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Spatio-temporal variations in seaweed diversity and abundance of selected coastal areas in Ghana

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ABSTRACT

The coast of Ghana is considered the most seaweed-endowed region in West Africa, although information on the local spatial and temporal distributions and abundance of seaweed species is limited. In this study, seaweed species were sampled monthly from five coastal sites in the Central (Elmina, Komenda, Mumford) and Western (Shama and Takoradi Fisheries) Regions of Ghana during low tides from 2017 to 2019 to determine their diversity and abundance (biomass). Sampling was conducted using two (2) transect lines and quadrats (each of dimension 0.25 m^2) at each site. Thirty-five (35) taxa were identified at the five sites: 15 belonging to Rhodophyta, 11 to Chlorophyta and 9 to Phaeophyta. The Komenda site recorded the highest species diversity index of 2.06 whereas the Takoradi Fisheries had the lowest value of 0.68. *Ulva fasciata, Padina durvillaei, Sargassum vulgare, Hydropuntia dentata* and *Hypnea musciformis* were the most dominant species at the sites. A mean monthly biomass of 2.19 g dry wt m^{-2} was recorded for all five sites during the study period, with the greatest recorded at Takoradi Fisheries (3.53 dry wt m^{-2}) and the least at Komenda (1.10 g dry wt m^{-2}). The greatest biomass of the highly economic important species, *H. musciformis*, was recorded at Shama. The highest mean monthly biomass was recorded between August and October while the least was observed from December to February. Results from this study indicate considerable spatial and temporal variability in the diversity and abundance of seaweeds across the studied sites. These findings provide important baseline information for conservation and utilization of seaweeds, particularly their cultivation along the Ghanaian coastal waters as an alternate source of livelihood for the local communities.

1. Introduction

Seaweeds are evolutionary primitive eukaryotic and multicellular photosynthetic plants that lack true differentiation (i.e., no true roots, stem and leaves) and constitute major primary benthic producers in marine ecosystems (Petsut et al., 2012). Also known as macro-algae, seaweeds serve as an important source of food for both humans and animals, and are rich in micro- and macro-nutrients, vitamins, natural omega-3, long-chain fatty acids, carbohydrates, proteins, lipids, growth hormones, low food calories and high dietary fiber (Kılınç et al., 2013; Delaney et al., 2016; FAO, 2018). Seaweeds are also essential resources for the production of hydrocolloids (polysaccharides of high economic value) and carbon sequestration, and thus contribute to the reduction of global warming (Phang et al., 2008).

Globally, three groups of seaweeds are recognized based on the type of pigmentation, their morphology and photosynthetic storage products (Kılınç et al., 2013; FAO, 2013). These three groups are the green (Chlorophyta), the brown (Phaeophyta) and the red (Rhodophyta) color-producing seaweeds. Morphologically, seaweeds range from crusts, leathery-like, leafy to complex arrangements with specialized features for reproduction, attachment and capturing of light for photosynthesis (FAO, 2013). They are found throughout the world's oceans (Guiry, 2009), and usually established between the intertidal rocky and subtidal zones (Norashikin et al., 2013). Their growth, production, distribution and function are mostly regulated by climate change factors,

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particularly rising seawater temperature and CO_2 concentration (ocean acidification) (Werner et al., 2016; Sunny, 2017). As a consequence, their importance as bio-indicators for early warning of climate change impact in the marine ecosystem is also well documented (El Shoubaky, 2013; Sunny, 2017).

On a larger scale, the abundance and distribution of seaweeds is influenced by many environmental factors including salinity, light intensity, pH, nutrient, temperature, precipitation, tidal exposure and shore features (Dhargalkar and Kavlekar, 2004; Thakur et al., 2008; Kang et al., 2011; Petsut et al., 2012). For instance, Echem and Metillo (2011) observed an increase in seaweed biomass during the dry season as a result of a rise in light intensity, which directly impacted photosynthetic activities of the thallus. Rocky shores provide suitable stable substratum for substantial growth of seaweeds. However, the local distribution of seaweeds is influenced largely by wave action of the sea as well as community disturbances (Thakur et al., 2008). Thakur et al. (2008) also observed community structure and seasonality as important correlates of seaweed biomass and composition at the local level. These factors are expected to change as part of the ongoing global environmental change, potentially causing considerable changes in the distribution and abundance of seaweeds (Kokabi et al., 2016). Thus, current understanding of the variations in seaweed species diversity and distribution over time and space is vital for their sustainable utilization and conservation planning, particularly at the local or regional levels.

The coastline of Ghana, especially the rocky shores, is endowed with varied and luxuriant growth of seaweeds and is considered the richest in West Africa (Anderson et al., 2012). Despite this biological richness and the associated economic as well as ecological benefits, information on the diversity and abundance of seaweeds and their variations over space and time in the coastal region of Ghana is limited. The few previous studies have focused mainly on elemental analysis and assessment of iodine, hydrocolloids as well as macro-algae diversity and zonation patterns (John and Asare, 1975; Serfor-Armah et al., 1999, 2000; Gbedemah, 2017). As a result, current data on the spatial and temporal (monthly/seasonal) variations of seaweed abundance are lacking in the country. Furthermore, for judicious use of the natural beds, the cultivation of seaweed as a resource for sustainable economic development and future exploitation, it is essential to determine the present seaweed diversity, distribution and abundance along the coast of Ghana. In the present study, the diversity, distribution and abundance of seaweeds and their temporal variability across selected sites in the Central and Western Regions of Ghana were evaluated. These seaweed attributes are expected to be similar across the Central and Western coasts of Ghana.

2. Materials and methods

2.1. Description of the study areas

Seaweed samples were collected from five (5) locations in the Central and Western regions of Ghana, which according to Issaka et al. (2012), fall within the coastal savanna and high rainforest zones, respectively. The five sampled sites were Mumford (N 05°15.730′, W 001° 45.376), Elmina (N 05°04.646′, W 001° 22.216′) and Komenda (N 05°02.688′, W 001° 30.061′) in the Central region, and Shama (N 05° 00.002′, W 001° 37.988′) and Takoradi Fisheries (N 04° 52.700′, W 001° 45.166′) in the Western region (Fig. 1).

The sites were selected based on the availability of seaweed bed, type of human activities, pollution levels and accessibility under varying weather conditions and tidal heights. The possibility of cultivating seaweed species of economic importance at the sites was also considered. The five selected sites are described below (Fig. 2).

Mumford: This site has a gentle slopping topography with high rocks jetting out of the sea in the intertidal zone (Fig. 2A). The shore has different rock sizes interspersed with sand and a sandy splash zone. There were small tide pools between the smaller rocks in the zone. About 500 meters eastwards from the sampled points were a landing site for canoes and a semi-closed lagoon. The lagoon is usually closed during the dry season and opened during the wet season. The residencies in the community are situated close to the sea. The geology of the coast is characterized by Tarkwaian rocks (detrital sediment, mainly sandstone and conglomerate, undifferentiated) and metamorphosis of lower greenschist facies alternating with patches of sand deposits along the shore (Duodu, 2009). The site can be described as moderately exposed or exposed to wave action. Common human activities included swimming, open defecation, and use as landing sites for canoes.

Elmina: The sampled location at Elmina is located in front of the Coconut Groove Beach Resort (Fig. 2B). Both the eastern and western parts of the site have wave sheltered bay with artificial boulder breakwater systems. The coast has a gently-sloped sandy shore with a short shoreline distance of 40 m from the sampling point during low tides. The rocks are naturally arranged in a gently slopy manner with some isolated higher rocks. Some of the rocks get totally immersed during high tides. The geology of the site is characterized by the Sekondian group, made of sandstone of undifferentiated interbedded shale (Duodu, 2009; Anim and Nyarko, 2017). The coast can be described as moderately exposed or exposed to wave action (Anim and Nyarko, 2017). There were limited human activities at the site during the study period. However, portions of the rocks that had seaweeds growing on them were exposed at certain periods of the year and covered with sand at other periods.

Komenda: The site has a gentle slope beach with evidence of erosion on the shore. It is dominated with continuous gently sloping flat rocks with few outcrops. The geology of the site is characterized by undifferentiated and non-metamorphic Eburnean plutonic suite granitoid (Fig. 2C). The site is similar to that of Mumford in terms of its wave action (i.e., moderately exposed to exposed). Human activities such as open defecation and sand winning are common at the site. Abundance of hiding holes on the rocks clearly indicated the presence of sea urchins (*Echinometra lucunter*) at the site.

Shama: The Shama beach has a gentle slope and is mostly filled up with sand and scattered short rocks in the intertidal zone. It is close to the Pra River. This site has a long distance (about 67 m) of sandy beach during the low tide (Fig. 2D). The rock type is categorized as Birimian super group with metamorphosis upper greenschist to amphibolite facies (Duodu, 2009). John and Asare (1975) described Shama as moderate to sheltered coastline. It has a quiet bay and a canoe landing site. Compared to the other sites, Shama appears to have more seaweeds, growing mostly on sand than on rocks at the sampling point and hence the high drifting of seaweeds on the shore. The beach is characterized by mass of seaweed washing long the shore. Effluent from alluvial mining activities (both legal and illegal) from the watershed of the Pra River are discharged via the estuaries into the sea (Mahu, 2014).

Takoradi Fisheries: Sampling at Takoradi was conducted behind the Fisheries Commission Offices (henceforth referred to as Takoradi Fisheries). This site has beach resorts along the shore. The shore slopes gently toward the sea. There are no rock outcrops or cliffs. The rock type belongs to the Sekondian Group (i.e., sandstone with undifferentiated interbedded shale). There were numerous sea urchins' holes in the rock interfaced with breakwater

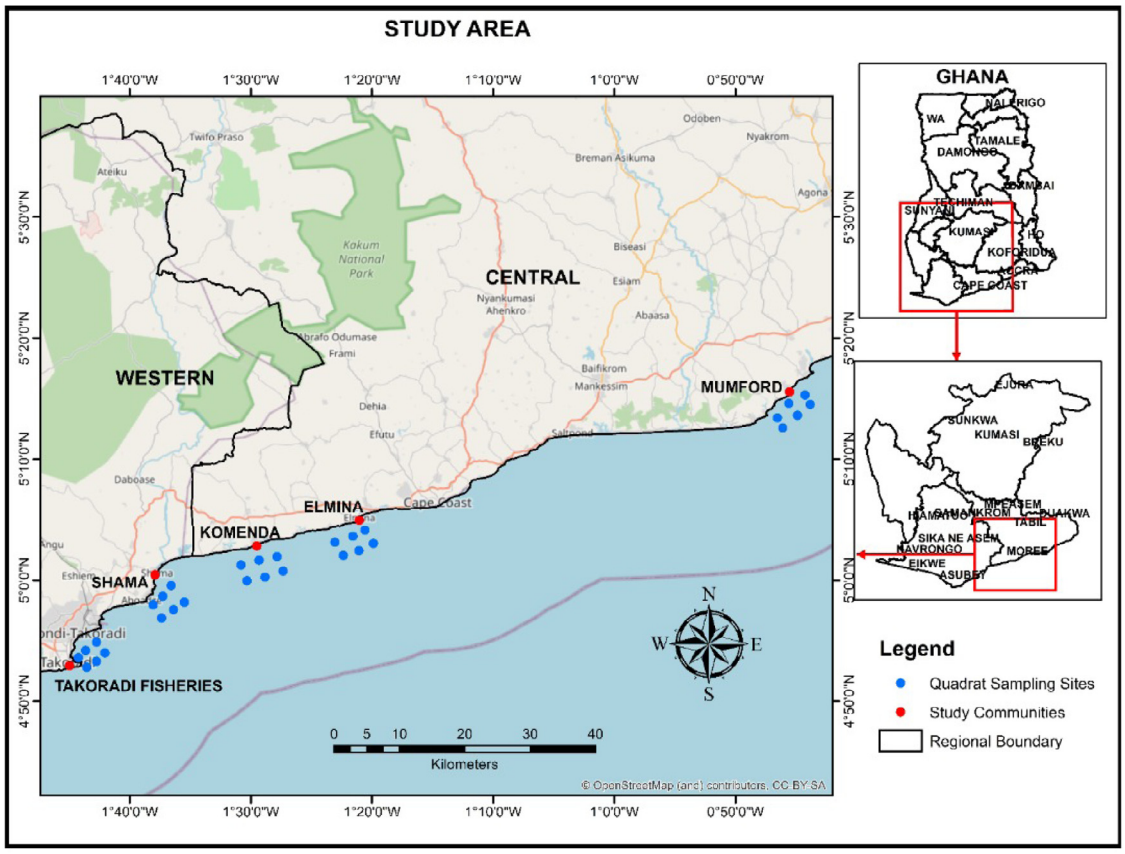

Fig. 1. Location of the five studied sites (red dots) in the Central (Elmina, Komenda and Mumford) and Western (Shama and Takoradi Fisheries) regions of Ghana.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

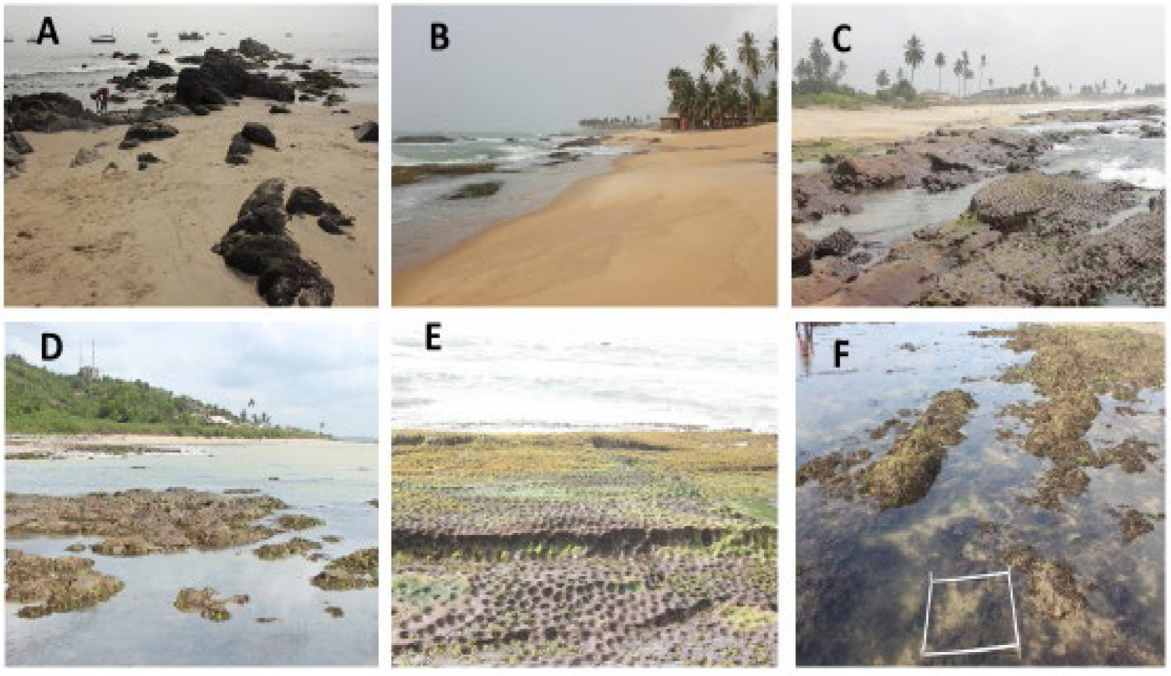

Fig. 2. Physical characteristics of the study sites (A: Mumford, B: Elmina, C: Komenda, D: Shama, E: Takoradi Fisheries, F: Study site with mounted quadrat for sampling).

pools. The wave action of the coastline is described as moderately sheltered with rocks that are naturally arranged in a horizontal flat position rather than vertical position (Fig. 2E). The rock arrangement aids in reducing the strength of the waves. The rocks are relatively flat with tide poles occurring at certain places (Gbedemah, 2017).

2.2. Sampling design

Sampling spanned the rainfall season (i.e., April April–Ocotber) and the dry season (i.e., November–March) in the country (Lawson, 1956; Lieberman et al., 1979). Monthly collection of seaweeds from the intertidal zones at the five sites was done during the low tide and low seawater height within the month. A transect line and metal quadrats ($0.5\ m \times 0.5\ m = 0.25\ m^2$) were used for the delineation and estimation of seaweed abundance at each site (Gallon et al., 2013; Smith, 2013). Two transect lines with a distance of 8 m between them were laid parallel to the shore line during low tide after the method of Pellizzari et al. (2017). A total of six permanent quadrats were located at each studied site, and this comprises three permanent metal quadrats located at 8 m interval on each transect line. The geographic coordinates of each sampled point were recorded using a hand-held GARMIN GPS 60 receiver. To facilitate future identification of sampling locations, permanent rocks or big stones close to the quadrats were marked with white oil paints and their distances to the quadrats taken. Rocks were also placed at the corners and in front of the quadrats to secure them. The distance between the quadrats and end of seashore for the five sampled sites ranged from 40 m at Elmina to 67 m at Shama.

2.3. Seaweed sampling

Seaweed abundance was assessed based on biomass (Kang et al., 2011; Dadolahi-Sohrab et al., 2012). Sample collection was planned mostly between 7am-11:45am on each sampling day with the aid of the online tidal table indicating periods for the low tide (https://tides4fishing.com/af/ghana/cape-coast & https://tides4fishing.com/af/ghana/takoradi). The monthly collection of seaweed from the five sites was conducted from February 2017 to April 2019 during low tide at a tidal height of 0–0.4 m. The biomass of seaweeds was determined using a modification of the harvesting methods described by Council (2009) and De San (2012). The fonds and stipes of all the thalli of different seaweed species present in each quadrat were carefully cut at the base (i.e., just above the holdfast) with a pair of scissors leaving the holdfast still attached to their substratum to facilitate regrowth. The cut seaweeds were immediately rinsed with sea water to remove all sediments, invertebrates and other debris attached to them. Different species were sorted according to their morphology, color and structure, and placed in separate well-labeled ziplock bags and transported to the laboratory in ice box. Identification of seaweed species was done with the help of diagnostic keys in the West African Seaweed Identification Manual (John et al., 2001) and algaebase (https://www.algaebase.org/). The identified seaweed species were confirmed using seaweed specimen voucher and were authenticated by Marine Biologists at the Ghana Herbarium in the Department of Plant and Environmental Biology of the University of Ghana, Legon. During the study, the sampling points at the Elmina site were covered with sand from November 2018 till the last collection month (April 2019). This seasonal phenomenon, which could partly be attributed to the existing breakwater system just east of the site (Lobban and Harrison, 1994) limited data collection at the site.

2.4. Laboratory procedures

In the laboratory, all the seaweeds were washed with tap water to remove excess salt, remaining soil particles, epiphytes, invertebrates, debris and other materials attached to the seaweeds. The seaweeds were shaken to drain out any water on them. The seaweeds were then air-dried for 3 days at room temperature, followed by oven drying at 105 °C for 4 h until constant weight was obtained (Mtolera and Buriyo, 2004; Wong and Phang, 2004). The oven-dried seaweeds were placed in a desiccator to cool before weighing with a digital analytical balance to the nearest 0.01 g (Mettler Toledo Analytical Balance). To determine the biomass, the seaweeds from all six quadrats at a site for each month were sorted into various species prior to weighing. Further, the biomass for the various species belonging to the same division were pooled. The biomass values for each site spanning the entire study period (i.e., 2017–2019) were then averaged for the respective months. Biomass for the wet (April–October) and dry (November–March) seasons were calculated as the sum of the monthly biomass at each site.

2.5. Data analysis

The data were entered into Microsoft Excel and screened for entry errors. The PRIMER (Plymouth Routine in Marine Ecological Research)- 6 software was used to compute the Shannon diversity index (H′), Margalef's species richness (d) and Pielou's evenness (J) of the seaweeds for the different sites. The Bray–Curtis similarity measure was also used to determine the similarity in the abundance and diversity of seaweeds among the studied sites. Variations in seaweed biomass among the sites and between the seasons were evaluated using the analysis of variance (ANOVA) and the student t-test, respectively, at 5% significance level. Where differences existed, the Tukey HSD (Honestly Significant Difference) was performed to separate them. All statistical analyses were performed using the SPSS software (Version 21), whereas the graphs were created using Sigma Plot (Version 10.0).

3. Results

3.1. Diversity and distribution of seaweeds across the studied sites

A total of 35 seaweed species were identified at the five studied sites during the study period (i.e., 2017–2019). The species belonged to three divisions (i.e., Chlorophyta, Rhodophyta and Phaeophyta), 3 classes, 13 orders, 22 families and 29 genera. Rhodophyta (red algae) recorded the greatest number of species (15) whereas Chlorophyta (green algae) and Phaeophyta (brown algae) had 11 and 9 species, respectively (Table 1). The three divisions were represented in all five sampled sites.

Species richness was highest at Komenda (31) and lowest at Shama (19). Komenda also recorded the highest Margalef and Shannon diversity indices (4.2 and 2.06, respectively) compared to the other sites studied. Similarly, the Pielou's evenness indicated a more equitable distribution of the seaweeds at Komenda than at the other sites. Although the studied sites shared eleven (11) species, they also had some unique species. For example, *Ceramium mazatlanense* (Rhodophyta) was found at Komenda only whereas *Grateloupia filicina* (Rhodophyta) and *Griffithsia schousboei* (Rhodophyta) were unique to the Elmina site. The studied sites in the Central Region generally recorded higher diversity of seaweeds compared to the Western Region. Bray–Curtis similarity analysis indicated 70% similarity in the diversity of seaweeds from Komenda and Mumford, both in the Central Region (Fig. 3). Seaweeds from both sites were 58% similar to those of Elmina. The seaweeds from Takoradi Fisheries and Shama sites formed the second main cluster, with a similarity index of 52%.

Table 1
Diversity, composition and abundance of seaweeds at the five sites sampled in the Western and Central regions of Ghana. Numbers in brackets are standard deviations.

Seaweed attribute	Elmina	Komenda	Mumford	Shama	Takoradi Fisheries	All Sites
Number of species in Chlorophyta	6	11	5	6	9	11
Number of species in Phaeophyta	6	8	9	5	4	9
Number of species in Rhodophyta	10	12	11	8	8	15
Number of genera	20	25	22	16	17	29
Total number of species	22	31	25	19	21	35
Margalef index (d)	3.03	4.2	3.06	2.42	2.59	3.74
Shannon diversity index (H')	1.68	2.06	1.62	0.77	0.68	1.78
Pielou's evenness index (J')	0.54	0.6	0.51	0.26	0.22	0.5
Mean monthly biomass (g dry wt m^{-2})	2.75 (0.30)	1.10 (0.66)	2.17 (0.11)	2.59 (0.18)	3.53 (0.31)	2.19 (0.75)
Total biomass (g dry wt m^{-2})	967.26	1261.1	2522.36	1660.82	2175.89	8587.43

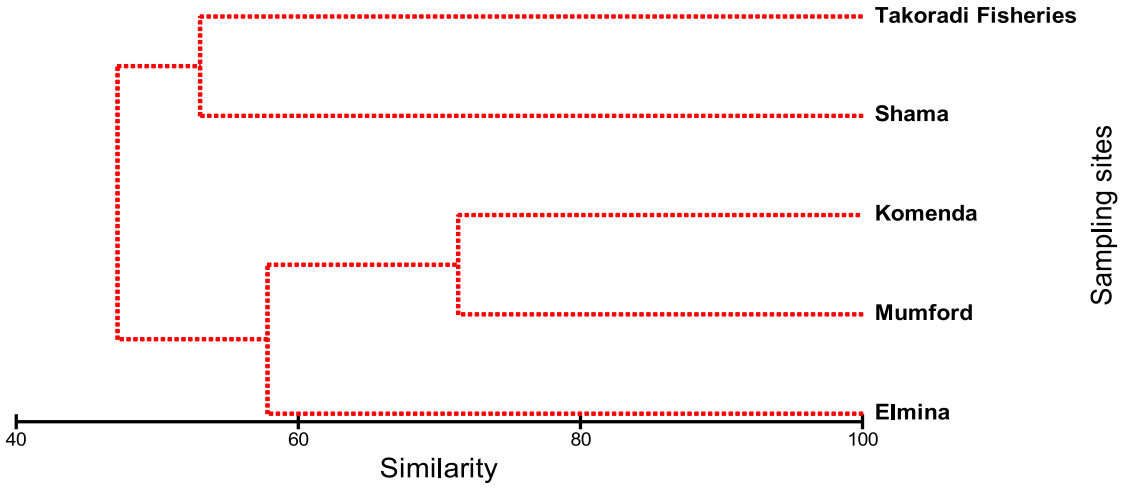

Fig. 3. Cluster analysis of seaweed diversity at the studied sites using the Bray–Curtis similarity measure.

3.2. Abundance of seaweeds across the studied sites

As with the diversity, the abundance (biomass) of seaweeds generally differed ($p<0.05$; Fig. 4) among the studied sites, with Takoradi Fisheries recording the highest mean monthly value of 3.53 g dry wt m^{-2}. Interestingly, Komenda, which had the highest diversity of seaweeds, recorded the least mean monthly biomass of 1.10 g dry wt m^{-2} during the study (Table 1). With respect to the three seaweed divisions, the rhodophytes emerged the most abundant; with a mean monthly biomass of 2.40 g dry wt m^{-2} whereas the chlorophytes were least with a corresponding value of 1.72 g dry wt m^{-2}. Besides the general differences, there were also substantial variations in the abundance of the seaweeds across the studied sites with respect to the three major divisions. Compared to the other divisions, the rhodophytes were disproportionately more abundant (averaging 5.12 g dry wt m^{-2}) at the Takoradi Fisheries site. On the other hand, the chlorophytes (3.72 g dry wt m^{-2}) and the phaeophytes (3.79 g dry wt m^{-2}) were more abundant at Elmina. Shama recorded the least abundance of chlorophytes and phaeophytes. Regionally, the rhodophytes were more abundant in the Western Region whereas the chlorophytes occurred more in the Central Region.

Hydropuntia dentata, Ulva fasciata and *Sargassum vulgare* were the three most dominant species encountered in the study (Table 2), accounting for 44%, 15% and 14%, respectively, of the relative abundance (biomass) of all the species. The distribution of these species differed among the sampled sites. *H. dentata*, for example, dominated the Takoradi Fisheries, Shama and Mumford sites with 82%, 69% and 31% of the relative abundance of species, respectively. On the other hand, *U. fasciata* (34%) and *P. durvillaei* (25%), respectively, dominated Elmina and Komenda sites.

3.3. Temporal variations in seaweed abundance across the studied sites

Results indicated a significant temporal (monthly) variability in the abundance of seaweeds across the studied sites (Fig. 5). With data from all five sites combined, the greatest mean monthly biomass was recorded for August–October (2.41–3.04 g dry wt m^{-2}) whereas December–February (1.67–1.77 g dry wt m^{-2}) had the least. The temporal pattern, however, differed with the division and species of the seaweeds. At the division level, mean monthly biomass of the chlorophytes was greatest between July and October although supplanted by the other groups from December to June. This pattern largely reflected the distribution of the seaweeds at Mumford, where the chlorophytes recorded the greatest mean monthly biomass between June and October, with a peak in August. At Komenda, the chlorophytes were also more dominant in February and August, but were trumped by the phaeophytes during the rest of the year. At Elmina, the phaeophytes recorded the greatest abundance from December to June while the chlorophytes became more dominant between July and October. The rhodophytes recorded the least mean monthly biomass throughout the year at this site. In sharp contrast, mean monthly biomass of the rhodophytes at Shama and Takoradi Fisheries (both in the Western Region) was significantly higher than those of the chlorophytes and the phaeophytes. The red seaweeds were generally more abundant from March–May but reduced somewhat in the later part of the year.

The five predominant seaweeds identified across the studied sites (i.e., *H. dentata, H. musciformis, S. vulgare, P. durvillaei* and *U. fasciata*) exhibited significant temporal variability in their abundance (Fig. 6). *H. dentata*, the most abundant species across all sites, recorded its greatest mean monthly biomass between

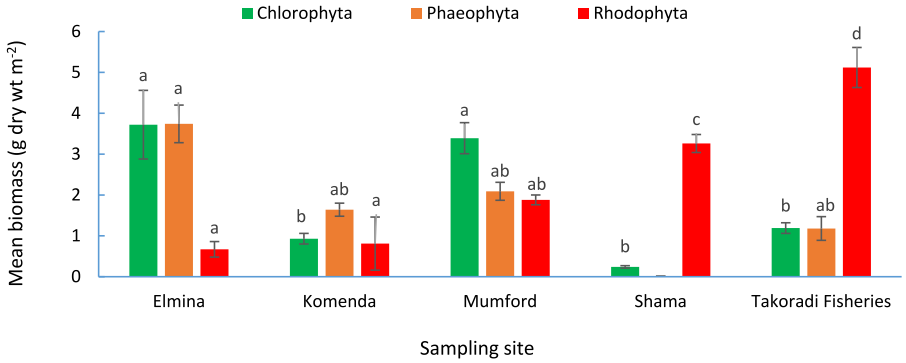

Fig. 4. Mean monthly biomass of seaweeds compared for each division across the five studied sites in coastal Ghana. Means of divisions with different letters are statistically different, $p<0.05$.

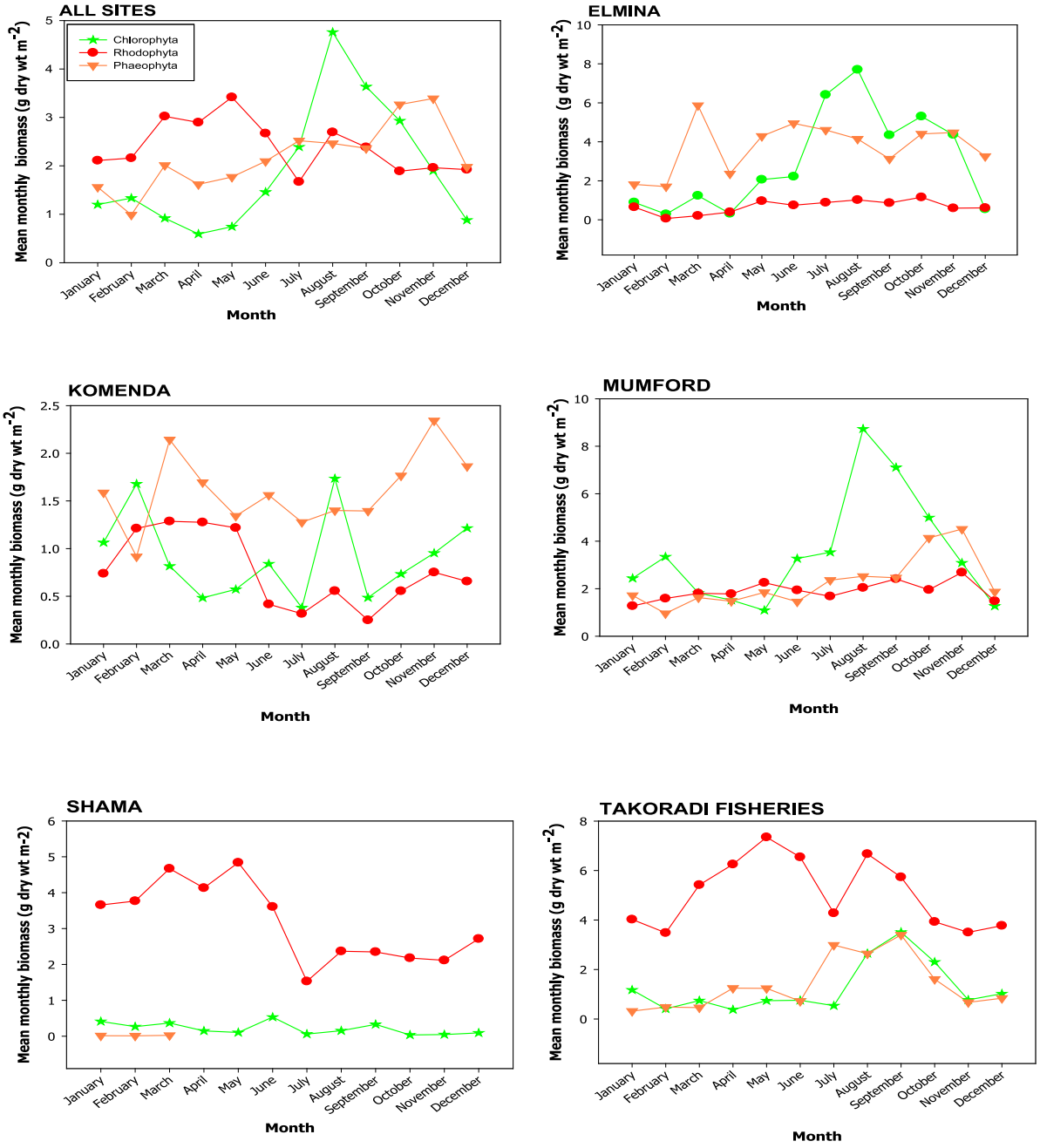

Fig. 5. Variations in monthly biomass of seaweed divisions (2017–2019) at the five studied sites.

Table 2
Variations in the abundance (total biomass from 2017–2019) of seaweeds across five sampled sites in Ghana.

Seaweed species	Biomass of seaweeds (g dry wt m^{-2})					
	Elmina	Komenda	Mumford	Shama	Takoradi Fisheries	Total
Rhodophyta						
Hydropuntia dentata (J.Agardh) Wynne	36.21	22.68	773.51	1143.75	1775.26	3751.41
Hypnea musciformis (Wulfen) Lamouroux	12.78	218.03	231.22	458.15	11.35	931.53
Centroceras clavulatum (C.Agardh) Montagne	3.43	44.67	46.13	0.01	77.85	172.09
Jania rubens (Linnaeus) Lamouroux	0.39	102.14	3.67	–	1.9	108.1
Gelidium corneum sensu Børgesen	1.11	32.68	20.75	0.2	10.42	65.16
Gelidiopsis variabilis (J.Agardh) Schmitz	0.55	8.06	10.28	15.25	0.43	34.57
Bryocladia thyrsigera (J.Agardh) Schmitz	18.75	12.66	0.73	–	–	32.14
Laurencia majuscula (Hervey) Lucas	9.04	0.07	0.77	10.72	0.25	20.85
Galaxaura marginata (Ellis & Solander) Lamouroux	–	16.3	0.09	–	–	16.39
Ceramium mazatlanense (Dawson)	–	3.7	–	–	–	3.7
Grateloupia filicina (Lamouroux) C.Agardh	1.34	–		–	–	1.34
Cryptonemia crenulata (J. Agardh) J.Agardh	–	–	0.51	0.77	–	1.28
Chondracanthus acicularis (Roth) Fredericq	–	0.05	–	0.01	0.03	0.09
Asparagopsis taxiformis (Delile) Trevisan	–	0.01	0.02	–	–	0.03
Griffithsia schousboei Montagne	0.02	–	–	–	–	0.02
Phaeophyta						
Sargassum vulgare C.Agardh	215.26	276.63	756.45	0.01	–	1248.35
Padina durvillaei (Bory)	19.58	314.44	72.58	0.03	0.13	406.76
Bachelotia antillarum (Grunow) Gerloff	279.61	0.54	0.18	–	45.39	325.72
Chnoospora minima (Hering) Papenfuss	11.79	1.37	14.99		0.24	28.39
Dictyota ciliolata Sonder ex Kützing	0.03	10.9	8.97	0.02	0.07	19.99
Padina antillarum (Kützing) Piccone	–	4.04	13.28	–	–	17.32
Dictyopteris delicatula Lamouroux	–	1.69	1.18	0.05	–	2.92
Spatoglossum schroederi C.Agardh	0.01	2.56	0.17	0.02	–	2.76
Colpomenia sinuosa (Roth) Derbès & Solier	–	–	0.33	–	–	0.33
Chlorophyta						
Ulva fasciata Delile	316.44	159.61	563.53	30.67	247.53	1317.78
Chaetomorpha linum (O.F.M̀uller) Ḱutzing	27.89	8.35	–	–	1.25	37.49
Cladophora ruchingerii (C.Agardh) Kützing	12.84	14.3	0.02	0.37	1.41	28.94
Ulva flexuosa (Wulfen ex Roth)		2.25		0.39	1.81	4.45
Cladophora vagabunda (Linnaeus) Hoek	–	0.3	2.09	–	–	2.39
Chaetomorpha antennina (Bory) Kützing	0.1	1.46	–	–	0.27	1.83
Bryopsis pennata (Lamouroux)	0.03	0.01	0.86	0.09	0.03	1.02
Codium guineense P.C. Silva ex G.W. Lawson & D.M. John	0.06	0.86	–	–	0.02	0.94
Phyllodictyon anastomosans (Harvey) Wynne & Kraft	–	0.53	–	0.07	0.17	0.77
Cladophora prolifera (Roth) Kützing	–	0.1	–	0.24	0.08	0.42
Caulerpa taxifolia (Vahl) C.Agardh	–	0.11	0.05	–	–	0.16

March and June with a peak in May (9.65 g dry wt m^{-2}). Conversely, *S. vulgare,* the second most abundant species, peaked between September and December, whilst *U. fasciata*, mirroring the general temporal pattern of the chlorophytes, recorded its highest abundance in August. At Elmina site, the dominance of seaweeds alternated between *U. fasciata* and *S. vulgare*. The former recorded the highest abundance from July to October (5.77–10.99 g dry wt m^{-2}) whereas the latter became more abundant from November to June (2.46–10.62 g dry wt m^{-2}). With the exception of *H. musciformis*, these dominant seaweeds increased marginally in their abundance from March to April, although the highest was recorded in November by *P. durvillaei*. The abundance of seaweed at Mumford, however, generally increased from August to November, with *U. fasciata* being more dominant in August (10.17 g dry wt m^{-2}) and *S. vulgare* in November (12.99 g dry wt m^{-2}). *H. dentata,* by far the most abundant seaweed at both the Shama and Takoradi Fisheries sites, recorded relatively greater mean monthly biomass from March to May and then August to October. The monthly biomass of *H. musciformis* at Shama, however, decreased steadily from December to July, increased slightly in August to 2.58 g dry wt m^{-2}, then decreased to 0.86 g dry wt m^{-2} in October after which it increased again. On the contrary, the mean monthly biomass of the other algal species except *H. dentata* remained very low and largely unchanged for the rest of the months at both the Shama and Takoradi Fisheries sites.

3.4. Seasonal variations in the abundance of dominant species

Besides the temporal variability described above, the dominant species (*U. fasciata, P. durvillaei, S. vulgare, H. musciformis* and *H. dentata*) also exhibited seasonal variations in their abundance (Fig. 7). *H. dentata* and *S. vulgare* showed greater mean total biomass in the wet season than in the dry season. On the other hand, *H. musciformis* and *P. durvillaei* were considerably more abundant ($p < 0.05$) in the dry season than in the wet season. The seasonal patterns of seaweed abundance also varied substantially with the site. The abundance of *H. dentata* at all sites but Elmina and Komenda was higher in the wet season than in the dry season. Similarly, *H. dentata* and *U. fasciata* recorded higher abundance in the wet season at the Takoradi Fisheries. Heavy washing of seaweeds, largely comprising *H. musciformis,* was observed in the wet season at Shama (Fig. 8). This phenomenon apparently resulted in lower abundance of *H. musciformis* at Shama during the wet season compared to the dry season. In contrast, significantly ($p < 0.05$) greater mean biomass of *H. musciformis* was observed in the dry season at Shama and Komenda. *P. durvillaei* also showed considerably greater mean biomass (2.67 g dry wt m^{-2}) in the dry season than in the wet season (1.45 g dry wt m^{-2}) at Komenda.

4. Discussion

4.1. Diversity and distribution of seaweed across the studied sites

The coast of Ghana is considered to be the most luxurious and diverse in terms of seaweed growth in West Africa (Bolton

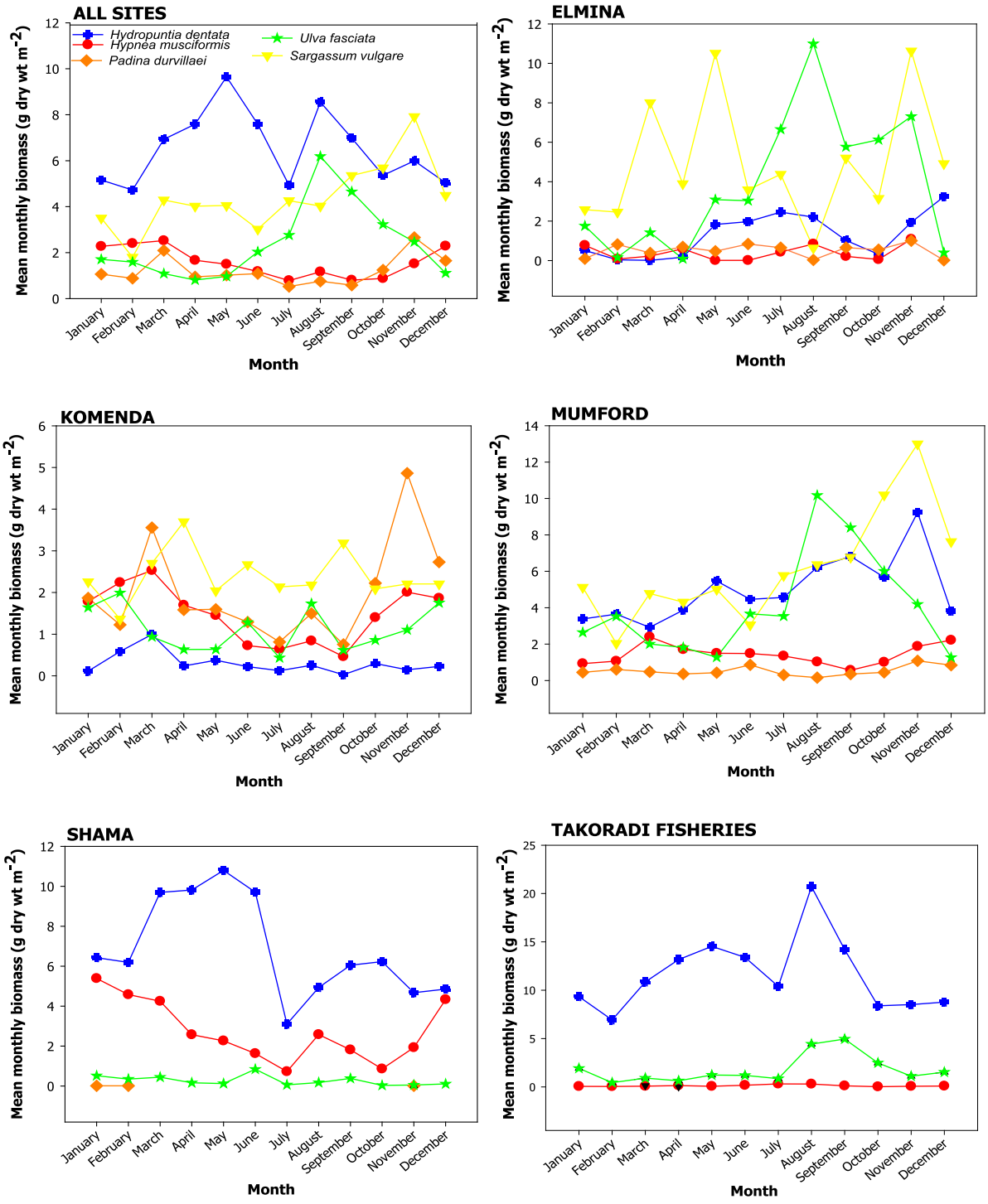

Fig. 6. Variation in monthly biomass of dominant seaweeds (2017–2019) across the studied sites.

et al., 2003). Consistent with this observation, the present study identified 35 seaweed species from only five sites in the Central and Western regions along the Gulf of Guinea, Ghana. These species account for 17.5% of the total number of seaweed species recorded in Ghana (Bolton et al., 2003). Amamoo (2019) reported 41 species at 10 locations and Gbedemah (2017) 36 species of seaweeds in two locations both along the coastal waters of Ghana. The species richness of seaweeds in the current study falls within the established trends reported by previous investigators (Gbedemah, 2017; Amamoo, 2019). However, difference in the species richness of seaweeds observed between the present and previous studies could be attributable to the sampling effort/design; while the previous studies investigated the diversity of seaweeds across three zones (i.e., supra, middle and sub-intertidal zones) and perpendicular to shoreline (Gbedemah, 2017; Amamoo, 2019), the current one focused on the middle intertidal zone and parallel to shoreline with the aim of accessing the same sampling points throughout the study period irrespective of water heights at low tides. The high diversity of rhodophytes (red algae) observed across the sites was expected since they are characteristically diverse and abundant both in the tropical and temperate regions (Lee, 1999; Littler and Littler, 2003). Gbedemah (2017) also found

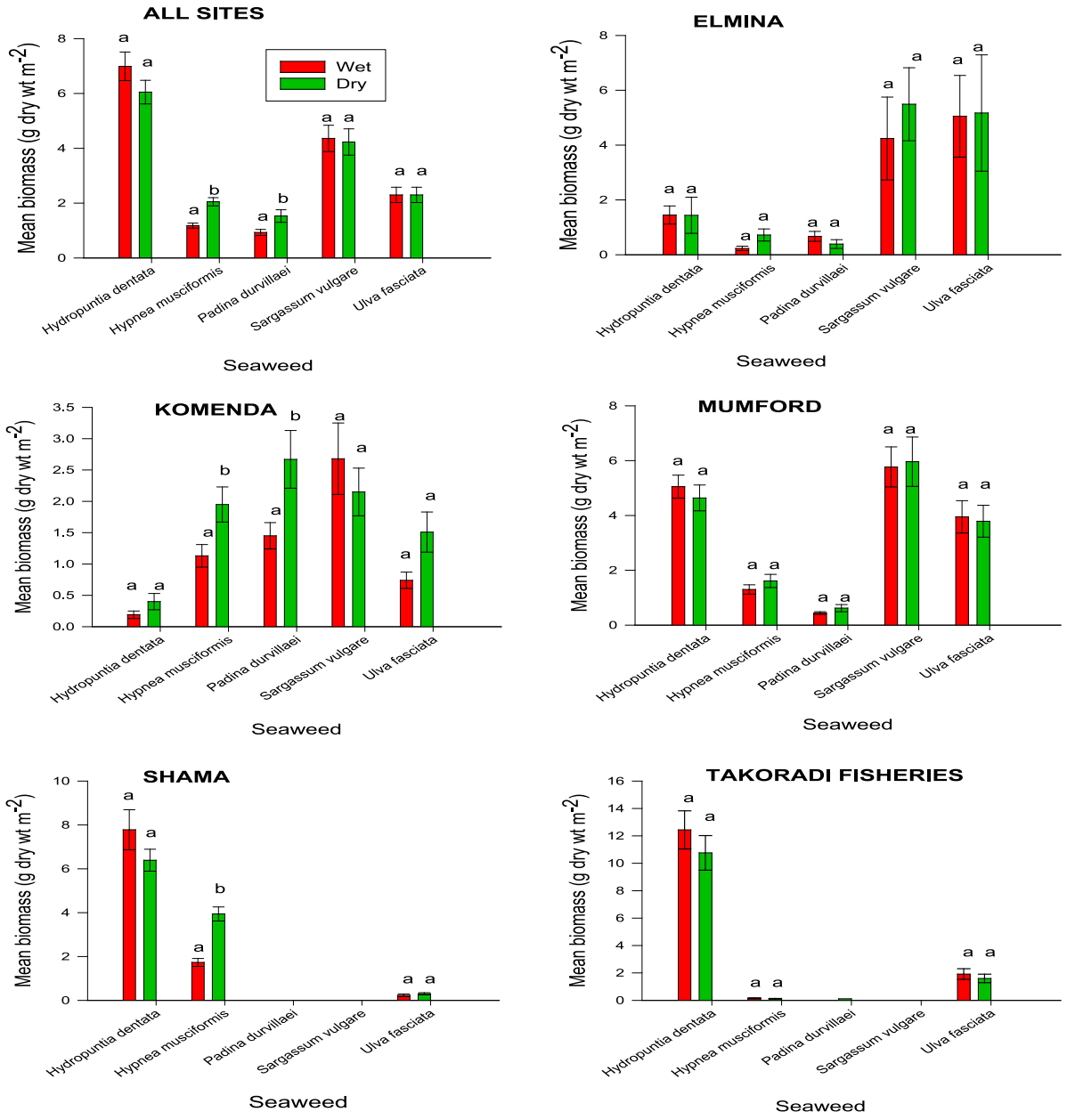

Fig. 7. Seasonal variations in seaweed biomass compared for the five most dominant species across the five studied sites in coastal Ghana. Bars for a species with different letters are statistically different ($p<0.05$).

Fig. 8. Heavy and relatively low washing of seaweeds on the sandy beach of Shama in the wet (A) and dry (B) seasons.

the rhodophytes to have the highest species richness in Ghana. In addition, the rhodophytes have wide ecological amplitude compared to the other two seaweed divisions (Romdoni et al., 2018).

Differences in seaweed diversity and abundance observed across the studied sites are associated with many environmental factors including wave action, substratum and nutrients (Thakur et al., 2008; Kang et al., 2011; Petsut et al., 2012). For example, the high diversity of seaweeds recorded at the rocky shores of Mumford, Komenda and Elmina (all in the Central Region) relative to that of Shama and Takoradi Fisheries (both in the Western Region) might be accounted for by the availability of stable solid rocks for seaweed attachment coupled with the moderately exposed to exposed wave actions at the coastal Central Region (Anim and Nyarko, 2017). The presence of these stable solid rocks could also be the underlying factor for the high degree of similarity in seaweed composition observed at the sites in the Central region relative to those of the Western region. This observation agrees with a study by Qari (2017) indicating high diversity of seaweeds at the Nathia Gali coast of Pakistan associated with the availability of stable intertidal rocks in the coastal waters. Other studies have documented the positive effect of moderately exposed to exposed wave action coasts on seaweed diversity (Prathep, 2005; Norashikin et al., 2013). Thus, the low species richness at Shama (19) could be due in part to the sandy nature of the beach and the paucity of large continuous rocks for seaweed attachment. Norashikin et al. (2013) cited the absence of solid surface (or the presence of soft sandy substratum) for seaweed colonization for the low diversity of seaweeds of coastal waters in a study comprising two contrasting coastal waters in terms of substratum for growth of seaweed. The influx of surface water coupled with turbid and silt-laden inflows from the Pra River might have also contributed to the low diversity of species reported for this site (John and Asare, 1975; Bolton et al., 2003). This assertion is consistent with the observed poor diversity of seaweeds in coastal areas that receive inland fresh water (Yendo, 1914).

4.2. Abundance of seaweeds across studied sties

Besides the presence of stable continuous rocks which serve as substratum for growth, the relatively low occurrence of omnivorous sea urchins (*Echinometra lucunter)* at Mumford compared to the other sites could have influenced the high abundance at this site. Sea urchins, together with grazing fishes, have been reported to feed on the seaweeds and invariably reduce their diversity and abundance in tropical and subtropical waters (John et al., 1977; Ateweberhan et al., 2012). Further, the common practice of open defecation by some community members at Mumford, leading to nutrient enrichment of the surrounding water, might be a contributory factor to the high abundance of seaweeds at the site. On the contrary, the low abundance of seaweeds at Komenda (despite its high species diversity) might have been affected by the grazing activities of the sea urchins and herbivorous fishes. Unlike Mumford, Komenda had numerous sea urchins holes bored in the rocks (Fig. 2C). Gbedemah (2017), in a study on seaweed zonation in the coastal waters of Ghana, attributed the low abundance of *U. fasciata* at Takoradi to the predatory feeding behavior of the sea urchins which are nocturnal feeders (Fig. 2E).

Inundation of sand at the coastal shores is observed to be a seasonal phenomenon that reduces seaweed diversity and abundance (Lawson, 1956; Engledow and Bolton, 1994; Lobban and Harrison, 1994). The occurrence of sand inundation during the last five months of sampling (i.e. November 2018 to April 2019) at the seaweed collection points at Elmina largely accounted for the low total abundance at the site. Moreover, the constructed breakwater systems both in the eastern and western portions of the sampled point could have contributed to the sand gathering at the site.

The five most dominant species (i.e., *U. fasciata, H. dentata, H. musciformis, P. durvillaei* and *S. vulgare)* recorded in this study were present throughout the year. *U. fasciata* occurred at all the five studied sites confirming its ubiquitous characteristics and ability to withstand varied condition (Botany, 2020a; Oliveira et al., 2019). Variability in the abundance of the seaweeds across the sites could be the result of habitat heterogeneity coupled with varied wave actions as alluded to earlier (Blamey and Branch, 2009). The sheltered to moderately exposed wave action experienced at Shama accounted for the high mean abundance of *H. musciformis* compared to the other sites. *H. musciformis* are polymorphic plants and commonly found to grow luxuriously on rocks in moderately wave sheltered coast (Lawson and John, 1987). *H. musciformis* have also been reported to be dominant in calm, silty, sandy flat rocks and sheltered intertidal shores (Botany, 2020b and Novaczek, 2001. This species, however, occurs as small and densely bunched plants in wave-exposed coasts (Lawson and John, 1987) as was the case at Elmina and Komenda. Similarly, *H. dentata* (also known as *Gracilaria dentata*) is noted to occur and develop well in moderately sheltered to moderately exposed wave action coasts (Lawson and John, 1987).

4.3. Temporal and seasonal variability of seaweeds across studied sties

The major upwelling period (July–October) along the coastal waters of Ghana (Anang, 1979) recorded the greatest mean monthly biomass of seaweeds. This period is characterized by low temperature of seawater coupled with high nutrients compared to the minor upwelling seasons (November–June) of high temperature and low nutrient and salinity levels (Anang, 1979). In Pakistan, Qari (2017) found abundant growth of seaweeds in the winter season, a climatic condition similar to the major upwelling period in the coastal waters of Ghana. Findings from the current study corroborate observation by Lawson (1956) that seaweeds have conducive and healthy growth periods between July and October and respond positively to factors such as high relative humidity, decrease in sea and air temperatures as well as maximum covering of seaweeds at low tides in the day. Moreover, Nunoo and Ameka (2005) observed high abundance of seaweeds in beach seine nets at Sakumono in Accra, Ghana, during the peak growing period between July and September.

The chlorophytes exhibited a temporal pattern similar to the general one discussed above, with greatest mean abundance recorded between July and October which could also be attributable to the afore-mentioned favorable growth factors for seaweeds. This pattern was true for majority of the studied sites (Mumford, Elmina and Takoradi Fisheries). This suggests that July–October was the most favorable growth period for the chlorophytes represented largely by *U. fasciata*. Biomass of *U. fasciata* is, however, reported to be low during summer (Qari, 2017) due to dying off of the seaweed. Furthermore, the high biomass of *H. musciformis* recorded from December to March coincides with period of minor upwelling along the Ghanaian coastal water (John et al., 1977). These months, according to Lieberman et al. (1979), are suitable for the growth of subtidal seaweeds due to the occurrence of low wave actions and decreased seawater turbidity. In a related study using percentage cover as a measure of abundance, Gbedemah (2017) reported high abundance of *H. musciformis* in March compared to November at Prampram in Accra, Ghana. The findings also agree with that of Rao (1970) and Mtolera and Buriyo (2004), who reported high biomass of *H. musciformis* in the dry season from November to February in India and Tanzania respectively.

Generally, there was minimal seasonal variation in the seaweed abundance across the studied sites although greater mean biomass was recorded in the wet season than the dry season. The present study confirms the findings of John et al. (1977) indicating a decrease in algal abundance along the coast of Ghana during the dry season. The slight reduction in abundance during the dry season is attributable to the increase in algal desiccation. In contrast, significantly high abundance of *H. musciformis* observed at Shama during the dry season could be explained by relatively massive drifting of this species on the shores through cobble agitation in the wet season. This phenomenon invariably decreases seaweed abundance along the shores during wet season (John et al., 1977). In addition, low levels of silt and turbidity of water experienced during the dry season compared to the wet season could contribute to the high abundance in the dry season. Lower levels of sea water turbidity coupled with reduced turbulence and cloud cover as noted during dry season is reported to promote seaweed growth and development (John et al., 1977). *H. musciformis* is considered to be an economically important seaweed species due to high biomass production and presence of κ-carrageenan in the cell walls (Craigie, 1990; Arman and Qader, 2012) and also are used in the pharmaceutical, cosmetic, chemical and food industries. The present results show that Shama would be the most suitable location for large-scale cultivation of *H. musciformis* due to the presence of favorable conditions that support high growth of this species. The high biomass of brown seaweeds during the dry season corroborate with findings of Rani et al. (2015) who reported high biomass of these species in the dry season at the intertidal area of Gulf of Mannar, India.

4.4. Conclusion

The study has demonstrated substantial spatial and temporal variations in the diversity and abundance of seaweed across the five studied sites, with those in the Central Region recording the highest species diversity. Findings from the current study reveals Komenda as the most stable seaweed community although the species were more abundant at Mumford. Peak periods for seaweeds growth generally occurred between August and October, even though *H. musciformis* and *U. fasciata* recorded greater abundance from December to March, and July to October, respectively. Luxurious growth of *H. musciformis, P. durvillaei, U. fasciata* and *H. dentata* were found in Shama, Komenda, Mumford and Takoradi Fisheries, respectively. Information from this study is useful as it identifies suitable locations for seaweed collection and cultivation as well as conducive periods for harvesting different seaweeds at the various study sites. These findings also provide important baseline information for further exploitation, particularly in the cultivation of seaweeds along the Ghanaian coastal waters as alternate source of livelihood for the local communities.

CRediT authorship contribution statement

M.O. Akrong: Designed the work, Collected the data, Analyzed the data, Writing of the paper. **A.K. Anning:** Designed the work, Analyzed the data, Writing of the paper. **G.N.D. Addico:** Designed the work, Collected the data, Analyzed the data, Writing of the paper. **K.A.A. deGraft-Johnson:** Designed the work, Collected the data, Writing of the paper. **A. Adu-Gyamfi:** Collected the data, Writing of the paper. **M. Ale:** Writing of the paper. **A.S. Meyer:** Designed the work, Writing of the paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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All the authors approved this submission of the revised version of the manuscript.

References

Amamoo, P.A., 2019. Distribution of Macroalgae in the Intertidal Zone of Ghana (Master of Philosophy thesis). University of Ghana, http://ugspace.ug.edu.gh/h{and}le/123456789/33355.

Anang, E.R., 1979. The seasonal cycle of the phytoplankton in the coastal waters of Ghana. Hydrobiologia 62 (1), 33–45. http://dx.doi.org/10.1007/bf00012560.

Anderson, R.J., Bolton, J.J., Smit, A.J., Neto, D.D.S., 2012. The seaweeds of Angola: the transition between tropical and temperate marine floras on the west coast of southern Africa. African. J. Mar. Sci. 34 (1), 1–13. http://dx.doi.org/10.2989/1814232X.2012.673267.

Anim, M., Nyarko, B.K., 2017. Lithological responses to sea erosion along selected coastlines between Komenda and Saltpond, Ghana. Ghana J. Geogr. 9 (1), 109–126.

Arman, M., Qader, S.A., 2012. Structural analysis of kappa-carrageenan isolated from *Hypnea musciformis* (red algae) and evaluation as an elicitor of plant defense mechanism. Carbohydr. Res. 88, 1264–1271.

Ateweberhan, M., Gough, C., Fennelly, L., Frejaville, Y., 2012. Nearshore Rocky Reefs of Western Ghana, West Africa: Baseline Ecological Research Surveys. Blue Ventures Conservation, London, United Kingdom, p. 104.

Blamey, L.K., Branch, G.M., 2009. Habitat diversity relative to wave action on rocky shores: implications for the selection of marine protected areas. Aquat. Conserv. Mar. Freshwater Ecosyst. 19 (6), 645–657. http://dx.doi.org/10.1002/aqc.1014.

Bolton, J.J., De Clerck, O., John, D.M., 2003. Seaweed diversity patterns in sub-Saharan Africa.

Botany, 2020a. University of Hawaii at Manoa 2001a. http://www.hawaii.edu/reefalgae/invasive_algae/chloro/ulva_fasciata.htm. (Accessed June 2020).

Botany, 2020b. University of Hawaii at Manoa 2001b. http://www.hawaii.edu/reefalgae/invasive_algae/rhodo/hypnea_musciformis.htm. (Accessed June 2020).

Council, M.S., 2009. Harvest guidelines for Maine seaweeds. Brunswick, Maine. Available: (March 2010).

Craigie, J., 1990. Cell walls. In: Cole, K., Sheath, R. (Eds.), Biology of the Red Algae. Cambridge Univ. Press, Cambridge, pp. 221–257.

Dadolahi-Sohrab, A., Garavand-Karimi, M., Riahi, H., Pashazanoosi, H., 2012. Seasonal variations in biomass and species composition of seaweeds along the northern coasts of Persian Gulf (Bushehr Province). J. Earth Syst. Sci. 121 (1), 241–250. http://dx.doi.org/10.1007/s12040-012-0141-6.

De San, M., 2012. The Farming of Seaweeds. Implementation of a Regional Fisheries Strategy for the Eastern - Southern Africa and India Ocean Region. Report: SF/2012/28.

Delaney, A., Frangoudes, K., Ii, S.A., 2016. Society and seaweed: understanding the past and present. In: Seaweed in Health and Disease Prevention. Academic Press.

Dhargalkar, V.K., Kavlekar, D., 2004. Seaweeds-a field manual. http://drs.nio.org/drs/h{and}le/2264/96.

Duodu, J.A. (Ed.), 2009. Geological Map of Ghana 1: 1 000 000. Geological Survey Department.

Echem, R.T., Metillo, E.B., 2011. Spatial and temporal patterns of the macrobenthic algae community structure in selected intertidal zones of Iligan Bay, Northern Mindanao, Philippines. Philipp. Sci. 48.

El Shoubaky, G.A., 2013. Comparison of the impacts of climate change and anthropogenic disturbances on the El Arish coast and seaweed vegetation after ten years in 2010, North Sinai, Egypt. Oceanologia 55 (3), 663–685. http://dx.doi.org/10.5697/oc.55-3.663.

Engledow, H.R., Bolton, J.J., 1994. Seaweed α-diversity within the lower eulittoral zone in Namibia: the effects of wave action, sand inundation, mussels and limpets. Bot. Mar. 37 (3), 267–276. http://dx.doi.org/10.1515/botm.1994.37.3.267.

FAO, 2013. Year book fishery. In: Year Book Fishery Statistics, Vol. 96. Food and Agriculture Organization, Rome Italy (ISSN: 0429-9345).

FAO, 2018. The state of world fisheries and aquaculture 2018 - Meeting the sustainable development goals.
Gallon, R.K., Ysnel, F., Feunteun, E., 2013. Optimization of an in situ subtidal rocky-shore sampling strategy for monitoring purposes. Mar. Pollut. Bull. 74 (1), 253–263. http://dx.doi.org/10.1016/j.marpolbul.2013.06.049.
Gbedemah, S.T., 2017. Current patterns in intertidal macro-algal diversity and zonation of two sites on Ghana's coast. J. Oceanogr. Mar. Res. 5 (2), http://dx.doi.org/10.4172/2572-3103.1000159.
Guiry, M., 2009. Seaweed Site, Seaweed Web Site. National University of Ireland, Galway, URL.: http://www.seaweed.ie/algae/seaweeds.html.
Issaka, R.N., Buri, M.M., Tobita, S., Nakamura, S., Owusu-Adjei, E., 2012. Indigenous fertilizing materials to enhance soil productivity in Ghana. In: Whalen, K.J. (Ed.), Soil Fertility Improvement and Integrated Nutrient Management—A Global Perspective. pp. 119–134. http://dx.doi.org/10.5772/27601.
John, D.M., Asare, S.O., 1975. A preliminary study of the variations in yield and properties of phycocolloids from Ghanaian seaweeds. Mar. Biol. 30 (4), 325–330. http://dx.doi.org/10.1007/BF00390637.
John, D.W., Lawson, G.W., Ameka, G., 2001. Seaweeds of the West African Sub-Region: Identification Manual. Publication for 'Marine Biodiversity Capacity-Building in the West African Sub-Region' Programme, Darwin Initiative for the Survival of Species. The Natural Museum, London, p. 213.
John, D.M., Lieberman, D., Lieberman, M., 1977. A quantitative study of the structure and dynamics of benthic subtidal algal vegetation in Ghana (tropical West Africa). J. Ecol. 497–521. http://dx.doi.org/10.2307/2259497.
Kang, J.C., Choi, H.G., Kim, M.S., 2011. Macroalgal species composition and seasonal variation in biomass on Udo, Jeju Island, Korea. Algae 26 (4), 333–342. http://dx.doi.org/10.4490/algae.2011.26.4.333.
Kılınç, B., Cirik, S., Turan, G., Tekogul, H., Koru, E., 2013. Seaweeds for food and industrial applications. In: Food Industry. IntechOpen, http://dx.doi.org/10.5772/53172.
Kokabi, M., Yousefzadi, M., Razaghi, M., Feghhi, M.A., 2016. Zonation patterns, composition and diversity of macroalgal communities in the eastern coasts of Qeshm Island, Persian Gulf, Iran. Mar. Biodiversity Records 9 (1), 96. http://dx.doi.org/10.1186/s41200-016-0096-4.
Lawson, G.W., 1956. Rocky shore zonation on the gold coast. J. Ecol. 44 (1), 153–170, Published by: British Ecological Society Stable URL: http://www.jstor.org/stable/2257159.
Lawson, G.W., John, D.W., 1987. The Marine Algae and Coastal Environment of Tropical West Africa, second ed. In: Beihefte zur Nova Hedwigia, vol. 93, pp. 1–415.
Lee, R.E., 1999. Phycology, third ed. Cambridge University Press, Cambridge, p. 614.
Lieberman, M., John, D.M., Lieberman, D., 1979. Ecology of subtidal algae on seasonally devastated cobble substrates off Ghana. Ecology 60 (6), 1151–1161. http://dx.doi.org/10.2307/1936963.
Littler, D.S., Littler, M.M., 2003. South Pacific Reef Plants. Off- shore Graphics, Inc., Washington, D.C, p. 331.
Lobban, C., Harrison, 1994. Seaweed Ecology and Physiology. Cambridge University Press.
Mahu, E., 2014. Geochemistry of Estuarine Sediments of Ghana: Provenance, Trace Metal Accumulation Trends and Ecotoxicological Risks (Doctoral dissertation). University of Ghana, http://ugspace.ug.edu.gh/h{and}le/123456789/22747.
Mtolera, M.S., Buriyo, A.S., 2004. Studies on Tanzanian Hypneaceae: Seasonal variation in content and quality of Kappa-carrageenan from *Hypnea musciformis* (Gigartinales: Rhodophyta). Western Indian Ocean J. Mar. Sci. 3 (1), 43–49.
Norashikin, A., Harah, Z.M., Sidik, B.J., 2013. Intertidal seaweeds and their multi-life forms. J. Fish. Aquat. Sci. 8 (3), 452. http://dx.doi.org/10.3923/jfas.2013.452.461.
Novaczek, I., 2001. A Guide to the Common Edible and Medicinal Sea Plants of the Pacific IslandS, Vol. 3. University of the South Pacific, Fiji Islands, p. 40.
Nunoo, F.K.E., Ameka, G.K., 2005. Occurrence of macro-algae in the by-catch of beach seine fisheries at Sakumono, Ghana. West Afr. J. Appl. Ecol. 8 (1), http://dx.doi.org/10.4314/wajae.v8i1.45787.
Oliveira, V.P., Ignacio, B.L., Martins, N.T., Dobler, L., Enrich-Prast, A., 2019. The Ulva spp. Conundrum: What does the ecophysiology of southern atlantic specimens tell us? J. Mar. Biol. http://dx.doi.org/10.1155/2019/5653464.
Pellizzari, F., Silva, M.C., Silva, E.M., Medeiros, A., Oliveira, M.C., Yokoya, N.S., Colepicolo, 2017. Diversity and spatial distribution of seaweeds in the South Shetland Islands, Antarctica: an updated database for environmental monitoring under climate change scenarios. Polar Biol. 40 (8), 1671–1685. http://dx.doi.org/10.1007/s00300-017-2092-5.
Petsut, N., Chirapart, A., Keawnern, M., 2012. A stability assessment on seasonal variation of seaweed beds in the Trat peninsula of Thailand. Biodiversity J. 3 (3), 229–236 (ISSN: 20390408).
Phang, S.M., Lim, P.E., Ooi, J.L.S., Yeong, H.Y., Ng, W.S., Küpper, F.C., 2008. Marine algae of Perak Island, Jarak Island and the Sembilan group of islands in the Straits of Malacca.
Prathep, A., 2005. Spatial and temporal variations in diversity and percentage cover of macroalgae at Sirinart Marine National Park, Phuket Province, Thailand. Sci. Asia 31, 225–233. http://dx.doi.org/10.2306/scienceasia1513-1874.2005.31.225.
Qari, R., 2017. An assessment of seaweeds diversity and distribution at the beach of Nathia Gali, Karachi. Pak. J. Mar. Sci. Res. Dev. 7, 228. http://dx.doi.org/10.4172/2155-9910.1000228, 9.
Rani, V., Jawahar, P., Jeya Shakila, R., 2015. Seasonal variation in biomass and distribution of brown seaweeds (Phaeophyceae) in Gulf of Mannar, Tamilnadu, India. Bioscan 10, 1123–1129.
Rao, K.R., 1970. Studies on growth cycle and phycocolloid content in *Hypnea musciformis* (WULF) LAMOUR. 1. Bot. Mar. 13 (2), 163–165.
Romdoni, T.A., Ristiani, A., Meinita, M.D.N., Marhaeni, B., 2018. Seaweed species composition, abundance and diversity in Drini and Kondang Merak Beach, Java. In: E3S Web of Conferences, Vol. 47. EDP Sciences, 03006.
Serfor-Armah, Y., Nyarko, B., Carboo, D., Osae, E., Anim-Sampong, S., Akaho, E., 2000. Instrumental neutron activation analysis of iodine levels in fourteen seaweed species from the coastal belt of Ghana. J. Radioanal. Nucl. Chem. 245 (2), 443–446. http://dx.doi.org/10.1023/a:1006768001441.
Serfor-Armah, Y., Nyarko, B., Osae, E., Carboo, D., Seku, F., 1999. Elemental analysis of some green and brown seaweeds from the coastal belt of Ghana. J. Radioanal. Nucl. Chem. 242 (1), 193–197. http://dx.doi.org/10.1007/BF02345918.
Smith, D., 2013. Ecology of the New Zealand Rocky Shore Community. New Zealand Marine Studies Centre, University of Otago, Otago, p. 61. http://dx.doi.org/10.1016/j.aquabot.2012.12.004.
Sunny, A.R., 2017. A review on effect of global climate change on seaweed and seagrass. Int. J. Fish. Aquat. Stud. 5 (6), 19–22, Corpus ID: 58904170.
Thakur, M.C., Reddy, C.R.K., Jha, B., 2008. Seasonal variation in biomass and species composition of seaweeds stranded along port Okha, northwest coast of India. J. Earth Syst. Sci. 117 (3), 211–218. http://dx.doi.org/10.1007/s12040-008-0025-y.
Werner, F.J., Graiff, A., Matthiessen, B., 2016. Temperature effects on seaweed-sustaining top-down control vary with season. Oecologia 180 (3), 889–901. http://dx.doi.org/10.1007/s00442-015-3489-x.
Wong, C.L., Phang, S.M., 2004. Biomass production of two Sargassum species at Cape Rachado, Malaysia. In: Asian Pacific Phycology in the 21st Century: Prospects and Challenges. Springer, Dordrecht, pp. 79–88. http://dx.doi.org/10.1023/B:HYDR.0000020312.86640.9f.
Yendo, K., 1914. On the Cultivation of Seaweeds: With Special Accounts of their Ecology. Royal Dublin Society.