INTERTIDAL CYANOBACTERIAL DIVERSITY ON A ROCKY SHORE AT BULEJI NEAR KARACHI, PAKISTAN

AZRA BANO AND PIRZADA J. A. SIDDIQUI*

Centre of Excellence in Marine Biology
University of Karachi, Karachi-75270 Pakistan

Abstract

The present study describes the species diversity of cyanobacteria on a rocky shore at Buleji near Karachi. Species of cyanobacteria were recorded from the surface sediments (edaphic), rock surfaces (epilithic), in rock-pool and open seawater. A total of 109 species were observed and classified under four orders and 24 genera. Eighty-five species recorded in this study are new records for intertidal cyanobacteria from Pakistan. About 50% of observed cyanobacteria appeared to inhabit only one niche. A difference in the distribution and diversity of cyanobacteria was also observed with respect to tidal height. Three types of enriched media were employed to boost growth of less abundant cyanobacterial species. A high diversity of cyanobacteria from intertidal environment was observed.

Introduction

Information on the distribution of cyanobacteria in the northern Arabian Sea bordering Pakistan is rather restricted to a few earlier reports (Shameel & Tanaka, 1992) and some recent studies from mangrove swamps (Saifullah & Taj, 1995; Saifullah et al., 1997; Mansoor et al., 2000; Siddiqui et al., 2000; Zaib-un-Nisa et al., 2000) and intertidal areas along Sindh and Balochistan coasts of Pakistan (Shameel et al., 1996; Shameel, 2000, 2001a; 2001b; Siddiqui & Bano, 2001). There are few reports available on the freshwater cyanobacteria from Pakistan (Shameel & Butt, 1984). It is generally known that intertidal cyanobacteria support a more diverse cyanobacterial population compared to that of open seawater assemblages (Hoffmann, 1999). The intertidal communities of cyanobacteria appeared to be involved in a number of physiological and ecological activities. For example, they act as natural detoxicant for oil and other chemicals (Alhasan et al., 1994; El-Enany & Issa, 2000; Gadd, 2000; Raghukumar et al., 2001) and are also a source for the production of secondary metabolites of ecological significance (Carmichael, 2001). These organisms help in the energy transformation to higher trophic levels (Lee et al., 2001) and also play ecologically significant role in the production of new nitrogen and carbon in the benthic environment (Bashan et al., 1998).

The distribution of cyanobacteria from other adjacent coasts, such as India (Desikachary, 1959; Devassy, 1987; Santra & Pal, 1988; Thajuddin & Subramanian, 1990,1992, 1994, 1995; Anand &Hoooper, 1995), Saudi Arabia (Khoja, 1987, Hussain & Khoja, 1993) and Gulf of Elat (Potts, 1980) has been reported. It would therefore be useful to determine the distribution and diversity of cyanobacteria along the coast of Pakistan which will help understand their geographical distribution. The current research is a part of an attempt to describe the distribution and diversity of marine cyanobacteria inhabiting different niches along a rocky shore at Buleji near Karachi. A number of species were identified from niches like surface sediments (edaphic), rock surfaces (epilithic), rock-pools and coastal waters.

*E-mail: [psiddiqui@sat.net.pk]
Materials and Methods

Rocky shore of Buleji is a high-energy zone along the coast located between Sandspit and Paradise Point. It provides a variety of habitats and harbours a high diversity of fauna and flora. Samples for cyanobacteria were collected from different niches at low and high tidal levels. Samples of surface sediment, scrapings from the stones and rocks, rock-pool water and coastal waters were randomly collected in replicates. Sterile tools were used and samples were kept separately in sterile bottles.

In the laboratory, samples were examined immediately under a microscope and observations noted. A portion of each sample was inoculated in three seawater based media viz., ASN-III and MN (Rippka, 1988), and Miquel’s medium (MM) (Imai, 1977). Samples were incubated at 28 ± 2°C under constant cool white fluorescent light. Any visible growth in culture tubes was observed using a light microscope. Cyanobacteria were classified according to descriptions given by Desikachary (1959), Anagnostidis & Komarek (1988, 1985) and Komarek & Anagnostidis (1989, 1986).

Results

Distribution and species diversity of cyanobacteria in the surface sediments (edaphic), on rock surfaces (epilithic), and in rock-pool and open seawater at Buleji coast is given in Tables 1 and 2. A total of 109 species were observed and classified under four orders and 24 genera (Table 1). The highest number of species were recorded in the order Nostocales (73 spp.) followed by orders Chroococcales (25 spp.), Chamaesiphonales (6 spp.), and Pleurocapsales (5 spp.). The edaphic (70 spp.) and epilithic (57 spp.) cyanobacteria were more diverse compared to the assemblages of cyanobacteria in rock-pools (42 spp.) and coastal waters (27 spp.).

About 50% of cyanobacteria appeared to inhabit any one niche only. For example, out of 109 species recorded from the rocky shore, 50 species were observed from any one habitat which includes 15 epilithic species, 21 edaphic species, 10 species from rock-pool and 4 species from coastal waters. A difference in the distribution and diversity of cyanobacteria was also observed with respect to tidal heights (Table 2). Habitat at low tide supports higher number of cyanobacteria (85 spp.) whereas high tidal zone had comparatively fewer species (59 spp.). Again some of the species were only present at either low or high tidal zone. The number of cyanobacterial species recorded from the low tide was higher (50 spp.) compared to the number of species observed only at high tide areas (24 spp.). Some 35 species were commonly present at both tidal heights.

All samples collected from the field were inoculated in three different media (ASN-III, MN & MM). The species of cyanobacteria observed from each media are shown in Table 1. ASNIII and MM appeared to be the best culture media which supported a large number of cyanobacteria (70 and 68 spp., respectively). MN medium supported 59 species. It is interesting to note that some cyanobacterial species grew only in one culture media used, for example 21 species were recorded only from MM culture medium and 16 and 13 species were only observed in ASN III and MN culture media, respectively.
<table>
<thead>
<tr>
<th>Cyanobacterial species</th>
<th>Culture media</th>
<th>Epilithic</th>
<th>Edaphic</th>
<th>Rock-pool water</th>
<th>Coastal water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chroococcales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aphanocapsa biformis</em></td>
<td>ASN-III</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>A. littoralis</em></td>
<td>ASN-III, MN</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>A. rivularis</em></td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Aphanotohece nidulans</em></td>
<td>ASN-III</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>A. stagnina</em></td>
<td>MN</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Chlorogloeopsis microcystoides</em></td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Chroococcus cohaerense</em></td>
<td>ASN-III, MN</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>C. indicus</em></td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>C. limneticus</em></td>
<td>MN</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>C. minor</em></td>
<td>ASN-III, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>C. minutus</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>C. schizodermaticus</em></td>
<td>MM</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>C. turgidus</em></td>
<td>ASN-III, MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Gloeocapsa calcarea</em></td>
<td>ASN-III</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>G. compacta</em></td>
<td>MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>G. criptidum</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>G. pleurocapsoides</em></td>
<td>MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Gloeotheca rhodochlamys</em></td>
<td>ASN-III, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Merismopedia convoluta</em></td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>M. elegans</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>M. glauca</em></td>
<td>MN</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>M. punctata</em></td>
<td>ASN-III</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Microcystis litoralis</em></td>
<td>ASN-III</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Synechocystis aquatilis</em></td>
<td>ASN-III, MM</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>S. pevdekii</em></td>
<td>ASN-III, MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><strong>Chamaesiphonales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Dermocarpa clavata</em></td>
<td>MM</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>D. flahaultii</em></td>
<td>MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>D. leibleiniae</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>D. olivacea</em></td>
<td>ASN-III, MM</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>D. parva</em></td>
<td>MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>D. sphaerica</em></td>
<td>MN</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Pleurocapsales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Hydrococcus rivularis</em></td>
<td>ASN-III, MN</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Myxosarcina burmensis</em></td>
<td>MN, MM</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>M. spectabilis</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Xenococcus cladophorae</em></td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>X. kerner</em></td>
<td>ASNIII</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Species</td>
<td>Leader Type</td>
<td>Position</td>
<td>Presence</td>
<td>Absence</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------</td>
<td>----------</td>
<td>----------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Calothrix brevissima</td>
<td>ASN-III</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>C. fusca</td>
<td>ASN-III</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Komvophron anabaenoides</td>
<td>ASN-III</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>K. crassum</td>
<td>ASN-III, MN, MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>K. minutum</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>K. schmidlei</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Lyngbea aequata</td>
<td>MN, MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>L. borgertii</td>
<td>ASN-III, MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>L. chlorospira</td>
<td>ASN-III, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>L. infixa</td>
<td>MN</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>L. lagerhamii</td>
<td>ASN-III</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>L. major</td>
<td>ASN-III, MN</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>L. prelagans</td>
<td>MN</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Microchaete grisea</td>
<td>ASN-III</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Oscillatoria amphigranulata</td>
<td>ASN-III, MN</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>O. angusta</td>
<td>ASN-III</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>O. chalybea</td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. chlorina</td>
<td>ASN-III</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. claricentrosa</td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. deflexa</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>O. earlei</td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. fremyi</td>
<td>ASN-III</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>O. grossegranulata</td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. kophylla</td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. linnetica</td>
<td>ASN-III</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>O. nigrostratosis</td>
<td>MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. nitida</td>
<td>ASN-III, MN, MM</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>O. pseudogaminata</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>O. raii</td>
<td>ASN-III, MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. sancta</td>
<td>MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>O. tenius</td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Phormidium africenamum</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>P. ambiguus</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>P. amplivaginatum</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>P. angustissimium</td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>P. animale</td>
<td>ASN-III, MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>P. breve</td>
<td>ASN-III, MN</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Species</td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td><em>P. ceylanicum</em></td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. corium</em></td>
<td>ASN-III, MM</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. endolithicum</em></td>
<td>MN</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. faveolarum</em></td>
<td>MN</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. favosum</em></td>
<td>MN</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. fragile</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>P. incrustatum</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. insigni</em></td>
<td>ASN-III, MN</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. jadianianum</em></td>
<td>ASN-III, MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. kutzingianum</em></td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. laminosum</em></td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. luteum</em></td>
<td>MM</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. molle</em></td>
<td>MM</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. mucicola</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>P. mucosum</em></td>
<td>MM</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. okenii</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. papyraceum</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>P. purpurascens</em></td>
<td>ASN-III, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. rezii</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. tenue</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. valderianum</em></td>
<td>ASN-III, MM</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Planktothrix clathrata</em></td>
<td>MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. compressa</em></td>
<td>ASN-III, MN</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Pseudoanabaena biceps</em></td>
<td>ASN-III, MN, MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>P. catenata</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>P. galeata</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>P. limnetica</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. lonchoides</em></td>
<td>ASN-III, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>P. papillaterinata</em></td>
<td>ASN-III, MN</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Spirulina labyrinthiformis</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>S. major</em></td>
<td>ASN-III, MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>S. meneghinitana</em></td>
<td>ASN-III, MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>S. subsalsa</em></td>
<td>ASN-III, MN, MM</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>S. subtilissima</em></td>
<td>MN, MM</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Symplaca muscorum</em></td>
<td>ASN-III</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Tychonema bourrellyi</em></td>
<td>MN, MM</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 2. Cyanobacterial species inhabiting low and high tidal levels. Some species were common at both tidal levels

<table>
<thead>
<tr>
<th>Species at low tide</th>
<th>Species at high tide</th>
<th>Common species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chroococcales</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aphanocapsa biformis</td>
<td>Merismopedia convoluta</td>
<td>Synechocystis pevalekii</td>
</tr>
<tr>
<td>A. littoralis</td>
<td>M. elegans</td>
<td>Gloeotrich rhodochlamys</td>
</tr>
<tr>
<td>A. rivularis</td>
<td>M. glauca</td>
<td></td>
</tr>
<tr>
<td>Aphanothece nidulans</td>
<td>M. punctata</td>
<td></td>
</tr>
<tr>
<td>A. stagnina</td>
<td>Microcystis litoralis</td>
<td></td>
</tr>
<tr>
<td>Chroococcus cohaerense</td>
<td>Synechocystis aquatilis</td>
<td></td>
</tr>
<tr>
<td>C. indicus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. limneticus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. minor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. minutus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. schizodermaticus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. turgidus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorogloeopsis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>microcystoides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gloecapsa calcarea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. compacta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. criphidinum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G. pleurocapsoides</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dermocarpa parva</strong></td>
<td>Dermocarpa clavata</td>
<td></td>
</tr>
<tr>
<td>D. sphaerica</td>
<td>D. flahaultii</td>
<td></td>
</tr>
<tr>
<td><strong>Pleurocapsales</strong></td>
<td>Hydrococcus rivularis</td>
<td></td>
</tr>
<tr>
<td>Xenococcus cladophorae</td>
<td>Myxosarcina burmensis</td>
<td></td>
</tr>
<tr>
<td>X. kernerii</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nostocales</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calothrix brevissima</td>
<td>Komvophoron anabaenoides</td>
<td>Komvophoron crassum</td>
</tr>
<tr>
<td>C. fusca</td>
<td>Lyngbea lagerhemi</td>
<td>K. minutum</td>
</tr>
<tr>
<td>Lyngbea borgertii</td>
<td>L. major</td>
<td>K. schmidlei</td>
</tr>
<tr>
<td>L. infixa</td>
<td>Oscillatoria chalybea</td>
<td>Lyngbea aestaurii</td>
</tr>
<tr>
<td>L. prelagans</td>
<td>O. earle</td>
<td>L. chlorospira</td>
</tr>
<tr>
<td>Microchaete grisea</td>
<td>O. freyit</td>
<td>Oscillatoria amphigranulata</td>
</tr>
<tr>
<td>Oscillatoria angusta</td>
<td>O. nitida</td>
<td>O. grossegranulata</td>
</tr>
<tr>
<td>O. chlorina</td>
<td>Phormidium breve</td>
<td>O. pseudogaminata</td>
</tr>
<tr>
<td>O. claricentrotosa</td>
<td>P. ceylanicum</td>
<td>O. sancta</td>
</tr>
<tr>
<td>O. deflexa</td>
<td>P. jadianianum</td>
<td>Phormidium ambiguum</td>
</tr>
<tr>
<td>O. koprophilla</td>
<td>P. laminosum</td>
<td>P. amplivaginatum</td>
</tr>
<tr>
<td>O. limnetica</td>
<td>Pseudoanabaena galeata</td>
<td>P. angustissim</td>
</tr>
<tr>
<td>O. nigroviridis</td>
<td>Spirulina subsalsa</td>
<td>P. corium</td>
</tr>
<tr>
<td>O. raoi</td>
<td>S. subtilissima</td>
<td>P. fragile</td>
</tr>
<tr>
<td>O. tenius</td>
<td>Tychonema bourrellyi</td>
<td>P. incrustatum</td>
</tr>
<tr>
<td>Phormidium africanum</td>
<td></td>
<td>P. insigni</td>
</tr>
<tr>
<td>P. animale</td>
<td></td>
<td>P. molle</td>
</tr>
<tr>
<td>P. endolithicum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. (Cont.)

<table>
<thead>
<tr>
<th>P. faveolarum</th>
<th>P. mucicola</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. favosum</td>
<td>P. okenii</td>
</tr>
<tr>
<td>P. kuetzingianum</td>
<td>P. papyraceum</td>
</tr>
<tr>
<td>P. luteum</td>
<td>P. tenue</td>
</tr>
<tr>
<td>P. mucosum</td>
<td>Pseudoanabaena biceps</td>
</tr>
<tr>
<td>P. purpurascens</td>
<td>P. limnetica</td>
</tr>
<tr>
<td>P. retzii</td>
<td>P. lonchoides</td>
</tr>
<tr>
<td>P. valderianum</td>
<td>P. papillaterminata</td>
</tr>
<tr>
<td>Planktothrix clathrata</td>
<td>Spirulina labyrinthiformis</td>
</tr>
<tr>
<td>P. compressa</td>
<td>S. major</td>
</tr>
<tr>
<td>Pseudoanabaena catenata</td>
<td>S. meneghiniana</td>
</tr>
<tr>
<td></td>
<td>Symploca muscorum</td>
</tr>
</tbody>
</table>

Discussion

In the present study a high diversity of cyanobacterial species was recorded (total 109 species) from the rocky shore at Buleji. Comparison of the recorded species with those reported in a previous study, conducted for the coast of Balochistan (Shameel, 2000) revealed that 24 species were commonly observed from Buleji (Sindh coast) as well as from Balochistan coast. Remaining 85 species recorded in the present study from Buleji rocky coast were not observed in samples collected from the entire coast of Balochistan, and therefore may be considered as new records for intertidal marine cyanobacteria from Pakistan. On the rocky shore of Buleji cyanobacteria are not generally observed as mats or as thick growth of encrusting cyanobacteria. This may be a consequence of high wave action on this shore. Grazing of cyanobacteria by herbivorous organisms may also be an added factor, as suggested by results of herbivore-exclusion experiments where the surfaces of experimental rocks showed dominated cyanobacterial growth (Williams et al., 2000). Also species of gastropods have been shown to consume cyanobacteria (Brendelberger, 1997; Lee et al., 2001) which appeared to be one of the most preferred diets of two marine gastropod species inhabiting intertidal area in Pakistan (Siddiqui, P.J.A., unpublished data).

Variation in the assemblages of cyanobacterial species in different niches was observed at Buleji, which is generally expected for other intertidal organisms. The distribution of cyanobacteria is function of a combination of chemical and physical parameters, and seasonal differences in the distribution of cyanobacteria in an intertidal area have been reported (Kennish et al., 1996; Nagarkar & Williams, 1999). The present study showed differences in the species diversity from the sediments, rock surfaces, and coastal and rock-pool waters. It also showed that some species were observed from only one niche. A possible niche-specific relationship of the intertidal cyanobacterial population would be interesting to test in future. The distribution of cyanobacteria also appears to be related with the tidal heights in the littoral zone. This is in agreement with some recent studies indicating differences in the species distribution with reference to tidal height, where higher number of species were restricted to the mid and low tidal heights (Nagarkar & Williams; 1999, Nagarkar, 2002).

Heterocystous cyanobacteria were only scarcely observed at Buleji. Absence of heterocystous cyanobacteria has also been noted at Balochistan coast (Shameel, 2000)
and in other saline environments (Howsley & Pearson, 1979; Thajuddin & Subramanian, 1992; Stall et al., 1996). The scarcity of heterocystous forms may be attributed to the nutritive and chemical conditions that exist. For example, high sulphide levels have been found toxic to heterocystous forms (Howsley & Pearson, 1979; Stall et al., 1996). Reduction in the abundance in heterocystous species of cyanobacteria has been noted subsequent to anthropogenically elevated levels of nutrients in a fresh-water ecosystem (Perona et al., 1998).

Use of more than one type of media, as revealed in this study, was useful in allowing a greater number of cyanobacterial species to grow as about 50% of the observed species were supported by only one type of media used. Boosting the growth of cyanobacteria in samples collected from nature made it possible to identify the species that were less abundant in nature and would have escaped detection otherwise.

Acknowledgements

Financial support received from Pakistan Science Foundation (PSF Project No. S-KU/Bio 277) is gratefully acknowledged.

References


(Received for publication 15 October 2002)