the Vestfold Hills, Antarctica. Bibliotheca Diatomologica, **44**, 1-82 (1999).

[2] Roberts D., van Ommen T. D., McMinn A., Morgan V., Roberts J. L.: Late-Holocene East Antarctic climate trends from ice-core and lake-sediment proxies. The Holocene, **11**, 117-120 (2001).
DOI: 10.1191/095968301677143452

[3] Hodgson D., Vyverman W., Sabbe K.: Limnology and biology of saline lakes in the Rauer Islands, eastern Antarctica. Antarctic Science, **13**, 255-270 (2001).

[4] Verleyen E., Hodgson D. A., Sabbe K., Vyverman W.: Late Quaternary deglaciation and climate history of the Larsemann Hills (East Antarctica). Journal of Quaternary Science, **19**, 361-375 (2004).
DOI: 10.1002/jqs.823

[5] Melles M., Kulbe T., Verkulich S. R., Puchina Z. V., Hubberten H. -W.: Late Pleistocene and Holocene Environmental history of Bunger Hills, East Antarctica, as revealed by fresh-water and epishelf lake sediments. in 'The Antarctic Region: Geological Evolution and Processes' (ed.: Ricci, C. A.) Terra Antarctica Publication, Siena, 809–820 (1997).

[6] Verkulich S., Melles M., Hubberten H.-W., Pushina Z.: Holocene environmental changes and development of Figurnoye Lake in the southern Bunger Hills, East Antarctica. Journal of Paleolimnology, **28**, 253-267 (2002).
DOI: 10.1023/a:1021661700899

[7] Hodgson D., Noon P., Vyverman W., Bryant C., Gore D., Appleby P., Gilmour M., Verleyen E., Sabbe K., Jones V.: Were the Larsemann Hills ice-free through the last glacial maximum? Antarctic Science, **13**, 440-454 (2001).
DOI: 10.1017/S0954102001000608

[8] Jones V. J., Hodgson D. A., Chepstow-Lusty A.: Palaeolimnological evidence for marked Holocene environmental changes on Signy Island, Antarctica. The Holocene, **10**, 43-60 (2000).
DOI: 10.1191/095968300673046662

[9] Juggins S., Battarbee R. W., Fritz S. C., Gasse F.: The CASPIA project: diatoms, salt lakes, and environmental change. Journal of Paleolimnology, **12**, 191-196 (1994).
DOI: 10.1007/bf00678020

[10] Fritz S. C.: Twentieth-century salinity and water-level fluctuations in Devils Lake, North Dakota: Test of a diatom-

based transfer function. Limnology and Oceanography, **35**, 1771-1781 (1990).

[11] Roberts D., McMinn A.: A weighted-averaging regression and calibration model for inferring lakewater salinity from fossil diatom assemblages in saline lakes of the Vestfold Hills: a new tool for interpreting Holocene lake histories in Antarctica. Journal of Paleolimnology, **19**, 99-113 (1998). DOI: 10.1023/a:1007947402927

[12] Smol J. P., Cumming B. F., Douglas M. S., Pienitz R.: Inferring Past Climatic Changes in Canada Using Paleolimnological Techniques. Geoscience Canada, **21**, (1994). DOI: 10.12789%2Fgs.v21i3.3840

[13] Adamson D. A., Pickard J.: Cainozoic history of the Vestfold Hills. in 'Antarctic Oasis Terrestrial Environments of the Vestfold Hills' (ed.: Pickard J.) Academic Press, New York, 63-98 (1986).

[14] Burton H. R.: 24. Chemistry, physics and evolution of Antarctic saline lakes. Hydrobiologia, **81-82**, 339-362 (1981). DOI: 10.1007/bf00048724

[15] Pickard J., Adamson D. A., Heath C. W.: The evolution of Watts Lake, Vestfold Hills, East Antarctica, from marine inlet to freshwater lake. Palaeogeography, Palaeoclimatology, Palaeoecology, **53**, 271-288 (1986). DOI: 10.1016/0031-0182(86)90063-5

[16] Kerry K. R., Woehler E. J., Robb M. S.: Oceanographic data: Prydz Bay region. FIBEX, MV Nella Dan, January-March 1981. Australian National Antarctic Research Expedition Notes No. 49, Antarctic Division, Kingston, Tasmania, Australia, 114 p (1987).

[17] Kerry K. R., Woehler E. J., Robb M. S.: Oceanographic data: Prydz Bay region. SIBEX II, MV Nella Dan, January 1985. Australian National Antarctic Research Expedition Notes No. 53, Antarctic Division, Kingston, Tasmania, Australia, 122 p (1987).

[18] Gibson, J. A.: Carbon flow through inshore marine environments of the Vestfold Hills, East Antarctica. ANARE Scientific Reports, **139**, 221 (1998).

[19] Schwerdtfeger, W.: The climate of Antarctica. in 'Climates of polar regions' (ed.: Orvig, S) Elsevier, Amsterdam, 253-355 (1970).

[20] Burton H. R., Campbell P. J.: The climate of the Vestfold Hills, Davis Station, Antarctica: with a note on its effect on the hydrology of hypersaline Deep Lake, Australian Government Publishing Service (1980).

[21] Setty M. A. P.: Preparation and method of study of fossil diatoms. micropaleontology, **12**, 511-514 (1966).

[22] Garrison D. L., Sullivan C. W., Ackley S. F.: Sea ice microbial

communities in Antarctica. Bioscience, **36**, 243-250 (1986).

[23] Kellogg D. E., Kellogg T. B.: Microfossil distributions in modern Amundsen Sea sediments. Marine Micropaleontology, **12**, 203-222 (1987).
DOI: 10.1016/0377-8398(87)90021-1

[24] Crosta X., Denis D., Ther O.: Sea ice seasonality during the Holocene, Adélie Land, East Antarctica. Marine Micropaleontology, **66**, 222-232 (2008).
DOI: 10.1016/j.marmicro.2007.10.001

[25] Hendey, N. J.: The plankton diatoms of the southern seas, Discovery Report, **16**, 151–364 (1937).

[26] Truesdale R. S., Kellogg T. B.: Ross Sea diatoms: Modern assemblage distributions and their relationship to ecologic, oceanographic, and sedimentary conditions. Marine Micropaleontology, **4**, 13-31 (1979).
DOI: 10.1016/0377-8398(79)90003-3

[27] Taylor F., Whitehead J., Domack E.: Holocene paleoclimate change in the Antarctic Peninsula: evidence from the diatom, sedimentary and geochemical record. Marine Micropaleontology, **41**, 25-43 (2001).
DOI: 10.1016/S0377-8398(00)00049-9

[28] Mazumder A., Govil P., Ravindra R., Khare N.: Indication of colder condition within Holocene period in a freshwater lake in Vestfold Hills area, East Antarctica region. Geosciences Journal, **17**, 235-239 (2013).
DOI: 10.1007/s12303-013-0015-1

[29] Sabbe K., Verleyen E., Hodgson D., Vanhoutte K., Vyverman W.: Benthic diatom flora of freshwater and saline lakes in the Larsemann Hills and Rauer Islands, East Antarctica. Antarctic Science, **15**, 227-248 (2003).
DOI: 10.1017/S095410200300124X

[30] Vyverman W., Verleyen E., Sabbe K., Vanhoutte K., Sterken M., Hodgson D. A., Mann D. G., Juggins S., Vijver B. V. d., Jones V., Flower R., Roberts D., Chepurnov V. A., Kilroy C., Vanormelingen P., Wever A. D.: Historical processes constrain patterns in global diatom diversity. Ecology, **88**, 1924-1931 (2007).
DOI: 10.1890/06-1564.1

[31] Sushanth V., Rajashekhar M.: Seasonal variation in diatoms in response to physico-chemical characteristics of coastal waters of Uttara Kannada district, West Coast of India. International Journal of Environmental Sciences, **2**, (2012).
DOI: 10.6088/ijes.00202030039

[32] Nwankwo D., Akinsoji A.: Epiphyte community on water hyacinth Eichhornia crassipes (MART.) Solms in coastal waters of southwestern Nigeria. Archiv für Hydrobiologie, **124**, 501-511 (1992).

[33] Onyema I., Nwankwo D., Owolabi K.: Temporal and spatial changes in the phytoplankton dynamics at the

Tarkwa-bay jetty in relation to environmental characteristics. Ecology, Environment and Conservation, **14**, 1-8 (2008).

[34] Eskinazi-Leça E., Gonçalves da Silva Cunha M. d. G., Santiago M. F., Palmeira Borges G. C., Cabral de Lima J. M., Da Silva M. H., De Paula Lima J., Menezes M.:Bacillariophyceae, in Catálogo de plantas e fungos do Brasil, Forzza R. C., Ed., Andrea Jakobsson Estúdio; Instituto de Pesquisas Jardim Botânico do Rio de Janeiro., Rio de Janeiro. 262-309 (2010).

[35] Pham M. N., Tan H. T., Mitrovic S., Yeo H. H.: A checklist of the algae of Singapore. Singpore: Raffles Museum of Biodiversity Research, National University of Singapore., 1-100 (2011).

[36] Varela M.: Catálogo florístico de las diatomeas bentónicas de las costas de Galicia. Collectanea Botanica, **13**, 987-996 (1982).

[37] Penna A., Ingarao C., Ercolessi M., Rocchi M., Penna N.: Potentially harmful microalgal distribution in an area of the NW Adriatic coastline: Sampling procedure and correlations with environmental factors. Estuarine, Coastal and Shelf Science, **70**, 307-316 (2006).
DOI: 10.1016/j.ecss.2006.06.023

[38] Cabrini M., Fornasaro D., Cossarini G., Lipizer M., Virgilio D.: Phytoplankton temporal changes in a coastal northern Adriatic site during the last 25 years. Estuarine, Coastal and Shelf Science, **115**, 113-124 (2012).
DOI: 10.1016/j.ecss.2012.07.007

[39] Perez M. d. C., Maidana N. I., Comas A.: Phytoplankton composition of the Ebro River estuary, Spain. Acta Botanica Croatica, **68**, 11-27 (2009).

[40] Cărăuş I.: Algae of Romania. A distributional checklist of actual algae. Stud.Cerc.Biol., Univ.Bacău, 2002, **7**, 1-809 (2012).

[41] Gil-Rodríguez M., Haroun R., Ojeda Rodriguez A., Berecibar Zugasti E., Domínguez Santana P., Herrera Morán B.:Proctoctista, in Lista de especies marinas de Canarias (algas, hongos, plantas y animales), Moro L., Martín J. L., Garrido M. J., Izquierdo I., Editor., Las Palmas: Consejería de Política Territorial y Medio Ambiente del Gobierno de Canarias. 5-30 (2003).

[42] Cunningham L., McMinn A.: The influence of natural environmental factors on benthic diatom communities from the Windmill Islands, Antarctica. Phycologia, **43**, 744-755 (2004).
DOI: 10.2216/i0031-8884-43-6-744.1

[43] Al-Handal Adil Y., Wulff A.: Marine epiphytic diatoms from the shallow sublittoral zone in Potter Cove, King George Island, Antarctica. Botanica Marina, **51**, 411 (2008).
DOI: 10.1515/bot.2008.053

[44] Mazumder, A., Govil, P., Sharma, S., Ravindra, R., Khare, N., Chaturvedi, S. K.: A testimony of detachment of an inland lake from marine influence during mid-Holocene in Vestfold Hills region, East Antarctica, (Communicated).

[45] Shevenell A. E., Domack E. W., Kernan G. M.: Record of Holocene palaeoclimate change along the Antarctic Peninsula: evidence from glacial marine sediments, Lallemand Fjord. in Papers and Proceedings of the Royal Society of Tasmania. **130**, 55-64 (1996).

[46] Goodwin I. D.: Did changes in Antarctic ice volume influence late Holocene sea-level lowering? . Quaternary Science Reviews, **17**, 319-332 (1998).
DOI: 10.1016/S0277-3791(97)00051-6

[47] Cromer L., Gibson J. A. E., Swadling K. M., Ritz D. A.: Faunal microfossils: Indicators of Holocene ecological change in a saline Antarctic lake. Palaeogeography, Palaeoclimatology, Palaeoecology, **221**, 83-97 (2005).
DOI: 10.1016/j.palaeo.2005.02.005

[48] Cremer H., Gore D., Melles M., Roberts D.: Palaeoclimatic significance of late Quaternary diatom assemblages from southern Windmill Islands, East Antarctica. Palaeogeography, Palaeoclimatology, Palaeoecology, **195**, 261-280 (2003).
DOI: 10.1016/S0031-0182(03)00361-4

[49] Björck S., Olsson S., Ellis-Evans C., Håkansson H., Humlum O., de Lirio J. M.: Late Holocene palaeoclimatic records from lake sediments on James Ross Island, Antarctica. Palaeogeography, Palaeoclimatology, Palaeoecology, **121**, 195-220 (1996).
DOI: 10.1016/0031-0182(95)00086-0

[50] Roberts D., McMinn A.: Relationships between surface sediment diatom assemblages and water chemistry gradients in saline lakes of the Vestfold Hills, Antarctica. Antarctic Science, **8**, 331-341 (1996).
DOI: 10.1017/S0954102096000508