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Sustainable Marine Structures
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ARTICLE

Spatio-temporal Variability of Dinoflagellates in Different Salinity Regimes in the Coast of Rakhine

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ARTICLE INFO

Article history
Received: 3 January 2021
Accepted: 5 February 2021
Published Online: 30 March 2021

Keywords:
Dinoflagellates
Salinity
Seasonal
Spatial

ABSTRACT

Regarding the spatial and seasonal variations of dinoflagellates in different salinities regimes, *Prorocentrum rostratum* showed a strong correlation with high salinity (≥ 29 ppt.). However, *P. micans* had a negative correlation with salinity. In Dinophysoids, *Dinophysis caudata* showed a wide salinity tolerance than other species in the group. *D. miles, Ornithocercus magnificus, O. steinii*, and *O. thumii* showed a strong correlation with salinity. In Gonyaulacoids, *Ceratium furca, C. fusus, C. horridum, C. trichoceros, C. tripos, Gonyaulax polygramma, G. spinifera,* and *Pyrophacus magnificus* showed a strong correlation with salinity. In Peridinoids, *Protoperidinium depressum, P. oblongum, P. oceanicum, P. pyreforme,* and *Podolampus palmipes* showed a strong correlation with salinity. In Gymnodinoid and Noctilucoid, *Gyrodinium estuariale* and *N. scintillans* showed a strong correlation with salinity.

1. Introduction

Dinoflagellates are important components of the phytoplankton in the near-shore and continental shelf environments [1]. Along with diatoms, over half of dinoflagellates are photosynthetic [2,3,4]. Their ecology and biology have permitted them to be among the most successful aquatic protists, capable of surviving in different conditions of resource availability [5,6]. They are one of the major groups of primary producers that constitute the basic source of energy in aquatic food webs [7,8]. Because of the annual variability in species composition of dinoflagellates, these species are regularly monitored in many developed countries. In Myanmar, however, has not yet set effective monitoring programs, though there are reports of some bloom events that had been occurred in the coastal area. Since the South-West Monsoon (SWM) is the main source of climatic variations subjected to make changes in the physicochemical parameters which in turn affecting dinoflagellate community structure in the water column [9,10]. Thus, observations on salinity and species occurrence of dinoflagellates were made monthly during three consecutive periods 2012, 2013, and 2014.

2. Materials and Methods

2.1 Environmental Parameters of the Study Area

The Rakhine coast experiences intense rainfall during

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 DOI: https://doi.org/10.36956/sms.v2i2.308

the monsoon months of June-September causing variations in salinity ranges. During the summer season (February- May), salinity was higher (32-34 ppt.) in all stations, and the lowest salinity range, 21-23 ppt. is in the rainy season, (June-September).

2.2 Sampling Sites and Sample Collection

A total of eight sampling sites were set along the Rakhine coast. Sampling sites were plotted at Wetthe (WTE) (N17º 08´ 34.474", E94º 27´51.226") as station-1; MaGyi tidal creek (upper) (MGU) as station-2; MaGyi tidal creek (lower) (MGL) as station-3; MaGyi coastal area (MGC) as station-4; Kyauk-Maung-Nama (KMN) as station-5; Phoe-Kala Island (PKI) as station-6; Ngwe-Saung (NSG) as station-7 and Chithu Island (CTI) near Ngwesaung beach (N16º 49´6.243", E94º 23´8.757") as station-8, respectively. Among the stations, stations 2, 3, and 7 are in and near the tidal creek; stations 1, 5, and 8 are in the open coastal areas and stations 4 and 6 are at the mouth of the tidal creek.

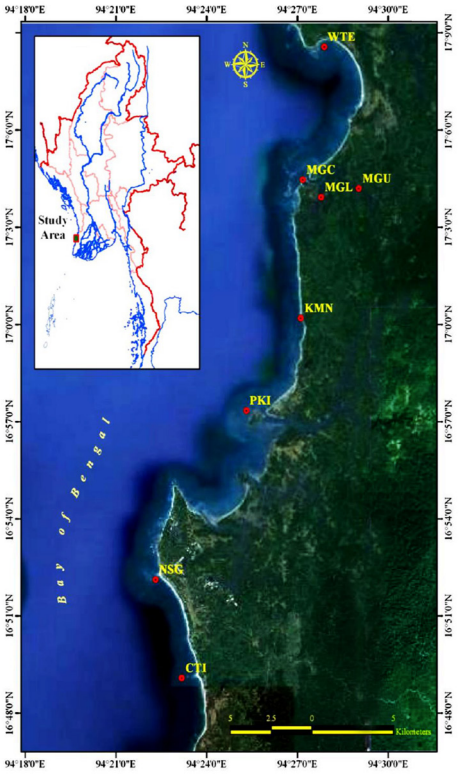

Figure 1. Sample collection sites at Rakhine coastal waters.

The sample collection was made by scooping a known volume of surface water using a basket and sieved with a 20 µm mesh phytoplankton net. Then transferred the water sample to the plastic bottles and immediately fixed it with formalin (final concentration 1%). While collecting the samples, water salinity was measured *in-situ* with a refractometer. Triplicate analysis of 1 mL sub-sample was taken from the samples and count with the Sedgwick-Rafter chamber. Pearson's correlation coefficient was performed to analyze the relationship between dinoflagellate species and the salinity.

3. Results and Discussion

3.1 Seasonal Variations of Salinity

At station 1, WTE, the highest salinity occurred in late summer, March-April, and the range was 34 ppt. in 2012; 33 ppt. in 2013 and 32-33 ppt. in 2014. During the monsoon period, July to September, salinity reaches its minimum values, 25-26 ppt. in 2012; 23-24 ppt. in 2013 and 23-25 ppt. in 2014. Mean salinities were 29.6±3.1 in 2012; 28.25±3.65 in 2013 and 28.5±2.87 in 2014.

At station 2, MGU, the highest salinity occurred in late summer, March-April, and the value was the same 30 ppt. in three successive years, 2012, 2013, and 2014. Station 2 has highly fluctuated with terrestrial runoff. During the monsoon period, July to September, salinity reaches its minimum values, 13-16 ppt. in 2012; 13-19 ppt. in 2013 and 13-18 ppt. in 2014. Mean salinities were 22.92±5.79 in 2012; 23±5.24 in 2013 and 22.75±5.48 in 2014.

At station 3, MGU, the highest salinity occurred in late summer, March-April, and the values were 29-32 ppt. in 2012; 32 ppt. in 2013 and 2014. During the monsoon period, July to September, salinity reaches its minimum values, 25-24 ppt. in 2012, 2013 and 24-25 ppt. in 2014. Mean salinities were 27.92±2.84 in 2012; 28.2±2.91 in 2013 and 28.2±3.1 in 2014.

At station 4, MGC, the highest salinity occurred in late summer, March-April, and the values were 33-34 ppt. in three successive years, 2012, 2013, and 2014. During the monsoon period, July to September, salinity reaches its minimum values, 25-26 ppt. in 2012, 22-24 ppt. in 2013 and 23-25 ppt. in 2014. Mean salinities were 25.50±5.77 in 2012; 26.25±5.00 in 2013 and 23.93±6.24 in 2014.

At station 5, KMN, the highest salinity occurred in late summer, March-April, and the values were 29-32 ppt. in 2012; 32 ppt. in 2013 and 2014. During the monsoon period, July to September, salinity reaches its minimum values, 18-21 ppt. in 2012, 24-22 ppt. in 2013 and 25-24 ppt. in 2014. Mean salinities were 26.7±5.68 in 2012; 27.83±3.98 in 2013 and 28.08±3.04 ppt.in 2014.

At station 6, PKI, the highest salinity occurred in late summer, March-April, and the values were 34 ppt. in 2012; 2013 and 2014. During the monsoon period, July to September, salinity reaches its minimum values, 26-24 ppt. in 2012, 26-23 ppt. in 2013 and 26-25 ppt. in 2014.

DOI: https://doi.org/10.36956/sms.v2i2.308

Mean salinities were 29±3.81 in 2012; 29±3.51 in 2013 and 29.58±3.55 ppt.in 2014.

At station 7, NSG, the highest salinity occurred in late summer, March-April, and the values were 32-33 ppt. in 2012; 33-34 ppt. in 2013 and 34 ppt. in 2014. During the monsoon period, July to September, salinity reaches its minimum values, 26-25 ppt. in 2012, 2013 and 28-27 ppt. in 2014. Mean salinities were 29±3.19 in 2012; 29.33±3.22 in 2013 and 30.58±2.63 ppt.in 2014.

At station 8, CTI, the highest salinity occurred in late summer, March-April, and the values were 32-33 ppt. in 2012; 33-32 ppt. in 2013 and 32-33 ppt. in 2014. During the monsoon period, July to September, salinity reaches its minimum values, 27-26 ppt. in 2012, 26-25 ppt. in 2013 and 24-25 ppt. in 2014. Mean salinities were 29.42±2.6 in 2012; 29.17±3.02 in 2013 and 28.58±3.55 ppt in 2014.

In the present study, the mean salinities of the study period, 2012-2014, were 29 ppt., 27 ppt., 28 ppt., 30.3 ppt., 30.1 ppt., 29 ppt., 30 ppt., and 29 ppt. at stations 1, 2, 3, 4, 5, 6, 7 and 8 respectively. Salinity distributions in all sampling stations vary from month to month within seasons (Table 1). The mean salinity of the whole study area was 29±2.83, and the mean salinity at the sampling stations was 29±1.2 part per thousand.

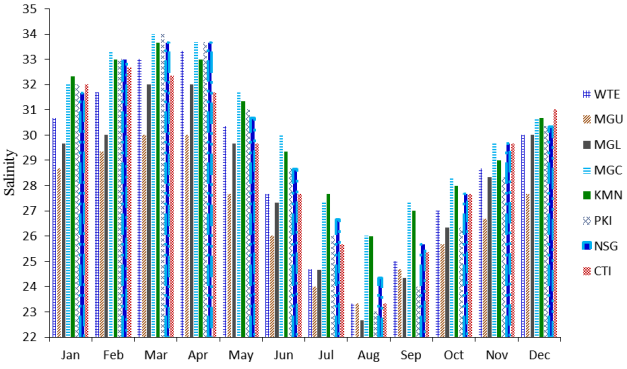

Figure 2. Mean salinity at sampling stations of the study areas during 2012-2014.

3.2 Spatio-temporal Variations of Dinoflagellates

Prorocentroids cell density varied from 1500 to 1780 cells L^{-1} during the study period. The cell density of Dinophysoids varied from 810 to 1590 cells L^{-1} during the summer and post-monsoon periods. Two genera such as *Dinophysis* and *Ornithocercus* were mainly composed in the Dinophysoid group which occupied 40% and 60%, respectively.

Gonyaulacoids was the largest and dominant group in the study area, and the cell density ranged from 540 to 1770 cells L^{-1}. A total of six genera were occupied in the

Table 1. Mean salinity of the study area during 2012-2014.

No.	Months	WTE	MGU	MGL	MGC	KMN	PKI	NSG	CTI	*Mean*	*SD*
1.	Jan	30.7	28.7	29.7	32	32.3	32	31.7	32	31.1	1.2
2.	Feb	31.7	29.3	30	33.3	33	33	33	32.7	32	1.4
3.	Mar	33	30	32	34	33.7	34	33.7	32.3	32.8	1.3
4.	Apr	33.3	30	32	33.7	33	33.7	33.7	31.7	32.6	1.2
5.	May	30.3	27.7	29.7	31.7	31.3	31	30.7	29.7	30.3	1.2
6.	Jun	27.7	26	27.3	30	29.3	28.7	28.7	27.7	28.2	1.2
7.	Jul	24.7	24	24.7	27.3	27.7	26	26.7	25.7	25.8	1.2
8.	Aug	23.3	23.3	22.7	26	26	23	24.3	23.3	24	1.2
9.	Sep	25	24.7	24.3	27.3	27	24	25.7	25.3	25.4	1.1
10.	Oct	27	25.7	26.3	28.3	28	26.3	27.7	27.7	27.1	0.9
11.	Nov	28.7	26.7	28.3	29.7	29	28.3	29.7	29.7	28.8	1.0
12.	Dec	30	27.7	30	30.7	30.7	30.3	30.3	31	30.1	1.0
Mean		29	27	28	30.3	30.1	29	30	29	29	1.2
SD		3.2	2.2	2.9	2.6	2.5	3.6	3.0	3.0	2.8	0.2

 DOI: https://doi.org/10.36956/sms.v2i2.308

Gonyaulacoids group, *Ceratium* 65%, *Gonyaulax* 10%, *Pyrocystis* 10%, *Alaxandrium* 5%, *Spiraulax* 5%, and *Pyrophacus* 5%, respectively.

The Peridinoids cell density ranged from 800 to 1440 cells L^{-1}, in which *Protoperidinium* composed 57%, *Podolampus* 28.6%, and *Peridinium* 14.3%, respectively. The Gymnodinoids and Noctilucoids group had the lowest cell density ranged from 90 to 112 cells L^{-1}. In the study area, the cell density was normally higher during summer and post-monsoon periods when the salinity was ≥29 ppt.

3.3 Statistical Analysis

Multiple correspondence analyses were made for the correlation coefficient of species and salinity changes. Salinity changes may vary from one station to another.

In Table 2, *P. rostratum* showed a strong correlation with high salinity, 29-31 ppt. *P. micans* showed no correlation with salinity. *P. gracile, P. lima, P. micans,* and *P. rostratum* species were not found in station 2 where salinity is low. High cell densities were found normally at salinity, 30-31 ppt. in February-March.

Table 2. Correlation coefficients of Prorocentroids and salinity.

No.	Prorocentroids	2012	2013	2014
1.	*Prorocentrum gracile*±	0.14	0.67	0.60
2.	*P.lima*±	0.16	0.79	0.19
3.	*P.micans*-	0.02	0.34	0.45
4.	*P.rostratum*++	0.72	0.68	1

(++) = strongly correlated, (±) = more or less correlated, (-) = less correlated

Table 3. Correlation coefficients of Dinophysoids and salinity.

No.	Dinophysoids	2012	2013	2014
1.	*Dinophysis caudata*±	0.83	0.41	0.86
2.	*D. miles*++	0.80	0.74	0.79
3.	*Ornithocercus magnificus*++	0.55	0.72	0.84
4.	*O.steinii*++	0.74	0.71	0.99
5.	*O.thumii*++	0.9	0.75	0.57

(++) = strongly correlated, (±) = more or less correlated, (-) = less correlated

In the Dinophysoids group, *O. thumii* species showed low salinity, 23-25 ppt. tolerant than other species in the group. *D. miles, O. magnificus, O. steinii,* and *O. thumii* showed a strong correlation with a wide salinity range, 23-34 ppt. *O. steinii* cannot tolerate low salinity than *O. magnificus* species. *D. caudata* cannot be found in low salinity of less than 22 ppt. (Table 3).

The Gonyaulacoids, the largest and dominant group in the study area, and among them nine species show a strong correlation with a wide range of salinity. They were *Ceratium dens, C. furca, C. fusus, C. horridum, C. trichoceros, C. tripos, Gonyaulax polygramma,* and *G. spinifera,* respectively. *G. polygramma* was found in low salinity, 23 ppt. (Table 4).

Table 4. Correlation coefficients of Gonyaulacoids and salinity.

No.	Gonyaulacoids	2012	2013	2014
1.	Alexandrium concavum±	0.24	0.65	0.05
2.	Ceratium breve-	0.02	0.34	0.45
3.	C. dens++	0.72	0.68	0.67
4.	C. extensum±	0.48	0.41	0.76
5.	C. furca++	0.70	0.92	0.79
6.	C. fusus++	0.65	0.50	0.78
7.	C.horridum++	0.67	0.71	0.66
8.	C.inflatum±	0.48	0.75	0.66
9.	C.lineatum-	0.25	0.49	0.19
10.	C.porrectum±	0.27	0.39	0.53
11.	C.macroceros±	0.53	0.36	1
12.	C.schmidtii±	0.42	0.61	0.69
13.	C. trichoceros++	0.71	0.60	0.93
14.	C. tripos++	0.89	0.75	0.51
15.	Gonyaulax polygramma++	0.65	0.71	0.74
16.	G.spinifera++	0.76	1.0	0.50
17.	Spiraulax kofoidii-	0.44	0.47	0.19
18.	Pyrocystis lunula±	0.08	0.45	0.07
19.	Pyrophacus magnificus++	0.53	0.53	0.67
20.	P.steinii±	0.48	0.40	0.65

(++) = strongly correlated, (±) = more or less correlated, (-) = less correlated

DOI: https://doi.org/10.36956/sms.v2i2.308

In the Peridinoid group, all the members of Protoperidinium show a strong correlation with salinity.

Some *Peridinium* were assigned to the genus *Protoperidinium* in some systematic studies. In this study, this species shows less correlation with salinity. The cell density of *Protoperidinium* may vary with salinity changes. Cell density will increase when the salinity increases in the water column. (Table 5).

Table 5. Correlation coefficients of Peridinoid and salinity.

No.	Peridinoid	2012	2013	2014
1.	*Protoperidinium depressum*$^{++}$	0.85	0.62	0.93
2.	*P. oblongum*$^{++}$	0.57	0.53	0.92
3.	*P.oceanicum*$^{++}$	0.51	0.69	0.99
4.	*P.pyreforme*$^{++}$	0.64	0.71	0.62
5.	*Peridinium pentagonum*-	0.24	0.65	-0.04
6.	*Podolampas elegans*±	0.39	0.47	0.77
7.	*P.palmipes*$^{++}$	0.74	0.72	0.93

(++) = strongly correlated, (±) = more or less correlated, (-) = less correlated

In the Gymnodinoids and Noctilucoids group, all species show a strong correlation with salinity. The abundance of Gymnodinoids and Noctilucoids was lower than that of other morphospecies groups throughout the study period. Distinct temporal and spatial variations in dinoflagellate cell densities were clear. Cell density changes may associate with the salinity concentration. (Table 6).

Table 6. Correlation coefficients of Gymnodinoids and Noctilucoids and salinity.

No.	Gymnodinoids and Noctilucoids	2012	2013	2014
1.	*Gyrodinium estuariale*$^{++}$	0.74	0.72	0.93
2.	*Noctiluca scintillans*$^{++}$	0.88	0.64	0.61

(++) = strongly correlated, (±) = more or less correlated, (-) = less correlated

In the Prorocentroid morphospecies group, *P. rostratum* shows a strong correlation with salinity while *P. micans* shows less correlation with salinity. *P. gracile* and *P. lima* show more or less correlation with salinity. In the Dinophysoid group, *D. caudata* shows less correlation with salinity during the study period, 2012-2014. The other species in the group show a strong correlation with salinity.

In the Gonyaulacoid group, C. dens, C. furca, C. fusus, C. horridum, C. trichoceros, C. tripos, G. polygramma, G. spinifera, and Pyrophacus magnificus show strongly correlated with salinity during the study period. Alexandrium concavum, C. extensum, C. inflatum, C. porrectum, C. macroceros, C. schmidtii, Pyrocystis lunula, and Pyrophacus steinii show more or less correlated with salinity. C. breve, C. lineatum, and Spiraulax kofoidii show less correlation with salinity.

In the Peridinoid group, *Protoperidinium depressum, P. oblongum, P. oceanicum, P. pyreforme*, and *Podolampas palmipes* show a strong correlation with salinity during the study period. *Peridinium pentagonum,* and *P. elegans* show more or less correlation with salinity.

In Gymnodinoid and Noctilucoid group, *G. estuariale* and *N. sintillans* show a strong correlation with salinity during the study period.

4. Conclusions

In terms of dinoflagellates distribution which was based on different salinity regimes, the Gonyaulacoid species, *Ceratium* comprises 65% and stands first in the dinoflagellate community. In the Dinophysoid group, *Ornithocercus* takes 60% in species composition. Moreover, in the Peridinoid group, *Protoperidinium* takes 57% in species composition of it. In the study areas, 52.6% of dinoflagellates are strongly correlated with salinity while 13.2% shows less in correlation with salinity. Braaurd (1961) suggested that some dinoflagellate species such as *Ceratium* spp., *Peridinium* spp. and *Prorocentrum* spp. reproduced more actively at the lower salinities. Thus, changing salinity in nearshore areas might influence the dinoflagellate species composition.

Acknowledgment

The authors are indebted to Dr. Aung Myat Kyaw Sein, Rector, and Dr. San San Aye, Pro-Rector of Mawlamyine University, for their support in preparing this research work. We are thankful to Dr. San Tha Tun, Professor and Head of the Department of Marine Science, Mawlamyine University, for providing the use of departmental facilities. Many thanks are especially to Dr. Khin Maung Cho, Pro-Rector (Retired), Mawlamyine University, for his kind suggestions in preparing the manuscript. Also, permission for this work from the Department of Higher Education, the Ministry of Education, and for facilities of the Department of Marine Science, Mawlamyine University

 DOI: https://doi.org/10.36956/sms.v2i2.308

is most appreciated.

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