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Comparison of seaweed communities of the two rocky shores in Sarawak, Malaysia

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Abstract—A study on seaweeds was carried out at Tanjung (Tg.) Batu (3°12′28.3″N, 113°02′38.4″E) and Kampung (Kg.) Kuala Nyalau (3°37′50.8″N, 113°22′16.1″E), Bintulu, Malaysia, from January to October 2008. This study examined the diversity and monthly distribution of seaweeds at two rocky shores with distinct landform characteristics and differences in their environmental conditions. A total of 32 seaweeds were identified belonging to 20 families and 27 genera comprising of 28 species (9 Chlorophyta, 5 Phaeophyta and 14 Rhodophyta) at Kg. Kuala Nyalau and 15 species (5 Chlorophyta, 2 Phaeophyta and 8 Rhodophyta) at Tg. Batu. Rhodophyta was dominant at both sites. Based on Bray-Curtis similarity evaluation, four distinct clusters on species occurrence in relation to months were observed at Tg. Batu: I–January, February and March, II–June and July, III–April and August, IV–September and October and, three clusters at Kg. Kuala Nyalau: I–February, March and April, II–January, III–June, July, August, September and October. Besides the topography and wave physical forces, a combination of some environmental (physical and chemical) factors were influencing the occurrence and differences in seaweed communities between the sites.

Key words: Bintulu, distribution, diversity, rocky shore, seaweed species

Introduction

Seaweeds are macroscopic marine algae that are differentiated into three distinct divisions, Chlorophyta (green algae), Phaeophyta (brown algae) and Rhodophyta (red algae). Most of the seaweeds are growing in the intertidal zone throughout the world (Thomas et al. 1984) although some occupied the supra-littoral and sub-littoral zones of the sea (Phang 1984). However, the dynamics of seaweed communities in a particular intertidal rocky shore are affected by a wide range of the ambient physical factors such as the effects of wave action, the water temperature and the substratum (McQuaid and Branch 1984). Several studies had been promoted on environmental factors influencing the occurrence of seaweeds at a particular site e.g. nutrients, temperature and salinity (Chung et al. 2007), temperature, substratum and wave exposure (McQuaid and Branch 1984), turbidity and nutrients (Su et al. 2009) and salinity (Russell 1988, Karsten 2007). The livelihood of seaweed communities in the tropical areas received less attention and thus the information concerning the diversity of these communities is still limited. In the present study, two rocky shores with distinct landform characteristics and differences in their environmental conditions have been selected to examine the diversity and distribution of the seaweed communities.

Materials and Methods

Two distinct intertidal rocky shores, Tanjung (Tg.) Batu (3°12′28.3″N, 113°02′38.4″E) and Kampung (Kg.) Kuala Nyalau (3°37′50.8″N, 113°22′16.1″E) were chosen for the study. Tg. Batu is a wave splashed short intertidal rocky shore extending up to 40 m seaward during low tide, with gradual slope, rocks, boulders and tide pools inhabited by epifauna such as mussels, barnacles, oysters and snails. Kg. Kuala Nyalau has a longer flat rocky shore of up to 200 m and during low tide, with exposed boulders and pebbles. Some part of the shore frequently receive splash of waves, occupied by various size of tide pools, inhabited by large numbers of oysters, snails, sea cucumbers, sea slugs, sea urchins and mussels. Landward the sand-mud environment gradually replaces the intertidal rocky shore.

Field data were obtained during low tides from January to October 2008 except for the month of May where extreme bad weather occurred. Samplings of seaweed were conducted to compile data on species composition, coverage, species assemblages using 20 random 50 cm×50 cm quadrat with 25 sub-divisions following the method developed by Saito and Atobe (1970). Seaweed species, coverage and the corresponding indices (referring to Table 1) in each of the 25 sub-divisions were recorded. The parameter obtained from each quadrat with respect to coverage (C; expressed as %) is used

Table 1. Indices of the degree of macroalgae cover and its representative multiplier.

Indices	Degree of algae cover	Multiplier, c_n
5	Covering 1/2–1/1 of substratum surface	3.0
4	Covering 1/2–1/2 of substratum surface	1.5
3	Covering 1/8–1/4 of substratum surface	0.75
2	Covering 1/16–1/8 of substratum surface	0.375
1	Covering less than 1/16 of substratum surface	0.1875

to compute for the area in the substrate occupied by the species. For convenience, the index numbers: 5, 4, 3, 2, 1 are used for recording data in the field as in Table 1. C (%)$=(qn_5\times c_5)+(qn_4\times c_4)+(qn_3\times c_3)+(qn_2\times c_2)+(qn_1\times c_1)=(qn_5\times 3)+(qn_4\times 1.5)+(qn_3\times 0.75)+(qn_2\times 0.375)+(qn_1\times 0.1875)$; where qn_n is the number of sub-divisions in which a species appeared to have the corresponding coverage area described in the above table. Data on other composition of seaweed such as density, relative density, frequency, relative frequency, dominance, relative dominance and importance value were also calculated. Representative seaweed samples were preserved in 5% saline formalin solution for taxonomical identification following the references of Lewmanomont and Ogawa (1995), Trono (1997, 2004) and Tsutsui et al. (2005). Environmental variables were recorded *in situ*, such as pH using HACH sension 1 pH meter, salinity by refractometer, temperature and conductivity by YSI 63 SCT meter, dissolved oxygen by Hanna HI9142 oxygen meter. Nutrients in water were analyzed in the laboratory adopting colorimetric methods such as nitrate (Morris and Riley 1963, Wood et al. 1967), ammonium (Riley 1953) and ortho-phosphate (Murphy and Riley 1962). Total suspended solid (TSS) was determined following APHA (1992).

The seaweed occurrence and the environmental physical and chemical variables at each site were compared by using Plymouth Routines in the Multivariate Ecological Research (PRIMER) statistical software package (v.5) (Clarke and Warwick 1994). The similarity matrix of species occurrence was classified according to Bray-Curtis similarity (Bray and Curtis 1957) by hierarchical agglomerative clustering via complete linkage method. BV-STEP was used to verify the environmental variables that explained the observed pattern of seaweed assemblage.

Results and Discussion

Diversity of seaweed

A total of 32 species of seaweed (20 families, 27 genus) were recorded with 28 species (19 families, 25 genus) at Kg. Kuala Nyalau and 15 species (9 families, 12 genus) at Tg. Batu (Table 2). Rhodophyta showed the highest species diversity at both sites as they possess multi-cellular rhizoidal holdfasts that serve to attach the thalli to hard substrates (Pritchard and Bradt 1984). At both areas, 11 generalist species were found: *Cladophora prolifera*, *Ulva intestinalis*, *Padina minor*, *Sargassum* sp., *Acanthophora spicifera*, *Ceramium* sp., *Gracilaria salicornia*, *Hydropuntia edulis*, *Hypnea cervicornis*, *Laurencia papillosa* and *Laurencia* sp. Four specialist species (*Chaetomorpha antennina*, *Ulva clathrata*, *U. prolifera* and *Porphyra* sp.) were found only at Tg. Batu, while 17 species (*Acetabularia major*, *Anadyomene plicata*, *Avrainvillea obscura*, *Caulerpa peltata*, *C. sertularioides*, *Halimeda macroloba*, *Valonia aegagropila*, *Dictyota* sp., *Lobophora variegata*, *Padina australis*, *Amphiroa fragilissima*, *Champia* sp., *Cheilosporum acutilobum*, *Gelidiella acerosa*, *Halymenia* sp., *Leveillea jungermannioides* and *Pterocladia parva*) were observed at Kg. Kuala Nyalau. Fewer species were recorded at Tg. Batu compared to Kg. Kuala Nyalau. This is attributed to its topography where rocky shore is short and exposed to strong waves that could dislodge and wash away seaweeds from the site (Boney 1969, Chapman 1979).

Laurencia papillosa was the most abundant and dominant species at Tg. Batu with the highest importance value (92.09) (Table 3). The values of relative frequency, relative density and percentage cover were 25.28%, 33.41% and 14.90% respectively, the highest among other seaweeds at the same site. Species such as *Padina minor* exhibited the lowest importance value (0.57%) indicating that the species was quite rare. At Kg. Kuala Nyalau *Sargassum* sp. possessing large erect thallus and broad “leaves” showed the highest importance value of 50.32 and relative density of 19.87% (Table 4). The species was second highest in its relative frequency (10.58%) and percentage cover (10.85%). *Acetabularia major* was rare with the lowest importance value (0.12) and was lowest in relative frequency (0.11) and percentage cover (0.01%). Based on our previous observation (Muta Harah et al. 2007), this alga occurred and grew on both rocky and sandy substrates at shallow water that received high wave splash.

Similarity of distribution

Based on Bray-Curtis 75% similarity evaluation, four distinct clusters on the species occurrence in relation to months were observed at Tg. Batu: I–January, February and March, II–June and July, III–April and August, IV–September and October (Fig. 1) and three clusters at Kg. Kuala Nyalau: I–February, March and April, II–January, III–June, July, August, September and October (Fig. 2).

Environmental variables (Table 5) for both sites showed differences that lead to the differences in seaweed distribution. Different environmental factors may vary with locality and govern the distribution of seaweed communities (Martin 2000). The stability of environmental factors plays important

Table 2. Monthly occurrence of seaweed species at inter-tidal rocky shores of Bintulu for year 2008. +-Tg. Batu, ●-Kg. Kuala Nyalau.

No.	Division, Family and Species	Month									
		J	F	M	A	M	J	J	A	S	O
	CHLOROPHYTA										
	Anadyomenaceae										
1	*Anadyomene plicata* C. Agardh	●					●	●	●	●	●
	Caulerpaceae										
2	*Caulerpa peltata* J. V. Lamouroux						●	●	●	●	●
3	*Caulerpa sertularioides* (S. G. Gmelin) M. A. Howe						●	●	●	●	●
	Cladophoraceae										
4	*Chaetomorpha antennina* (Bory) Kützing			+							
5	*Cladophora prolifera* (Roth) Kützing	●					+●	●	●	●	●
	Halimedaceae										
6	*Halimeda macroloba* Decaisne						●	●	●	●	●
	Polyphysaceae										
7	*Acetabularia major* G. Martens						●	●			
	Udoteaceae										
8	*Avrainvillea obscura* (C. Agardh) J. Agardh	●			●		●	●	●	●	●
	Ulvaceae										
9	*Ulva clathrata* (Roth) C. Agardh	+	+		+						
10	*Ulva intestinalis* Linnaeus	+	+●	+	+		+	+	+●		
11	*Ulva prolifera* O.F. Müller	+	+	+							
	Valoniaceae										
12	*Valonia aegagropila* C. Agardh	●	●	●	●		●				●
	PHAEOPHYTA										
	Dictyotaceae										
13	Dictyota sp.	●		●			●	●	●	●	●
14	*Lobophora variegata* (J. V. Lamouroux) Womersley ex Oliveira	●		●			●	●	●	●	●
15	*Padina australis* Hauck						●	●	●	●	●
16	*Padina minor* Yamada						+●	+●	●	●	●
	Sargassaceae										
17	*Sargassum* sp.	+●	+●	+●	+●		+●	+●	+●	+●	+●
	RHODOPHYTA										
	Bangiaceae										
18	*Porphyra* sp.	+	+	+							
	Ceramiaceae										
19	*Ceramium* sp.	+	+				+	+	+		●
	Champiaceae										
20	*Champia* sp.				●						
	Corallinaceae										
21	*Amphiroa fragilissima* (Linnaeus) J. V. Lamouroux	●	●	●			●	●	●	●	●
22	*Cheilosporum acutilobum* (Decaisne) Piccone	●						●			
	Cystocloniaceae										
23	*Hypnea cervicornis* J. Agardh	+	+	+	+		+	+	+		+●
	Gelidiellaceae										
24	*Gelidiella acerosa* (Forsskål) Feldmann & G. Hamel	●	●	●	●				●	●	●
	Gracilariaceae										
25	*Gracilaria salicornia* (C. Agardh) E.Y. Dawson	+●	+●	●	●		+●	+●	●	+●	●
26	*Hydropuntia edulis* (S.G. Gmelin) Gurgel & Fredericq	+●	+●	+●	+●		+●	+●	+●	+●	+●
	Halymeniaceae										
27	*Halymenia* sp.										●
	Pterocladiaceae										
28	*Pterocladia parva* E.Y. Dawson							●	●	●	●
	Rhodomelaceae										
29	*Acanthophora spicifera* (M. Vahl) Børgesen	+	+●	+●	+●		+●	+	+●	+●	+●
30	*Laurencia papillosa* (C. Agardh) Greville	+	+●	+●	+●		+	+	+●	+●	+
31	*Laurencia* sp.	+	+	+	+		+	+	+●	+●	+
32	*Leveillea jungermannioides* (K. Hering & G. Martens) Harvey						●	●			●
	TOTAL Tg. Batu	**12**	**12**	**10**	**8**		**11**	**10**	**8**	**6**	**6**
	TOTAL Kg. Kuala Nyalau	**12**	**9**	**10**	**9**		**18**	**18**	**20**	**19**	**22**

roles in determining, controlling and maintaining seaweed distribution. Salinity, conductivity and total suspended solid (TSS) affect the growth of seaweeds which determine the distribution of the species. Salinity of marine environment generally ranges between 33–37 psu (Dawson 1966) where seaweeds are able to survive. Some seaweeds are sensitive to salinity changes whereas others can tolerate wide range of salinity changes. For example, *Enteromorpha* is able to live on the hulls of ships travelling from saltwater to freshwater (Prescott 1968). The salinity recorded in the present study at

Table 3. Species percentage cover (%), density, relative density, frequency, relative frequency, dominance, relative dominance and importance value of seaweeds at Tg. Batu.

Division and Species	Percentage cover (%)	Density	Relative Density (%)	Frequency	Relative Frequency (%)	Dominance	Relative dominance (%)	Importance value (%)
CHLOROPHYTA								
Ulva clathrata	4.72	0.002	1.60	0.033	1.61	0.032	1.60	4.80
Ulva intestinalis	2.16	0.002	1.67	0.039	1.26	0.032	1.67	4.59
Ulva prolifera	19.97	0.009	9.53	0.156	6.88	0.187	9.53	25.94
PHAEOPHYTA								
Padina minor	0.23	0.000	0.06	0.017	0.46	0.001	0.06	0.57
Sargassum sp.	6.87	0.009	10.20	0.261	8.73	0.177	10.20	29.12
RHODOPHYTA								
Acanthophora spicifera	9.16	0.014	15.80	0.478	15.12	0.281	15.80	46.72
Ceramium sp.	0.47	0.001	0.97	0.050	1.52	0.012	0.97	3.46
Gracilaria salicornia	0.42	0.000	0.58	0.061	2.42	0.008	0.58	3.58
Hydropuntia edulis	3.87	0.006	8.03	0.350	12.90	0.128	8.02	28.95
Hypnea cervicornis	3.09	0.003	3.74	0.256	8.15	0.069	3.74	15.63
Laurencia papillosa	14.90	0.025	33.41	0.717	25.28	0.507	33.40	92.09
Laurencia sp.	2.93	0.004	5.71	0.272	9.07	0.087	5.71	20.49
Porphyra sp.	16.94	0.009	8.72	0.139	6.61	0.173	8.72	24.05
Total		**0.084**	**100.01**	**2.829**	**100.00**	**1.694**	**100.00**	

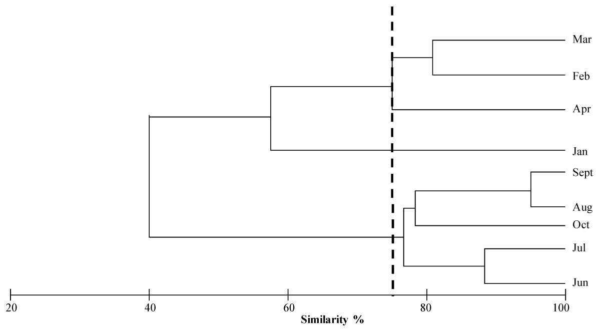

Fig. 1. Tg. Batu: dendrogram showing similarity (Bray-Curtis, 75%) according to month in relation to species occurrence.

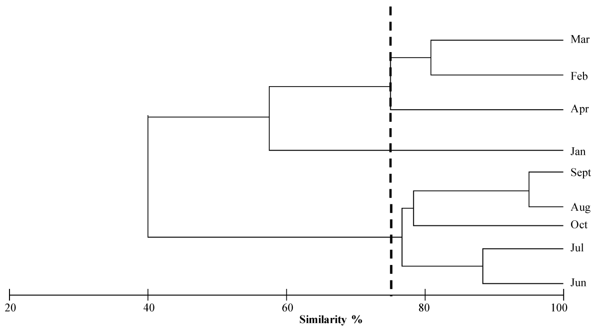

Fig. 2. Kg. Kuala Nyalau: dendrogram showing similarity (Bray-Curtis, 75%) according to month in relation to species occurrence.

Tg. Batu and Kg. Kuala Nyalau ranged from 14.18–29.20 psu and 30.00–32.40 psu respectively. Low salinity in the area is attributed to input from precipitations and runoff of freshwater into the area.

The level of conductivity in water is a good indication of the amount of ionizable substances dissolved in it. With both areas occupied by tide pools, as water evaporates and the solute becomes concentrated, conductivity will rise (Slingsby and Cook 1986). However, such condition is reverse during rainy days.

TSS affects the turbidity of the water. The higher the TSS, the more turbid is the water (Slingsby and Cook 1986). Based on Table 5, TSS at Tg. Batu fluctuated from 19.20 to 961.60 $mg\,L^{-1}$ and at Kg. Kuala Nyalau from 36.00 to 1094.40 $mg\,L^{-1}$. Wide ranges of TSS in both sites are attributed to precipitation caused by runoff of silt and sediments. In a study by Phang (1988), the sheltered west coast of Peninsular Malaysia is especially vulnerable to silts from land-based activities and the silts have been cited as one of the pollutants that affect the seaweeds' survival. Short tuft forms and encrusting species are especially vulnerable to sedimentation. Large flexible or branched forms like *Sargassum* and *Padina* are less susceptible as they are able to avoid smothering by silt.

Seaweed and environmental factor

Based on BVSTEP analysis (PRIMER v5) the combination of multiple environmental variables (physical and chemical variables, Table 6) explains the observed occurrence and

Table 4. Species percentage cover (%), density, relative density, frequency, relative frequency, dominance, relative dominance and importance value of seaweeds at Kg. Kuala Nyalau.

Division and Species	Percentage cover (%)	Density	Relative Density (%)	Frequency	Relative Frequency (%)	Dominance	Relative dominance (%)	Importance value (%)
CHLOROPHYTA								
Acetabularia major	0.01	0.000	0.000	0.006	0.11	0.000	0.000	0.12
Anadyomene plicata	2.93	0.002	6.20	0.217	6.55	0.035	6.21	18.95
Avrainvillea obscura	0.03	0.000	0.03	0.017	0.50	0.000	0.04	0.57
Caulerpa peltata	1.83	0.000	1.42	0.028	0.77	0.005	0.04	2.23
Caulerpa sertularioides	0.10	0.000	0.04	0.006	0.17	0.000	1.03	1.24
Cladophora prolifera	1.17	0.000	2.14	0.189	5.41	0.009	2.14	9.68
Halimeda macroloba	3.30	0.000	4.19	0.106	2.99	0.008	4.18	11.37
Ulva intestinalis	2.47	0.000	0.51	0.028	0.75	0.005	0.51	1.77
Valonia aegagropila	18.89	0.012	17.71	0.350	10.62	0.243	17.71	46.04
PHAEOPHYTA								
Dictyota sp.	3.18	0.002	7.59	0.267	7.73	0.042	8.00	23.32
Lobophora variegata	4.17	0.003	8.17	0.178	5.40	0.064	8.18	21.74
Padina minor	1.98	0.000	3.22	0.211	6.78	0.010	3.22	13.22
Sargassum sp.	9.85	0.009	19.87	0.322	10.58	0.187	19.87	50.32
RHODOPHYTA								
Acanthophora spicifera	1.11	0.001	2.01	0.150	4.99	0.014	2.01	9.02
Amphiroa fragilissima	3.19	0.002	7.74	0.278	8.07	0.033	7.75	23.57
Ceramium sp.	0.05	0.000	0.02	0.006	0.17	0.000	0.02	0.20
Cheilosporum acutilobum	0.04	0.000	0.02	0.011	0.29	0.000	0.02	0.33
Gelidiella acerosa	6.02	0.003	4.36	0.211	6.30	0.061	4.36	15.02
Gracilaria salicornia	2.85	0.003	6.36	0.306	9.27	0.053	6.37	22.00
Hydropuntia edulis	2.45	0.002	5.44	0.272	7.38	0.043	5.44	18.26
Hypnea cervicornis	0.08	0.000	0.03	0.006	0.17	0.000	0.03	0.22
Laurencia papillosa	0.71	0.000	0.42	0.089	2.55	0.005	0.42	3.39
Laurencia sp.	7.69	0.001	1.95	0.017	0.69	0.011	1.95	4.59
Leveillea jungermannioides	0.04	0.000	0.02	0.006	0.11	0.000	0.02	0.14
Pterocladia parva	0.60	0.000	0.49	0.044	1.66	0.003	0.50	2.65
Total		**0.041**	**99.95**	**3.319**	**100.00**	**0.832**	**100.01**	

Table 5. Environmental variables (given as range) of monthly mean for Tg. Batu and Kg. Kuala Nyalau throughout sampling months.

Environmental variables	N	Tg. Batu	Kg. Kuala Nyalau
Physical			
Salinity (psu)	45	14.18–32.00	24.60–32.40
Temperature (°C)	45	28.86–32.18	28.12–34.60
Turbidity (NTU)	45	8.50–971.00	14.86–505.40
Conductivity (mS cm^{-1})	45	16.09–48.86	29.52–53.66
Dissolved oxygen (mg L^{-1})	45	5.98–12.86	7.32–13.76
Total suspended solid (mg L^{-1})	45	19.20–961.60	36.00–1094.40
Chemical			
pH	45	6.76–8.64	6.84–8.58
Nitrate (ppm)	36	0.767–7.444	0.612–1.598
Nitrite (ppm)	36	0.089–0.149	0.086–0.133
Ammonium (ppm)	36	0.046–0.422	0.036–1.102
Orthophosphate (ppm)	36	0.004–0.033	0.005–0.020

distribution of seaweeds. The correlation between the variables is described by the Spearman rank correlation (ρ) which ranges from $+1$ (perfect correlation), through 0 (no correlation), to -1 (perfect negative correlation). ρ values up to 0.33 is considered weak relationships, between 0.34 to 0.66 medium strength relationships and over 0.67 as strong relationships. At Tg. Batu, the best combination for physical variable responsible for the seaweed occurrence was conductivity with its ρ of 0.390 and for chemical variables was nitrite with ρ of 0.580. However, at Kg. Kuala Nyalau, salinity, conductivity and TSS were the best combination for physical variables responsible for the seaweed occurrence with ρ of 0.211 whilst ammonium and orthophosphate were the chemical variables with ρ of 0.77.

Nitrite content at Tg. Batu fluctuated between months in the range from 0.0890 to 0.1491 ppm. In similar environment, e.g. in waters of coral reef and seagrass ecosystem of the Palk Bay, India, the nitrite content fluctuated from 0.03 to 2.91 ppm as observed by Sridhar et al. (2008). Several factors

Table 6. The environmental variables or the combination producing the observed changes in seaweed assemblage during the months. Physical environmental variables-salinity, temperature, turbidity, conductivity, dissolved oxygen, total suspended solid; Chemical environmental variables-pH, nitrate, nitrite, ammonium and orthophosphate.

Environmental variable/ study site	Number of variable	Spearman rank correlation (ρ)	Best variable combination
Physical			
A. Tg. Batu	1	0.390	Conductivity
B. Kg. Kuala Nyalau	3	0.211	Salinity, conductivity, total suspended solid
Chemical			
A. Tg. Batu	1	0.580	Nitrite
B. Kg. Kuala Nyalau	2	0.771	Ammonium, orthophosphate

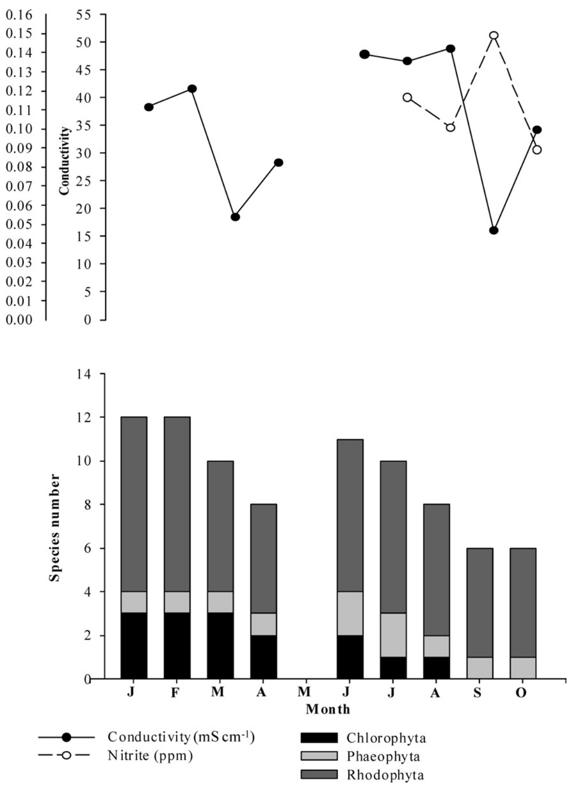

Fig. 3. Tg. Batu: number of seaweed species and the influencing environmental variables with months in year 2008.

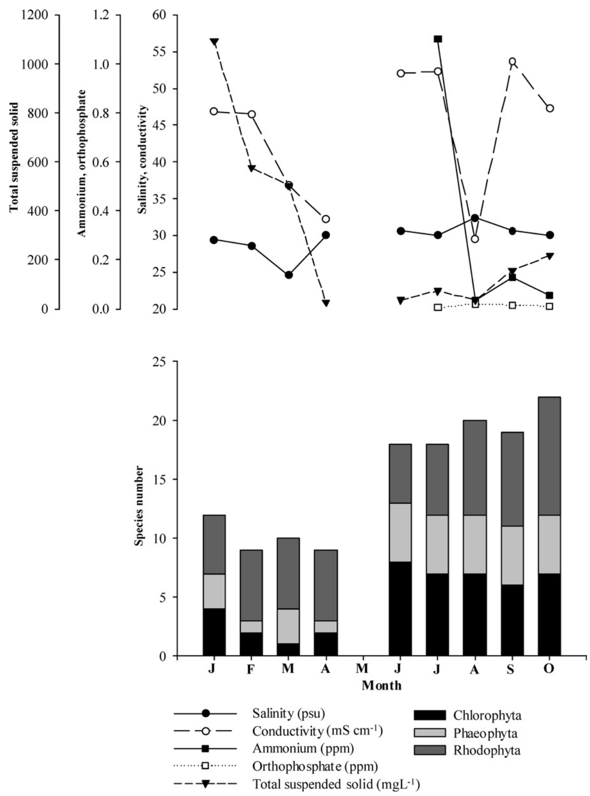

Fig. 4. Kg. Kuala Nyalau: number of seaweed species and the influencing environmental variables with months in year 2008.

influenced the nitrite content in the water. Lower nitrite content in seawater is due to less freshwater input in certain months of the year (Soundarapandian et al. 2009) while higher nitrite content could be attributed to decomposition of phytoplankton, oxidation of ammonia, reduction of nitrate (Kannan and Kannan 1996) and influence of seasonal floods (Soundarapandian et al. 2009). Ammonium was high partly due to death and decomposition of phytoplankton and excretion of ammonia by planktonic organisms (Segar and Hariharan 1989). Industrial effluents mixing with estuary water could be the source of ammonium and orthophosphate in water.

Salinity, conductivity and TSS were linked with rainfall. Salinity becomes low during heavy rainfall giving rise to large quantity of freshwater inflow (Soundarapandian et al. 2009). TSS was high during heavy rainfall and caused the conductivity to increase due to increase in contaminants.

Based on Figs. 3 and 4, the number of seaweed species differed when the above environmental variables changed. Other studies documented the effect of salinity on seaweed growth (Dawes et al. 1998, Israel et al. 1999, Larsen and Sand-Jensen 2006). In southeastern Taiwan, nutrients (nitrate 2.05±3.39 μM, nitrite 0.06±0.10 μM, ammonium 2.37±1.88 μM and dissolved inorganic phosphorus 0.47±0.48 μM) and salinity (31.47±4.77 psu) were reported as the governing factors for variation in the structure and abundance of tropical benthic seaweed assemblages (Chung et al. 2007).

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