Benthic microalgae on a sheltered intertidal mudflat in Kuwait Bay of the Northern Arabian Gulf

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Abstract

The sheltered intertidal mudflats of Kuwait Bay have scanty macrophytes but are rich in microflora. The dominant epipsammic organisms of the microbial mats are cyanobacteria. Dominant cyanobacterial forms include Microcoleus chthonoplastes, Oscillatoria nigro-viridis, and Lyngbya aestuarii. Algal biomass (measured as chlorophyll a concentrations) varied at the three study sites (A, S and K) reflecting their relative shelteredness. The mean annual chlorophyll a concentrations at sites A and S were 57 mg chl a m\(^{-2}\) and 315 mg chl a m\(^{-2}\) respectively. The most sheltered site K had a mean annual chlorophyll a concentration of 815 mg chl a m\(^{-2}\). Seasonal variation in the total epipsammic mat biomass contribution to the bay from the three sites was not observed reflecting its perennial nature in the sheltered Sulaibikhat Bay of Kuwait Bay.

Keywords: Cyanobacteria, microflora, epipsammic, biomass, intertidal mudflats, Kuwait Bay

Introduction

Intertidal zones are subjected to naturally occurring fluctuations in water movement owing to tidal and wind induced currents and waves. These have led to the formation of unique shore assemblages of flora and fauna as resultants of horizontal gradient of shore exposure. In the dynamically sheltered Kuwait Bay, microbial mats thrive on broad expanses of mudflats (Jones, 1986 a, b; Clayton, 1986) where water movement does not scour surfaces too harshly.

Microbial mats or the lab-lab, formed of epipsammic (attached) and epipelic (motile) microalgal associations are highly productive ecosystems and their importance as a source of primary productivity have received great attention in temperate areas (Sundbäck and Jönsson, 1988; de Jonge and Colijn, 1994; MacIntyre et al., 1996; De Sousa et al., 1998). Their role in food webs as source of fixed carbon for many macrofauna has been studied (Herman et al., 1999; Al-Mohanna et al., 2004; Al-Zaidan et al., 2006). However, in comparison to epipelic microalgal associations, epipsammic associations have received very little attention, particularly for the northern Arabian Gulf region. This paper reports the composition, biomass and spatial distribution pattern of epipsammic benthic microalgae on a highly sheltered intertidal mudflat region in Kuwait Bay.

Materials and methods

Study site: Kuwait Bay is a semi-estuarine area located along the northern province of the Kuwaiti coast (Figs.1 & 2). It extends 48 km inland from the Arabian Gulf, and is 40 km long and 25 km wide at the mouth. Its bottom topography is generally flat and featureless. It has shallow depths not exceeding 8 m at its entrance (Khalaf, 1988). Surrounding the bay are intertidal mudflats, up to 4 km wide at low tide. Tidal currents form the major source of water circulation in the bay, and a weak counterclockwise circulation appears to prevail over most of the year (Figs. 3 & 4). The speed of the currents is highest at the entrance of the bay and decreases progressively towards its western portion, where it is usually < 40 cms\(^{-1}\). Sulaibikhat Bay (approximately 70 km\(^{2}\)) forms a highly sheltered tidal embayment that lies in the southwestern corner of Kuwait Bay (Figs. 1 & 3). For the present study, three sites (A, K and S) were selected at the intertidal mudflat of Sulaibikhat Bay (Fig. 2). Site ‘A’ located north of Sulaibikhat Bay, is part of a pristine salt marsh tidal flat of Ashish Al-Doha area. This site faces eastward and hence receives direct solar radiation from dawn to dusk. This shore is subjected to frequent strong NE wind. On the other hand, site ‘K’ is located south of Sulaibikhat Bay, adjacent to Shuwaikh Port. This site has been subjected to infill at the landward edge, has few man-made mangrove plants and characterized by the presence of perpendicular seaward barriers constructed for commercial use. This site fails to receive direct solar radiation until the sun is well up in the horizon (35-40°) due to its facing westward and surrounded from the east by anthropogenic alterations that include tall trees and
buildings. Moreover, this shore is characterized by a mild prevailing wind. Site ‘S’ located opposite Sulaibikhat residential area, between site ‘A’ and site ‘K’, has also been subjected to extensive infill at the landward edge. As microbial mats are centered on the upper shore, the horizontal region from mean highest high water down to 150m toward low waterline was marked as the survey boundary at each site.

Sample collection and preparation: Sediment samples were collected using a hand-held 5 cm diameter corer inserted to a depth of 10 cm. Five random samples were collected from each site every month during March 2002 to February 2003. Samples were stored on ice and kept in the dark until return to the laboratory, where they were frozen for later analysis. The top 3 mm of the collected sediment cores were carefully separated and repeatedly swirled with filtered seawater to remove the non-epipsammic micro-flora. The epipsammic micro-flora, being heavy, readily settled down, while the non-attached epipelagic benthic and planktonic algae and detrital material remained in suspension, and was decanted off. Sub-samples of epipsammic microflora were prepared for pigment analysis, ash free dry weight determination and microscopy. The remaining sediment from each core was air-dried, and 25 g of it was mixed with 250 ml of tap water containing 10 ml aqueous sodium hexametaphosphate (6.25 g/litre). This mixture was allowed to soak overnight. After breaking the soaked sediment with a glass rod, a 63-µm sieve was used to separate the sand fraction (particle > 63 µm) and mud fraction (particle = 63 µm). The sieve containing the sand fraction was dried in an oven at 100°C and cooled in a desiccator. The dried sand was weighed on a digital balance (Scientech SL 5200D) to the nearest 0.01g. The percentage of sand and mud was calculated for sediment analysis.
Temperature at mud surface was recorded using a digital thermocouple thermometer (Cole-Parmer Instrument Co., Chicago). A mercury thermometer with an accuracy of ±0.5°C was used to measure the temperature of air and water in tide pools. Salinity and pH of water in tide pools were measured using a hand-held refractometer and digital pH meter (KAHLSICO, California) respectively. The above physical and chemical parameters were recorded monthly during the sampling period.

Absorption spectrophotometry (Lorenzen, 1967) was employed for pigment analysis, using the digital single cell mode UV/VIS spectrophotometer (BECKMAN DU® 520). Total organic (AFDW) content of the sediment was determined after oven drying at 80°C to constant weight, followed by the loss on ignition at 500°C for 5 h in a muffle furnace (Gallenkamp Co.). Taxonomical determination of the dominant mat components was carried out to lowest possible taxon, using Jones (1986a) and Al-Hasan and Jones (1989). An Olympus IX50 Inverted Microscope and a Nikon Microphot-FXA Microscope were used for this exercise. Sediment type at the three sites was determined, based on mud/sand ratio (Flemming, 2000).

Results

Physical and chemical parameters: From the profiles of environmental parameters, it is evident that temperatures (air, sediment surface and water pool) were always higher at site A than at the other two sites (Table 1). Salinity of tidal pool water was highest at site A and lowest at site K.

Sediment type: In sites A and K, the dominant sediment constituent was sand (64% and 74% respectively). Mud was the dominant fraction in site S (65%). As per mud/sand ratio, the sediment in sites A and K were classified as 'muddy sand', while that in site S as 'sandy mud' (Table 2).

Mat components: The epipsammic mat associations were found to occur as dark green-blue layer at the fringe of the eulittoral zone (Figs. 5 - 7). Filamentous cyanobacteria formed the dominant components at the three sites (Fig. 7). Few diatoms remained attached. 80-90% of the mat at the three sites were composed of Microcoleus chthonoplastes, Oscillatoria nigro-viridis, and Lyngbya aestuarii (Figs. 8-11). M. chthonoplastes dominated on the top areas of the littoral zone where the substrate was well drained at low tide and last covered by water during high tide (Fig. 8), while O. nigro-viridis and L. aestuarii prevailed in the lower adjacent moist areas of littoral zone (Figs. 9 & 10). The less dominant Spirulina major (Fig. 11) was occasionally found at site K. Faecal pellets were frequently encountered on top of the microbial mat, reflecting that the mat were heavily grazed upon (Fig. 12).

Pigment analysis: Mean annual biomass of mat (as measured by chlorophyll a) at site K differed significantly from sites A and S (ANOVA, F=25.54, P<0.001). The mean annual concentration of chlorophyll a at site A and S were 57 mg chl a m⁻² and 315 mg chl a m⁻² respectively, whereas mean annual value of mat biomass at site K was much higher (815 mg Chl a m⁻²) in comparison to the other two sites.

The mudflats of Sulaibikhat Bay were rich in mat biomass throughout the year. There was no significant seasonal variation in total biomass of the three sites (ANOVA, F=1.26, P>0.05). However, site K which made highest contribution to the total biomass (815 mg Chl a m⁻²), showed a significant seasonal variation (ANOVA, F=3.87, P<0.003). This site experienced an early summer bloom after which the standing stock of chlorophyll a decreased and remained low until November (Fig. 13). The standard errors are found to increase with increasing chlorophyll a concentration at site K (Fig. 13). A significant correlation existed between AFDW and chlorophyll a concentrations in the surface sediment (r²=0.636, P<0.01). Figure 14 shows the scatter plot of

<table>
<thead>
<tr>
<th>Sites</th>
<th>Air Temp. (°C)</th>
<th>Mud surface Temp. (°C)</th>
<th>Tide pool Temp. (°C)</th>
<th>Tide pool Salinity (ppt)</th>
<th>Tide pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>19.0-42.6</td>
<td>16.9-37.7</td>
<td>17.3-36.8</td>
<td>53.43-75.83</td>
<td>7.00-8.87</td>
</tr>
<tr>
<td>S</td>
<td>17.0-36.7</td>
<td>14.4-31.1</td>
<td>13.4-31.1</td>
<td>47.67-68.00</td>
<td>7.00-8.68</td>
</tr>
<tr>
<td>K</td>
<td>17.0-36.0</td>
<td>16.2-31.9</td>
<td>14.8-31.0</td>
<td>41.33-51.67</td>
<td>7.02-9.53</td>
</tr>
</tbody>
</table>

Table 1. Range of physical and chemical parameters during the period 2002-2003

Table 2. Sediment texture fraction at sites A, S and K

<table>
<thead>
<tr>
<th>Sites</th>
<th>Sand</th>
<th>Mud</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>64%</td>
<td>35%</td>
</tr>
<tr>
<td>S</td>
<td>35%</td>
<td>65%</td>
</tr>
<tr>
<td>K</td>
<td>74%</td>
<td>26%</td>
</tr>
</tbody>
</table>

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Figs. (5) Extensive (cyanobacterial) mat - *Microcoleus chthonoplastes* (arrow), *Oscillatoria nigro-viridis* mat (arrowhead), aggregates of benthic diatoms on *Oscillatoria* (block arrow); (6) Intact sheet of *Oscillatoria* (arrow); (7) The mat formed of cyanobacterial filaments (arrow); (8) Single trichome of *Microcoleus chthonoplastes* surrounded by thick mucilage layer (arrows); (9) Several filaments of *Oscillatoria*; (10) *Lyngbya aestuarii* filaments; (11) Several filaments of *Spirulina major*; (12) Faecal pellets (arrows) on top of the algal mat.
these two variables. Spearman rank correlation coefficients ($r^2$) between concentrations of chlorophyll $a$ and a range of physico-chemical parameters at the three sites indicated that there was no significant correlation between chlorophyll $a$ and mud surface temperature, salinity and $pH$ (tide pool) at site A and S (Table 3). However, significant correlations were found at site K: (i) mud surface temperature ($r^2=-0.713$, $P<0.01$) and (ii) salinity

Table 3. Spearman rank correlation coefficient between concentration of Chlorophyll $a$ and environmental parameters at sites A, S and K

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Site A</th>
<th>Site S</th>
<th>Site K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mud-surface Temp.</td>
<td>0.448</td>
<td>-0.308</td>
<td>-0.713 *</td>
</tr>
<tr>
<td>Tide pool salinity</td>
<td>-0.547</td>
<td>-0.224</td>
<td>0.768 *</td>
</tr>
<tr>
<td>Tide pool $pH$</td>
<td>-0.098</td>
<td>-0.224</td>
<td>-0.084 ns</td>
</tr>
</tbody>
</table>

ns = not statistically significant. * = $P<0.01$

($r^2=-0.768$, $P<0.01$). No significant correlation was found between $pH$ and chlorophyll $a$ even at this site.

Discussion

Mean annual microalgae (cyanobacteria) biomass was highest at site K (Fig. 13), reflecting the relatively more sheltered nature of this area of Sulaibikhat Bay. This site of mudflat is highly wave-protected when compared to the other sites. This is due to the construction of perpendicular seaward barriers (jetties or groins) for commercial use. Such a shore alteration along site K has interfered with the natural processes, affecting the general water circulation, diminishing the velocity of water (wave fetch), limiting the rip currents and interfering with the long shore drift during rise of tide. The increase in the degree of shore exposure from sites K to A through S is reflected in the biomass recorded at these sites. Wave-generated turbulence and shear stress may cause resuspension of surface sediments and their associated microphytobenthos and, consequently, lower the microalgae biomass (de Jonge and van Beusekom, 1995). During the present investigations, it was realized that increasing exposure carries an increased risk of dislodgement and physical damage, limiting the range and abundance of microbial mat at the three sites of Sulaibikhat Bay. Indeed, site A is a pristine shore that is much exposed to prevailing NE winds, relatively fast longshore currents and long-shore drifts.

Epipsammic mat associations usually occur as a band of microbial bio-film along the fringe of the eulittoral zone of mudflats (Figs. 5 & 6). The sediment (in top of littoral zone) is coarse and less moist, while the adjacent lower regions are characterized by a mixture of mud and sand. Krumbein et al. (1994) reported that cyanobacteria prefer
coarse sediments for colonization. During the present study, it was observed that the filamentous cyanobacteria formed intertwined network of mat, binding the sand particles (Fig. 7), while diatoms prefer the finer grain size with lesser interstitial space to avoid hampering their migration. This agreed with the findings of Watermann et al. (1999) who stated that cyanobacteria favour coarser sediments while diatoms dominate on mud with small grains. In this study _M. chthonoplastes_ is found to dominate the uppermost sandy region of the intertidal zone that is characterized by relatively large sand grains and covered by water during high tide. The filaments of this cyanobacterium are enveloped by thick mucilage layer (Fig. 8) that helps to protect its trichomes to overcome the long periods of exposure to atmospheric air and desiccation. _O. nigro-viridis_ and _L. aestuarii_, on the other hand, occur as single filaments surrounded by thin mucilage layer and tend to prefer relatively moister and finer substrates where mud and sand mix. The ability of microbial biofilms to influence the behaviour of intertidal sediments is now recognized (Grant and Gust, 1987; Paterson et al., 1990). The mats dominated by cyanobacterial cells and extracellular polymeric secretions effectively stabilize the substrate (Watermann et al., 1999). It may, therefore, be possible to relate the degree of biostabilization to biomass as well as the physical properties of the sediment (Paterson et al., 1990).

Watermann et al. (1999) reported that beside grain size, temperature is also an important limiting factor for the microbial mat growth. The intertidal mudflats frequently experience much wider range of temperature than the other habitats. This is due, in part, to their relatively large surface area/volume ratios, thus allowing heating and cooling more rapidly under prevailing atmospheric conditions (Boaden and Seed, 1996). This is true for site A where sediment surface is highly exposed to various fluctuations in atmospheric and environmental conditions including weathering (wind), degree of exposure to sun and wave actions compared with other sites. Such factors have led to low values of abundance and restricted the distribution of microbial mat at this site. A correlation between chlorophyll _a_ and temperature was seen only at site K, which is most sheltered and where temperature fluctuation was less pronounced. Laboratory studies by Watermann et al. (1999) have proved that a high temperature range (15°C–25°C) favours cyanobacteria growth, with highest biomass at 15°C on sand, while diatoms dominate at a low temperature range (10°C - 15°C). Barranguet et al. (1997) have observed that, in the uniformly sandy NE region of Molenplaat, there is a succession from diatoms in spring to cyanobacteria and euglenoids in summer, then back to diatoms in autumn. In the present study, a negative correlation (r²=-0.713, P<0.01) between chlorophyll _a_ and mud surface temperature (16.2°C – 31.9°C) suggests that extremely high temperatures have a negative impact on the growth of cyanobacteria.

Salinity values were always highest at site A and lowest at K. Exposure at low tide opens the shore and its substratum to high air temperatures resulting in a high evaporation rate and the perfusion of the sediments with water of high salt content. Indeed white crust of salt was always encountered on the sediment surface of sites A and S, particularly during the neap tides. Clayton (1986) stated that salinity gradient across the mat and alternate saturation and desiccation of it produce changes in the sediment surface morphology leading to zoning in the microalgal mat itself. A correlation between chlorophyll _a_ and salinity was seen only at site K where the sediment was relatively more moisture laden and no white crust of salt was encountered. It is apparent that other factors such as the duration of emergence and submergence, influence of weather and evaporation, indirectly affect temperature and salinity, thus determining the abundance, distribution and biomass of cyanobacteria _in situ_.

There is no significant seasonal variation in total biomass of microbial mats for the three sites of Sulaibikhat Bay. A similar pattern in the seasonal variation of microphytobenthos biomass has been reported by Brotnas et al. (1995); De Sousa et al. (1998) in Tagrus Eastuary (Portugal) and Santos Estuary (Brazil) respectively. However, an initial summer bloom was observed at site K because at very favourable temperatures, cyanobacteria appeared in mud as patches amid the diatoms. Watermann et al. (1999) concluded from laboratory experiments that at high temperatures, grain size may have less control on the growth behaviour of cyanobacteria, and temperature effects apparently over-rule the substrate factor. The characteristic patterns of laminated biomass intertwined with sand grains is lacking on mud. Here, the filamentous cyanobacteria only build surficial biofilms (Paterson, 1994). Microphytobenthos communities are known to present heterogeneous distributions in space – patchiness (Brotas and Plante-Cuny, 1998). The large standard error computed for site K represents an irregular or patchy distribution of chlorophyll _a_ due, in part, to blooming of microbial mats. Thus, patchiness increases with increase in biomass. Declines in algal biomass could be due to a range of factors, such as nutrient limitation, consumption by grazers, desiccation or dislocation by adverse weather conditions. Cyanobacteria were found to be resistant to
Epipsammic benthic microalgae of Kuwait Bay

nutrient stress (Villbrandt et al., 1990). It has been well established that grazing by micro-, meio- and macrofauna (Fig. 12) may affect microphytobenthos biomass, but most studies have been limited to a single or few consumer species and have been performed in laboratory or experimental systems rather than in situ (Miller et al., 1996; Al-Zaidan et al., 2003; Al-Mohanna et al., 2004). Montagna (1984) and Morrisey (1988) suggested desiccation and grazing to be possible causes for summer declines in mat biomass. The absence of seasonal variation in the total epipsammic mat biomass from the three sites reflects their perennial nature in the Bay which is barren of macroalgal life. It is reasonable, therefore, to suggest that the microbial mats (lab-lab) at the mudflats of Sulaibikhat Bay/Kuwait Bay form an important and/or main source of carbon to tidal flat’s inhabitants.

In the Arabian Gulf, the ecological importance of cyanobacteria in the intertidal mudflats was recognized for the first time after the 1991 Gulf War and subsequent massive oil spill along the eastern shores of Saudi Arabia. These impacted-oil tar shores experienced extensive growth of cyanobacterial mats that allowed re-colonization of macrofauna in these areas after being wiped out completely by the oil spill (Hoffman, 1996; Jones et al., 1996). The recolonized macrofauna were reported to graze on cyanobacterial mats as source of nutrition, thereby reducing their biomass to a narrow band on the top of the shores (Jones et al., 1996). Despite mudflats’ unique entity and ecological importance, many coastal planners and engineers frequently look at them as un-interesting coastal habitats or wastelands and subject them to several alterations associated with urbanization and industrialization. Unplanned actions could destroy such habitats and their primary producers (microbial mats) beyond repair, which can result in total loss of biodiversity that sustains local commercial fisheries.

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