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Seasonal changes in benthic algal communities of the upper subtidal zone in Sanya Bay (Hainan Island, China)

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A floristic study of the marine plants and algae at Luhuitou reef, Sanya Bay, Hainan Island, China, was conducted during the rainy (October 2008 and November 2010) and dry seasons (April 2009 and February 2012). Specimens were collected in the upper subtidal zone (from 0.5 to 3 m depth at low tide). A total of 156 taxa were collected, including 143 macrophyte species (90%), 12 blue–green algal species (10%), and the seagrass, Thalassia hemprichii. *The most diverse group was the Rhodophyta (79 taxa or 55%), followed by the Chlorophyta (38 taxa or 25%) and then the Phaeophyceae (26 taxa or 20%). In the upper subtidal zone, macroalgae formed two types of communities: polydominant communities of turf-forming algae and monodominant and bidominant communities of foliose or fleshy algae. Seasonal changes occurred in the dominant species, which appear to be caused by periodic annual events of thalli detachment and subsequent community succession. In spite of heavy pollution from dissolved inorganic nitrogen and phosphorus in Sanya Bay, the subtidal flora has not undergone any dramatic changes in species numbers or composition and is similar to that of unpolluted regions in the Indo-Pacific.*

Keywords: inventory, macroalgae, algal communities, South China Sea, Hainan, pollution, seasonal changes

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INTRODUCTION

Hainan Island (Figure 1) is located in the subtropical northern periphery of the Indo-Pacific Ocean in the South China Sea (18°10′ − 20°9′N108°37′ − 111°1′E). The island has an area of 33.920 km² and a coastline of more than 1610 km. The annual mean sea surface temperature (SST) is 26°C (1970 − 2002) with an average seasonal range of 12.1°C (Sun *et al.*, 2005). The annual SST maximum (30.8°C) and minimum (18.7°C) commonly occur in July and January, respectively. Mean sea surface salinity (SSS) in the South China Sea fluctuates between 33.3 and 34.0 psu. However, SSS is strongly seasonal at Hainan Island, decreasing to a mean value of 26.5 psu owing to freshwater run-off and rain during the summer wet season (Levitus & Boyer, 1994). The mean tidal range is generally less than 1.5 m (Zhang *et al.*, 1996). The rainy season in the southern part of Hainan occurs from May to October and accounts for 95% of the yearly rainfall; the dry season occurs from November to April (Li, 2011).

The coral reefs of Hainan Island are among the most prominent fringing reefs of China. However, the diversity of coral reef species has been declining. The highest biodiversity was recorded between the 1950s and 1960s (Gurianova, 1959) but decreased severely during the next 20 years (Hutchings & Wu, 1987; Zhang *et al.*, 2006). Almost 80% of the fringing reefs along the coastline of Hainan Island (including the coral reef of Luhuitou Peninsula) have been damaged arising from human activities during the 1970 − 1990s (fishing with dynamite, removal of corals for lime and construction). Recently, the eutrophication of Hainan coastal waters, particularly in the shallow gulfs, has increased owing to greater tourist numbers, hotel building along the coast and mariculture in coastal ponds and pools with wastes draining into the sea (Hutchings & Wu, 1987; Fiege *et al.*, 1994; Zhang *et al.*,

Fig. 1. Hainan Island (South China Sea, China) and details of the investigation area, Luhuitou reef in Sanya Bay.

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1996; Hodgson & Yau, 1997; Zhang *et al.*, 2004; Tadashi *et al.*, 2008; Titlyanov *et al.*, 2011c).

It is known that degradation processes on coral reefs (especially in eutrophic waters) lead to changes in macroalgal associations (e.g. Smith *et al.*, 1981; Lapointe *et al.*, 1997; Diaz-Pulido & McCook, 2002; Gartner *et al.*, 2002; Oliveira & Qi, 2003; McClanahan *et al.*, 2006; Sergeeva *et al.*, 2007; Sfriso & Curiel, 2007; Titlyanov & Titlyanova, 2008; Titlyanov *et al.*, 2008, 2011b). Ephemeral fast-growing green algae in the intertidal zone displace slow-growing macroalgae. Frondose and fleshy algae are quickly overgrown by epiphytes, which then become the dominant biomass (Morand & Briand, 1996; Morand & Merceron, 2004; Lapointe *et al.*, 2005a, b; Titlyanov *et al.*, 2011b).

It is also known that changes in biomass and species composition in coastal ecosystems occur throughout the year, and that they have seasonal characteristics that appear to be connected to rhythmic changes in abiotic and biotic environmental factors (Fong & Zedler, 1993; Kennish, 1996; Pedersen & Borum, 1996; Kentula & DeWitt, 2003; Su *et al.*, 2009). The greatest seasonal floristic changes are caused by environmental changes in light intensity, temperature, salinity, rainfall, nutrient concentration, and wave action (Costa *et al.*, 2000, 2002; Ateweberhan *et al.*, 2006; Thakur *et al.*, 2008; Su *et al.*, 2009).

This investigation is the first seasonal comparison (during the dry and rainy seasons) of marine algal species diversity and distribution in the upper subtidal zone, and community structure in the coral reefs at Hainan Island. In addition, seasonal changes in the flora of Sanya Bay were examined, the influence of eutrophication on these communities was estimated and the seasonal impact of different environmental factors was determined.

MATERIALS AND METHODS

Study site, time and conditions

Investigations were conducted at Luhuitou reef, Sanya Bay, Hainan Island, China. The algae were collected in front of the Marine Biological Station of the South China Sea Institute of Oceanology during the rainy (October 2008 and November 2010) and dry (April 2009 and February 2012) seasons (Figure 1).

Algal sampling was conducted from 6–15 October 2008, 6–22 April 2009, 15 November–3 December 2010 and 2–28 February 2012. For two months before and one month during sampling (August–October 2008, February–April 2009, September–November 2010 and December 2011–February 2012), climatic characteristics such as surface seawater temperature (SST), number of sunny days (SD), the average concentration of dissolved inorganic nitrogen (DIN) and inorganic orthophosphates (PO_4^{-3}) in seawater of the investigated area are presented in Table 1. Climatic characteristics were obtained from the weather station at the Marine Biological Station while nutrient data were obtained at the stations close to Luhuitou reef from the Chinese Ecosystem Research Network (http://www.cern.ac.cn; Huang *et al.*, 2003).

Table 1. Climatic characteristics of the investigated area.

Time of measurement	SST, °C	SD	Rainfall, mm	DIN, μM	PO_4^{-3}, μM
August–October 2008	27.7–29.0	60	361.9	5.3	0.24
February–April 2009	24.2–26.8	63	28.3	4.8	0.40
September–November 2010	26.0–29.5	53	185.6	4.1	0.32
December 2011–February 2012	20.0–26.2	50	14.4	4.5	0.36

SST, surface seawater temperature; SD, number of sunny days; DIN: the average concentration of dissolved inorganic nitrogen and orthophosphates (PO_4^{-3}). Data source: Li 2011 and Tropical Marine Biological Research Station in Hainan, Chinese Academy of Sciences.

Collection, conservation and identification of marine plants

Marine plants were collected in the upper subtidal zone (from 0.5 to 3 m depth during low tide). At the sites investigated, the upper subtidal zone consisted of a sloping shore (50 – 200 m wide) composed primarily of dead and live colonies of massive and branched corals interspersed with sand, stones and dead coral fragments of various shapes and sizes (Figure 2). Sampling of the marine plants was carried out via snorkelling and SCUBA diving during low and high tides. Samples were extracted from all substratum types at more than 50 sites. Quadrates in algal turf communities were 100 cm² while those in the communities of large fleshy or foliose algae were 625 cm².

The collections were preserved as dried herbarium specimens. Freshly collected material was identified using monographic publications, floristic studies and systematic articles by Børgesen, 1913a, b, c, 1914, 1915–1920, 1924, 1940, 1948; Setchell & Gardner, 1930; Yamada, 1934, 1938; Tseng, 1936, 1938, 1942; Tanaka, 1938; Shen & Fan, 1950; Taylor, 1950, 1960, 1966; Egerod, 1952; Dawson, 1954, 1956, 1957, 1961, 1962; Durairatnam, 1961; Chiang, 1962; Womersley, 1967, 1984, 1987, 1994; Zinova, 1967; Hollenberg, 1968a, b; Trono, 1968, 1969, 1997; Pham, 1969; Womersley & Bailey, 1970; Itono, 1972; Abbott & Hollenberg, 1976; Jaasund, 1976; Reyes, 1976; Tseng & Dong, 1978; Vinogradova, 1979; Lu & Tseng, 1980; Perestenko, 1980; Tseng *et al.*, 1980, 1983, 2001, 2005; Trono & Put, 1982; Tseng & Lu, 1983;

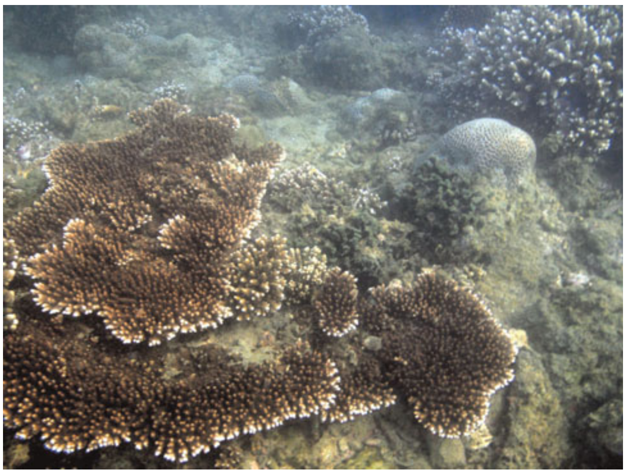

Fig. 2. Luhuitou coral reef, upper subtidal, 3 m depth at low tide, April 2012.

Table 2. Species composition, abundance and distribution of marine plants in subtidal Sanya Bay at Luhuitou coral reef

	October 2008	April 2009	December 2010	February 2012
RHODOPHYTA				
Order STYLONEMATALES				
Family STYLONEMATACEAE				
Stylonema alsidii (Zanardini) K.M. Drew	E +++	E +	E ++ +	E + ++
Chroodactylon ornatum (C. Agardh) Basson	E +	E +	E +	E +
Order ERYTHROPELTIDALES				
Family ERYTHROTRICHIACEAE				
Erythrotrichia carnea (Dillwyn) J. Agardh	E +	E ++ +	E ++	E ++ +
Acrochaetium chaetomorphae (Tanaka & Pham-Hoàng Hô) Heerebout			E +	
**Erythrocladia irregularis* Rosenvinge			S, E	
Sahlingia subintegra (Rosenvinge) Kornmann	E +	E +	E +	E +
Order ACROCHAETIALES				
Family ACROCHAETIACEAE				
Acrochaetium hypneae (Børgesen) Børgesen	E +	E + ++	E +	E +
Acrochaetium robustum Børgesen			+	E +
Acrochaetium microscopicum (Nägeli ex Kützing) Nägeli in Nägeli & Cramer		E +		E + ++
Order COLACONEMATALES				
Family COLACONEMATACEAE				
Colaconema gracile (Børgesen) Ateweberhan & Prud'homme van Reine	E +		E +	E + +
Order NEMALIALES				
Family GALAXAURACEAE				
**Tricleocarpa fragilis* (Linnaeus) Huisman & R.A. Townsend				+
Actinotrichia fragilis (Forsskål) Børgesen	+	+	+	+
Family LIAGORACEAE				
Liagora ceranoides J.V. Lamouroux		+		+
Order GELIDIALES				
Family GELIDIACEAE				
Gelidium pusillum (Stackhouse) Le Jolis	++		++ +	+
Family GELIDIELLACEAE				
Gelidiella acerosa (Forsskål) Feldmann & G. Hamel	++	++	+	+
Parviphycus adnatus (E.Y. Dawson) B. Santelices	+		+	+
Parviphycus pannosus (Feldmann) G. Furnari	+		+	+
Order HALYMENIALES				
Family HALYMENIACEAE				
Halymenia maculata J. Agardh	+	+		++
**Grateloupia filicina* (J.V. Lamouroux) C. Agardh		+		
Order PEYSSONNELIALES				
Family PEYSSONNELIACEAE				
Peyssonnelia conchicola Piccone & Grunow in Piccone	++	++	++	++
Peyssonnelia inamoena Pilger	+		+	+
Peyssonnelia rubra (Greville) J. Agardh	+	+	+	+
Order CORALLINALES				
Family CORALLINACEAE				
Amphiroa foliacea J.V. Lamouroux	++	++ +	++ +	+
Amphiroa fragilissima (Linnaeus) J.V. Lamouroux	++ +		++ +	+
Hydrolithon boreale (Foslie) Y.M. Chamberlain		+E	E +	E +
Hydrolithon farinosum (J.V. Lamouroux) D. Penrose & Y.M. Chamberlain	E +++	E ++ +	E +	E +
Jania adhaerens J.V. Lamouroux	++	E +	++ +	E +
Jania capillacea Harvey	E + ++	++ + ,	++ +	E +
Jania pumila J.V. Lamouroux	+	+	+	+
Jania ungulata f. *brevior* (Yendo) Yendo	+		+	E +
Pneophyllum fragile Kützing	E + +	E ++ +	E +	E +
Family HAPALIDIACEAE				
Lithothamnion sp	++	+	+	+
Order GIGARTINALES				
Family CYSTOCLONIACEAE				
**Hypnea esperi* Bory de Saint-Vincent				S
Hypnea pannosa J. Agardh	++ +	++ +	++	++ +
Hypnea spinella (C. Agardh) Kützing			+	E +
Hypnea valentiae (Turner) Montagne	+	++ +	+	++ +
Order RHODYMENIALES				
Family CHAMPIACEAE				
Champia parvula (C. Agardh) Harvey		E +		E +

Continued

Table 2. Continued

	October 2008	April 2009	December 2010	February 2012
Champia vieillardii Kützing	E +		E +	E +
Family LOMENTARIACEAE				
Ceratodictyon intricatum (C. Agardh) R.E. Norris	+	+	+	E +
**Ceratodictyon scoparium* (Montagne & Millardet) R.E. Norris			+	
Ceratodictyon spongiosum Zanardini	++	++	++	++
Lomentaria corallicola Børgesen	E +		+	+
Order GRACILARIALES				
Family GRACILARIACEAE				
Gracilaria salicornia (C. Agardh) E.Y. Dawson	+	+		+
Gracilaria tenuistipitata C.F. Chang & B.M. Xia	+	+		
Hydropuntia eucheumatoides (Harvey) Gurgel & Fredericq	+	+	+	+
Order CERAMIALES				
Family CERAMIACEAE				
Centroceras clavulatum (C. Agardh) Montagne	E ++	+	++	+++
**Centroceras japonicum* Itono			+	
**Centroceras minutum* Y.Yamada				E +
Ceramium cimbricum H.E. Petersen in Rosenvinge	E +	E +	E +	E +
Ceramium cingulatum Weber-van Bosse			+	E +
**Ceramium codii* (H. Richards) Mazoyer			+	
Ceramium comptum Børgesen		E +++	+	
Ceramium marshallense E.Y. Dawson	E +	E +	E +	E +
Ceramium procumbens Setchell & N.L. Gardner	+		+	
Ceramium tenerrimum (G. Martens) Okamura	+ E	E + ++		E +
Corallophila kleiwegii Weber-van Bosse	+ E	E +++	+	E +
Gayliella flaccida (Harvey ex Kützing) T.O. Cho & L.J. McIvor in Cho *et al.*	E +++	E +++	E +++	E + ++
**Antithamnionella elegans* (Berthold) J.H. Price & D.M. John			E +	
Family RHODOMELACEAE				
Acanthophora muscoides (Linnaeus) Bory de Saint-Vincent		+++		+++
Acanthophora spicifera (M. Vahl) Børgesen	++	++		+
Herposiphonia secunda (C. Agardh) Ambronn	+	+	+	E +
Herposiphonia secunda f. *tenella* (C. Agardh) M.J. Wynne		+	E + ++	
Leveillea jungermannioides (K. Hering & G. Martens) Harvey	+	+E		E +
Neosiphonia ferulacea (Suhr ex J. Agardh) S.M. Guimarães & M.T. Fujii in Guimarães *et al.*		+E		E +
**Neosiphonia howei* (Hollenberg) Skelton & G.R. South				E ++
Neosiphonia sphaerocarpa (Børgesen) M.S. Kim & I.K. Lee			+	E +
**Neosiphonia tongatensis* (Harvey ex Kützing) M.S. Kim & I.K. Lee				+
Polysiphonia japonica var. *savatieri* (Hariot) Yoon		E +++	++	E +
Polysiphonia scopulorum var. *villum* (J. Agardh) Hollenberg	E ++		E +	E +
Polysiphonia subtilissima Montagne	E ++		E ++	
Palisada papillosa (C. Agardh) K.W. Nam [*Laurencia papillosa* (C. Agardh) Greville; *Chondrophycus papillosus* (C. Agardh) D.J. Garbary & J.T. Harper]	+	+	+	+
Tolypiocladia glomerulata (C. Agardh) F. Schmitz	+	+++		
**Chondria repens* Børgesen				+
Family WRANGELIACEAE				
Anotrichium tenue (C. Agardh) Nägeli		+E	E +	E +
Griffithsia metcalfii C.K. Tseng	+	+	+	
**Griffithsia rhizophora* Grunow ex Weber-van Bosse		E +		
Wrangelia argus (Montagne) Montagne		E +		E +
Family SPYRIDIACEAE				
Spyridia filamentosa (Wulfen) Harvey in Hooker		++		+++
OCHROPHYTA				
Order ECTOCARPALES				
Family ACINETOSPORACEAE				
**Hincksia conifera* (Børgesen) I.A. Abbott				+
Feldmannia mitchelliae (Harvey) H.-S. Kim	+	E +		E +
**Kuetzingiella elachistaeformis* (Heydrich) M. Balakrishnan & Kinkar				E +
Family SCYTOSIPHONACEAE				
Rosenvingea intricata (J. Agardh) Børgesen		+		+
Colpomenia sinuosa (Mertens ex Roth) Derbès & Solier in Castagne	+	++	+	+++
**Chnoospora implexa* J. Agardh				+
Hydroclathrus clathratus (C. Agardh) M.A. Howe		++	+	+, E +
Hydroclathrus tenuis C.K. Tseng & Lu		+		++
Family CHORDARIACEAE				
**Myrionema strangulans* Greville				E +

Continued

Table 2. Continued

	October 2008	April 2009	December 2010	February 2012
Family PYLAIELLACEAE				
**Pylaiella littoralis* (Linnaeus) Kjellman				E +
Order SPHACELARIALES				
Family SPHACELARIACEAE				
Sphacelaria novae-hollandiae Sonder	+	+	+	E +
Sphacelaria rigidula Kützing	+		E ++ +	E + ++
Sphacelaria tribuloides Meneghini	E +++	E ++ +		E +
Order RALFSIALES				
Family NEORALFSIACEAE				
Neoralfsia expansa (J. Agardh) P.-E. Lim & H. Kawai ex Kraft	++	+	+	++
Order DICTYOTALES				
Family DICTYOTACEAE				
Canistrocarpus cervicornis (Kützing) De Paula & De Clerck in De Clerck *et al.*		+		+
Dictyota bartayresiana J.V. Lamouroux	+	++		++
Dictyota friabilis Setchell	+	++	++	E +
**Dictyota implexa* (Desfontaines) J.V. Lamouroux		+		
Lobophora variegata (J.V. Lamouroux) Womersley ex Oliveira	++ +	+	++ +	E +
Padina australis Hauck	+	+	+	++ +
Padina minor Yamada	+	++	+	+
Order FUCALES				
Family SARGASSACEAE				
Sargassum ilicifolium (Turner) C. Agardh	+	++ +	+	+
Sargassum sanyaense Tseng & Lu	+	++	+	++ +
Sargassum polycystum (C. Agardh)	+	++ +	+	++ +
Sargassum sp.	+	+	+	++
Turbinaria ornata (Turner) J. Agardh	++	++	++	++
CHLOROPHYTA				
Order CHLOROCOCCALES				
Family CHLOROCHYTRIACEAE				
Chlorochytrium cohnii E.P. Wright			+	E +
Order ULOTRICHALES				
Family ULOTRICHACEAE				
**Ulothrix implexa* (Kützing) Kützing		++		
Order ULVALES				
Family ULVELLACEAE				
**Acrochaete geniculata* (N.L. Gardner) O'Kelly		+En		
**Acrochaete leptochaete* (Huber) R. Nielsen		+En		
Ulvella lens P.L. Crouan & H.M. Crouan	E ++	+E	E ++ +	E + +
Ulvella scutata (Reinke) R. Nielsen, C.J. O′Kelly		E + +	E +	E +
Ulvella viridis (Reinke) R. Nielsen, C.J. O′Kelly		+En		+En
Family ULVACEAE				
Ulva clathrata (Roth) C. Agardh			E +	E +
**Ulva flexuosa* Wulfen				E +
Ulva prolifera O.F. Müller	+	+		+
Order CLADOPHORALES				
Family CLADOPHORACEAE				
Chaetomorpha gracilis Kützing	+	+		+
Chaetomorpha linum (O.F. Müller) Kützing	+	+	+	+
**Chaetomorpha minima* F.S. Collins & Hervey			E +	
Cladophora laetevirens (Dillwyn) Kützing		+E	+E	E +
Cladophora vagabunda (Linnaeus) Hoek	++		+	E +
Rhizoclonium riparium var. *implexum* (Dillwyn) Rosenvinge	E +	+E	+E	
Family ANADYOMENACEAE				
Anadyomene wrightii Harvey ex J.E. Gray	+	+	+	+
Order SIPHONOCLADALES				
Family BOODLEACEAE				
**Cladophoropsis fasciculata* (Kjellman) Wille [*Cladophoropsis sundanensis* Reinbold]	E +			
Cladophoropsis membranacea (Hofman Bang ex C. Agardh) Børgesen	+	+	+	+
Boodlea composita (Harvey) F. Brand	+	++		
Phyllodictyon anastomosans (Harvey) Kraft & M.J. Wynne	+	+	+	
Family SIPHONOCLADACEAE				
Dictyosphaeria cavernosa (Forsskål) Børgesen	++		+	+
Family VALONIACEAE				

Continued

Table 2. Continued

	October 2008	April 2009	December 2010	February 2012
**Valoniopsis pachynema* (G. Martens) Børgesen			+	
**Valonia utricularis* (Roth) C. Agardh			+	
Valonia ventricosa J. Agardh	+	+	+	
Order DASYCLADALES				
Family DASYCLADACEAE				
Bornetella nitida Munier-Chalmas ex Sonder in Mueller		+		+
**Bornetella oligospora* Solms-Laubach		+		
Bornetella sphaerica (Zanardini) Solms-Laubach	+	+	+	
Neomeris annulata Dickie	++	++	+	++
Family POLYPHYSACEAE				
Parvocaulis clavatus (Yamada) S. Berger, U. Fettweiss, S. Gleissberg, L.B. Liddle, U. Richter, H. Sawitzky & G.C. Zuccarello	+		+	+
**Parvocaulis exiguus* (Solms-Laubach) S. Berger, U. Fettweiss, S. Gleissberg, L.B. Liddle, U. Richter, H. Sawitzky, H.& G.C. Zuccarello		+		
Parvocaulis parvulus (Solms-Laubach) S. Berger, U. Fettweiss, S. Gleissberg, L.B. Liddle, U. Richter, H. Sawitsky & G.C. Zuccarello	+	+	+	+
Order BRYOPSIDALES				
Family BRYOPSIDACEAE				
Bryopsis pennata J.V. Lamouroux	++	++	+	++
Family CAULERPACEAE				
Caulerpa racemosa (Forsskål) J. Agardh	+	+		++
Caulerpa serrulata (Forsskål) J. Agardh	+	++	+	+
**Caulerpella ambigua* (Okamura) Prud'Homme van Reine & Lokhorst		+		
**Rhipidosiphon javensis* Montagne		++		
**Penicillus sibogae* A. Gepp and E.S. Gepp			+	
CYANOBACTERIA				
Order SYNECHOCOCCALES				
Family MERISMOPEDIACEAE				
**Aphanocapsa litoralis* Hansgirg				E +
Order OSCILLATORIALES				
Lyngbya majuscula Harvey ex Gomont		++		+
**Lyngbya polychroa* (Meneghini) Rabenhorst		+		
Oscillatoria limosa C. Agardh ex Gomont		+		E +
**Oscillatoria margaritifera* Kützing ex Gomont				+
Family PHORMIDIACEAE				
Phormidium nigroviride (Thwaites ex Gomont) Anagnostidis & Komárek				+++
Coleofasciculus chthonoplastes (Thur. ex Gomont) Siegesmund, J.R. Hohans. & Friedl		+++		
Phormidium sp.		+++		
Planktothrix agardhii (Gomont) Anagnostidis & Komárek [*Oscillatoria agardhii* Gomont]		+++		
**Trichocoleus tenerrimus* (Gomont) Anagnostidis				E +
Order PSEUDANABAENALES				
Family PSEUDANABAENACEAE				
**Spirulina major* Kützing ex Gomont		+		
Spirulina subtilissima Kützing ex Gomont	++	+	++	
Phylum TRACHEOPHYTA				
Order ALISMATALES				
Family HYDROCHARITACEAE				
Thalassia hemprichii (Ehrenberg) Ascherson	++	++	++	++

Annotation: E − epiphyte; En − endophyte; S − single sighting; +− rare sighting; ++ − common; +++ −abundant, * − rare found only during one sampling

Dong & Tseng, 1985; Lewis & Norris, 1987; Trono & Ganzon-Fortes, 1988; Kornmann, 1989; Luan, 1989; Burrows, 1991; Price & Scott, 1992; Luan & Luan, 1995; Wynne, 1993, 1995; Lewis & Mei-Lan, 1996; Draisma *et al*., 1998; Abbott, 1999; Huang, 1999; Littler & Littler, 2000, 2003; Leliaert & Coppejians, 2003; Skelton, 2003; South & Skelton, 2003; Abbott & Huisman, 2004; Skelton & South, 2004, 2007; Xia *et al*., 2004; Brodie *et al*., 2007; Dawes & Mathieson, 2008; Zheng & Li, 2009.

The systematics and nomenclature followed Guiry & Guiry (AlgaeBase, searched 2012). The previously known and newly recorded species for Hainan and China were verified using Algaebase, the Catalogue of Life China (2010 Annual Checklist) and the checklist of marine biota of China seas by Liu (2008).

Analysis of algal communities

The abundance of taxa was determined visually by estimating relative percentage cover. The following codes were used: a single sighting (S); a rare sighting (+); common or 10−30% cover (++); and abundant or 30−50% cover (+++). Algal dominance in the communities was also determined visually and defined as: monodominant if one algal species occupied more than 50% of the surface area; bidominant if two species occupied more than 50%; and polydominant if more species were involved. Calculations of species diversity in the upper subtidal zone included species of marine algae and seagrasses found at Luhuitou reef during all samplings. Rare species found during one of the samplings were not used (in Table 2 these species are marked with asterisks).

RESULTS

In total, 156 species of marine algae and plants were found in the upper subtidal zone of Luhuitou Peninsula during the investigations. These included 143 taxa of macrophytes (90%), 12 cyanobacterial taxa (Cy) (10%) and the seagrass (*Thalassia hemprichii*). Among the macrophytes, 79 species (55%) were Rhodophyta (Rh), 38 (25%) were Chlorophyta (Ch) and 26 (20%) were Phaeophyceae (Ph) (Table 2).

Algal communities in the rainy season (October 2008 and December 2010)

In total, during the autumn–winter periods of 2008 and 2010, 96 species of marine macroalgae, one species of blue–green alga (*Spirulina subtilissima*) and one species of seagrass (*Thalassia hemprichii)* were collected. The macroalgae included 57% red, 24% green and 19% brown algae (Table 2).

In October 2008, 80 species of macroalgae and one species of blue–green alga were collected. The macroalgae included 57% red, 23% green and 20% brown algae.

In November–December 2010, 90 taxa of macroalgae and one species of blue–green alga were collected. The macroalgae consisted of 60% red, 25% green and 15% brown (Table 2).

algal communities in october 2008

The upper subtidal zone was occupied primarily by polydominant turf algal communities (70–90%, 3–6 cm high) with a mosaic dominance of long-lived articulated calcareous algae (Figure 3) such as *Amphiroa fragilissima* and *Jania capillacea,* the fleshy alga *Hypnea pannosa* (Rh) and coriaceous *Lobophora variegata* (Ph).

Turf communities included long-lived species *Jania adhaerens*, *Amphiroa foliacea*, *Gelidiella acerosa* (Rh), *Bryopsis pennata, Neomeris annulata*, *Dictyosphaeria cavernosa*, *Cladophora vagabunda* (Ch), and short-lived *Polysiphonia subtilissima*, and *P. scopulorum* var. *villum* (Rh). Young plants of *Sargassum* spp. were also common within turf communities as well as outside the communities. *Ceratodictyon spongiosum* (Rh) and the seagrass, *Thalassia hemprichii,* were common on sandy bottom areas between patch-reefs and dead coral blocks. Some dead coral blocks were overgrown with calcareous crust-like algae such as *Peyssonnelia conchicola, P. inamoena*, *P. rubra*, *Lithothamnion* sp. Among the epiphytic algae, *Stylonema alsidii*, *Erythrotrichia carnea*, *Hydrolithon farinosum, Jania capillacea*, *Gayliella flaccida* (Rh) and *Sphacelaria tribuloides* (Ph) were dominant (Table 2).

Scleractinian corals from the genera *Porites, Acropora, Pocillopora, Galaxea, Montipora, Platygyra, Favites,* and so forth, were also common in the upper subtidal zone.

algal communities in november–december 2010

In November–December 2010, similar to that observed in October 2008, the upper subtidal hard substratum was mainly occupied by polydominant communities of algal turf

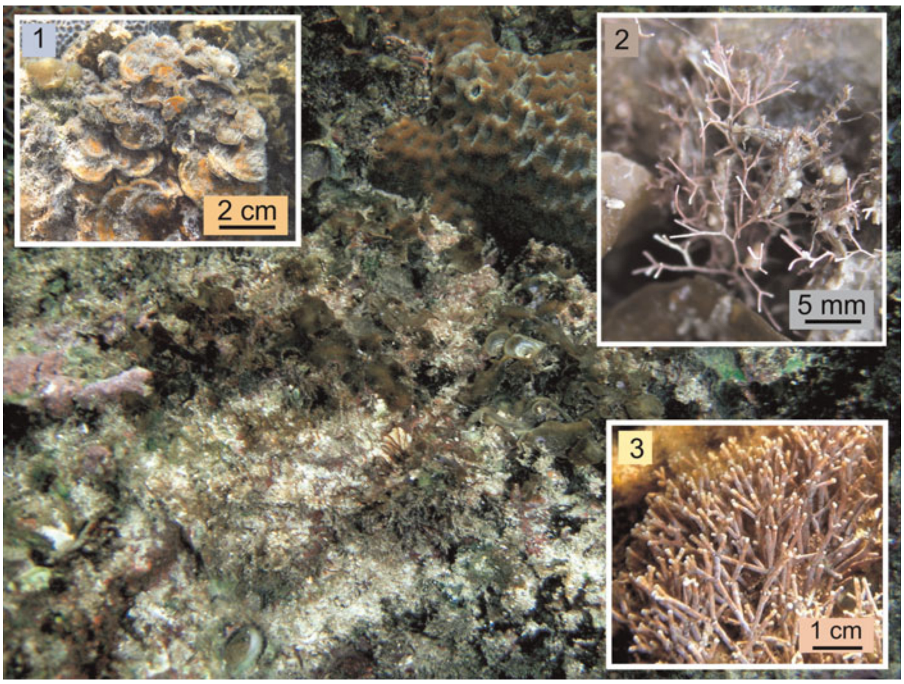

Fig. 3. Algal turf community in the upper subtidal zone, Sanya Bay, October 2008. Inserts: predominant species: 1, *Lobophora variegata*; 2, *Jania capillacea; 3, Amphiroa fragilissima.*

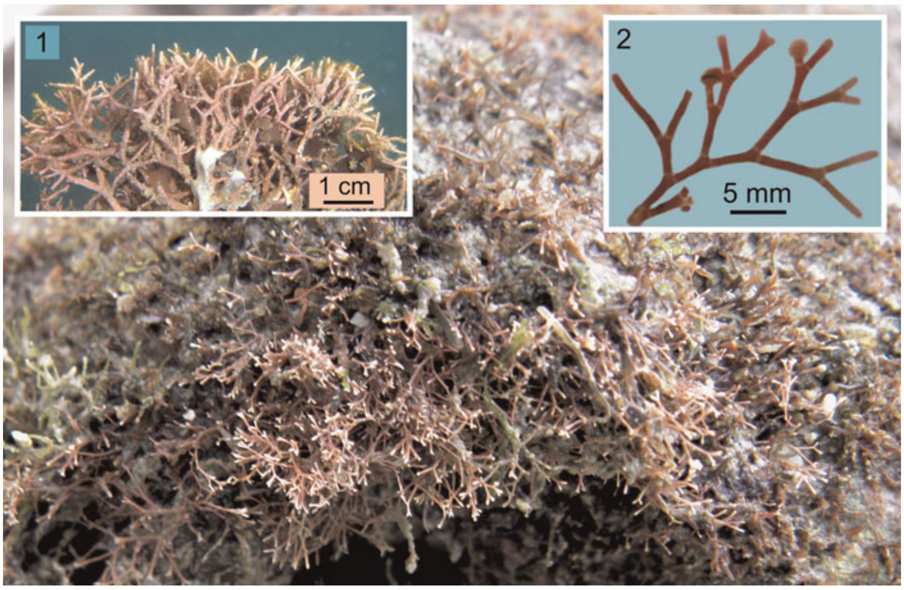

Fig. 4. Algal turf community in the upper subtidal zone, Sanya Bay, November 2010. Inserts: predominant species: 1, *Amphiroa foliacea*; 2, *Jania adhaerens*.

(Figure 4). These were dominated by long-lived articulated calcareous species such as *Amphiroa fragilissima*, *A. foliacea*, *Jania adhaerens* and *J. capillacea* (Rh). Long-lived *Hypnea pannosa* (fleshy form), *Gelidium pusillum, Gelidiella acerosa* (caespitose form), *Dictyota friabilis* (fleshy form) and filamentous ephemeral species, such as *Centroceras clavulatum, Polysiphonia japonica* var. *savatieri* and *P. subtilissima* (Rh), were common. *Turbinaria ornata* and young thalli of *Sargassum* spp. were also found on areas of hard substratum not occupied by algal turf. Some dead coral blocks were overgrown by *Peyssonnelia conchicola, P. inamoena*, *P. rubra* and *Lithothamnion* sp. Among the epiphytic algae, *Stylonema alsidii*, *Gayliella flaccida*, *Herposiphonia secunda* f. *tenella* (Rh), *Sphacelaria rigidula* (Ph) and *Ulvella lens* (Ch) were dominant (Table 2).

Algal communities during the dry seasons (April 2009 and February 2012)

In total, during the winter–spring periods of 2009 and 2012, 114 species of marine algae and plants were found, including 105 taxa (94%) of macroalgae, seven taxa of cyanobacteria and one species of seagrass (*Thalassia hemprichii*). The macroalgae consisted of 58% red, 24% green and 18% brown algae.

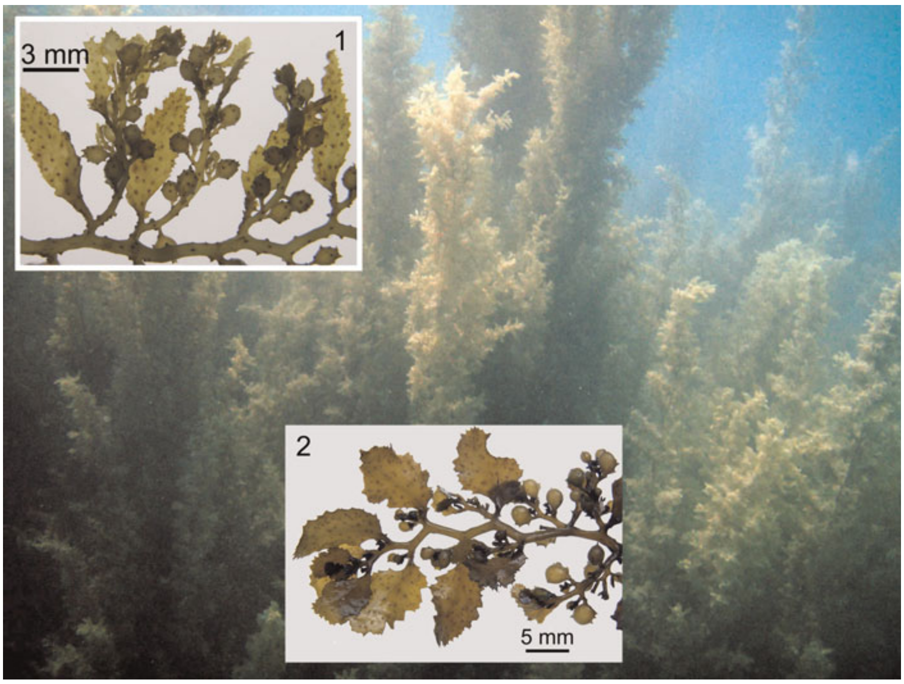

Fig. 5. Bidominant community of *Sargassum* species in the subtidal zone of Sanya Bay, April 2009. Inserts: 1, *Sargassum polycystum*; 2, *Sargassum sanyaense*.

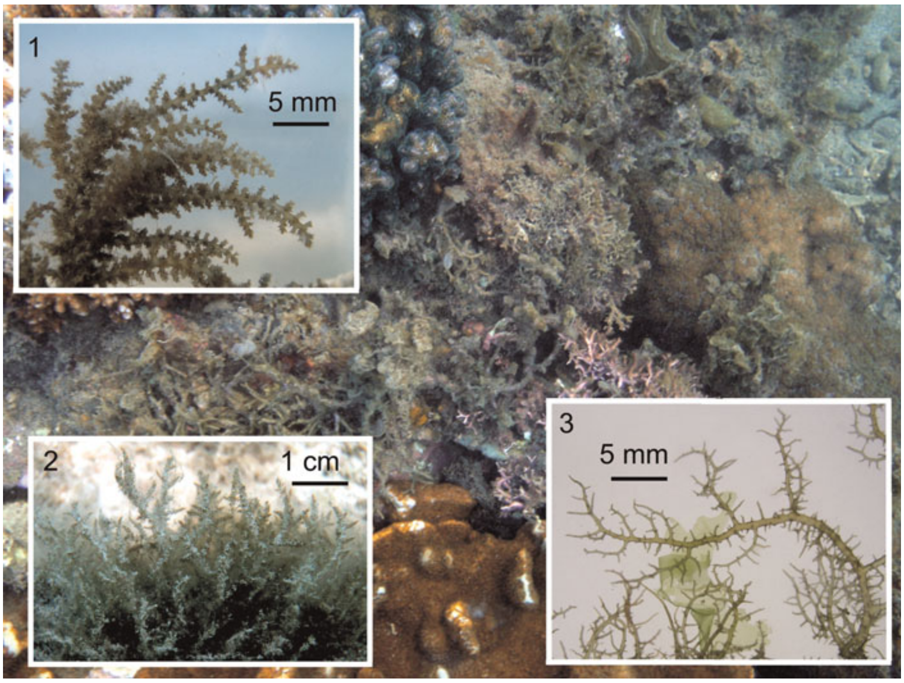

Fig. 6. Algal turf community in the upper subtidal zone, Sanya Bay, April 2009. Inserts: predominant species: 1, *Acanthophora muscoides*; 2, *Tolypiocladia glomerulata*; 3, *Hypnea valentiae*.

In April 2009, 89 species of marine macroalgae, six species of cyanobacteria and one species of seagrass, *Thalassia hemprichii,* were found. The macroalgae comprised 56% red, 22% green and 22% brown algae. In February 2012, 97 species of marine macroalgae, three species of blue–green algae and one species of seagrass, *Thalassia hemprichii*, were found. Macroalgae included 60% red, 20% green and brown 20% algae (Table 2).

ALGAL COMMUNITIES IN APRIL 2009

In April 2009, a bidominant community of brown frondose algae, *Sargassum polycystum* and *S. ilicifolium,* was distributed along the foreshore at the border between the low intertidal and upper subtidal zones (Figure 5). *Sargassum sanyaense* and *Sargassum* sp. were also found in the community. At the edge of the *Sargassum* spp. community bed, *S. polycystum* was densely overgrown by epiphytes such as *Acrochaetium robustum, Centroceras clavulatum, Gayliella flaccida, Ceramium comptum, C. borneense, Polysiphonia japonica* var. *savatieri* (Rh), *Hincksia mitchelliae* and *Sphacelaria tribuloides* (Ph). Behind the *Sargassum* spp. bed, the hard substrate, consisting of patch-reef debris and dead coral blocks, was occupied by a polydominant community of turf algae (Figure 6). This community was dominated by *Amphiroa foliacea, Acanthophora muscoides*, *Hypnea pannosa, H. valentiae*, *Tolypiocladia glomerulata* and *Jania capillacea* (Rh). Within this community *Gelidiella acerosa*, *Acanthophora spicifera* (Rh), *Dictyota friabilis* (Ph), *Boodlea composita, Bryopsis pennata, Caulerpa serrulata* and *Neomeris annulata* (Ch) were also common. *Turbinaria ornata* (Ph) and *Halymenia maculata* (Rh) were found outside of the algal turf community.

Padina australis (Ph) formed monodominant communities with inclusions of *P. minor* at the border with the low intertidal zone. *Ceratodictyon spongiosum* (Rh) and the seagrass, *Thalassia hemprichii,* were common on sandy bottom areas between dead coral blocks. Crust-like algae of the genera *Peyssonnelia*, *Lithothamnion* (Rh) and *Neoralfsia* (Ph) occupied about 10% of the hard substratum. In cyanobacterial films (often covering algal turf communities), three communities were identified: (1) a monodominant community of *Phormidium* sp. (bright green colour); (2) a bidominant community (dark brown colour) with a predominance of *Coleofasciculus chthonoplastes* and *Oscillatoria* spp. and accompanying species of *Spirulina subtilissima, Lyngbya majuscula*, *Phormidium* sp.; and (3) a green colour community with a predominance of *Planktothrix agardhii* [*Oscillatoria agardhii*] and *L. majuscula.* Among the epiphytes growing on the turf algae, *Erythrotrichia carnea*, *Stylonema alsidii*, *Acrochaetium hypneae*, *Hydrolithon farinosum*, *Pneophyllum fragile*, *Jania capillacea*, *Centroceras clavulatum*, *C. minutum*, *Ceramium marshallense*, *Gayliella flaccida*, *Wrangelia argus* (Rh), *Feldmannia mitchelliae*, *Sphacelaria novae-hollandiae* (Ph), *Acrochaete leptochaete* (endophyte), *Rhizoclonium riparium*, *R. riparium* var. *implexum* (Ch) and *Licmophora* sp. (Bacillariophyta) were all common (Table 2).

ALGAL COMMUNITIES FEBRUARY–MARCH 2012

In February–March 2012, in the upper subtidal zone at Luhuitou Peninsula, two main algal communities (bidominant and polydominant) were found. The bidominant community comprised of brown frondose algae, *Sargassum polycystum* and *S. sanyaense,* with accompanying species of *S. ilicifolium* and *Sargassum* sp. This community was distributed along the border between the upper subtidal zone and the low intertidal zone. Within this community, *Sargassum* spp. were densely overgrown by epiphytes, such as *Chroodactylon ornatum*, *Erythrotrichia carnea*, *Acrochaetium robustum*, *A. hypneae*, *A. microscopicum*, *Colaconema gracile*, *Jania ungulata* f. *brevior*, *Gayliella flaccida*, *Neosiphonia sphaerocarpa* (Rh), *Kuetzingiella elachistaeformis*, *Sphacelaria novae-hollandiae*, *S. rigidula* (Ph) and *Ulva clathrata* (Ch).

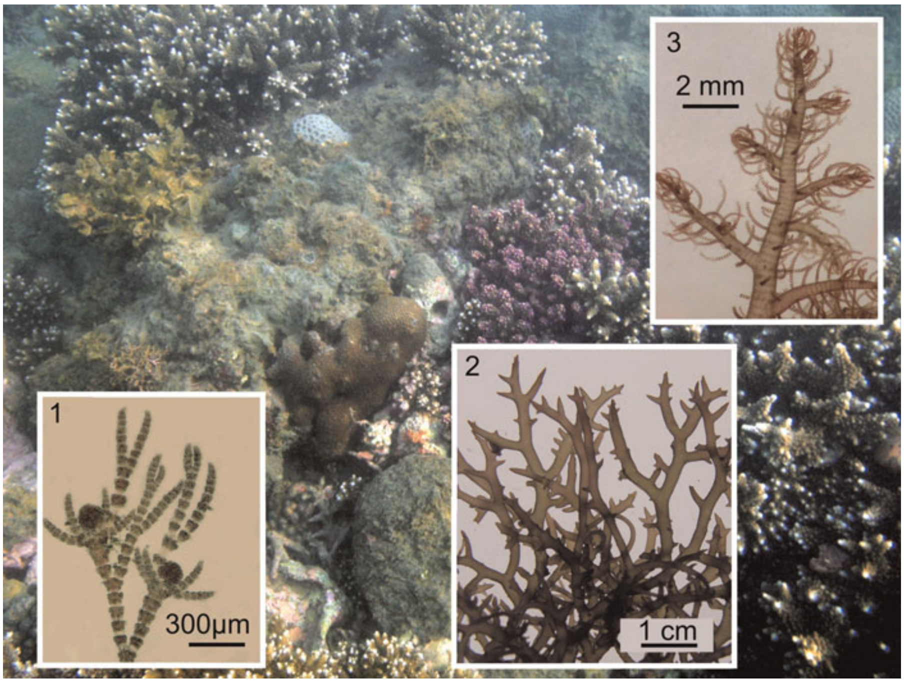

Fig. 7. Algal turf community in the upper subtidal zone, Sanya Bay, March 2012. Inserts: predominant species: 1, *Gayliella flaccida*; 2, *Hypnea pannosa*; 3, *Spyridia filamentosa*.

The polydominant community occupied the hard substrate, which consisted of the patch-reef debris in-between the *Sargassum* spp. bed and behind the bed (towards the sea). This community (2–5 cm high with 100% algal cover) comprised long-lived fleshy algae *Hypnea pannosa, H. valentiae, Acanthophora muscoides*, *Spyridia filamentosa* (Rh) and ephemeral finely-branched algae *Gayliella flaccida* and *Centroceras clavulatum* (Figure 7). *Caulerpa serrulata, Bryopsis pennata, Neomeris annulata* (Ch), *Colpomenia sinuosa*, *Hydroclathrus tenuis*, *Dictyota bartayresiana* (Ph) and *Halymenia maculata* (Rh) were common between the turf algae or growing above the turf. *Turbinaria ornata, C. sinuosa*, *Chnoospora implexa*, *Rosenvingea intricata* (Ph), *H. maculata* (Rh) and *Caulerpa racemosa* (Ch) were common outside of the community.

Padina australis formed a monodominant community on separate dead coral blocks along the border with the low intertidal zone, often with *Padina minor* interspersed. On sandy

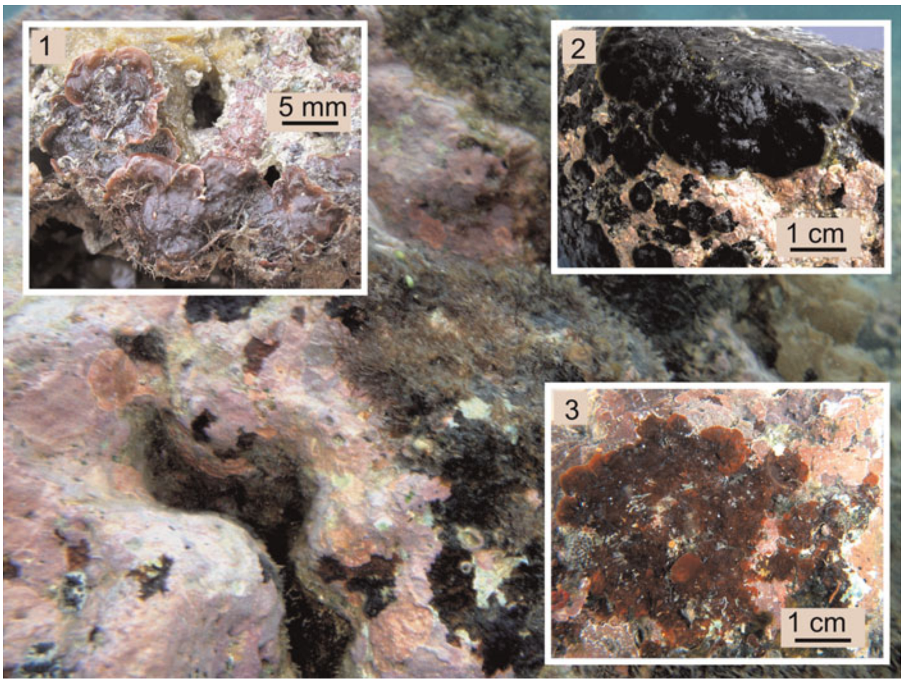

Fig. 8. Community of crust-like algae in upper subtidal, Sanya Bay, March 2012. Inserts: 1, *Peyssonnelia rubra*; 2, *Neoralfsia expansa*; 3, *Peyssonnelia conchicola*.

bottom areas with dead coral debris, *Ceratodictyon spongiosum* and the seagrass, *Thalassia hemprichii,* were common. Some dead coral blocks were occupied by crust-like algae such as *Peyssonnelia conchicola, P. rubra*, *Lithothamnion* sp. and *Neoralfsia expansa* (Figure 8). A community of blue–green algae dominated by *Phormidium nigroviride* and with accompanying species of *Aphanocapsa litoralis, Oscillatoria margaritifera, Trichocoleus tenerrimus* and *Oscillatoria limosa* was found on the substratum not occupied by algal turf. *Stylonema alsidii*, *Erythrotrichia carnea*, *Acrochaetium microscopicum*, *Gayliella flaccida*, *Polysiphonia japonica* var. *savatieri* (Rh) and *Sphacelaria rigidula* (Ph) were dominant among the epiphytic algae (Table 2).

DISCUSSION

According to the floristic analysis conducted in the upper subtidal zone of the Luhuitou reef, marine macroalgae mostly occupied the hard substrate (rocky bottom, carbonate reef, dead coral colonies and their debris), blue–green algae grew commonly on turf algae, and seagrass occupied sandy–silty bottom sites. The average cover by marine plants in the zone was about 60%, and about 22% by live hermatypic corals. Subtidal flora comprised mainly algal turf, calcareous crusts, large brown algal communities and separately growing fleshy, frondose and foliose algae (Table 2).

Species diversity

A total of 436 taxa (macroalgae and blue–green algae) have been recorded from the coastal area of Hainan Island and nearby islets in the last century and the beginning of the present century. Of these, 250 taxa (60% of macroalgae) belong to Rhodophyta, 106 taxa (25%), to Chlorophyta and 65 (15%) to Phaeophyceae (Liu, 2008; Titlyanov *et al.*, 2011b). The floristic richness of Hainan Island among the southern provinces of China is second only to Taiwan, where 600 species of macroalgae have been recorded (Lewis & Norris, 1987). The floristic composition and abundance of the species found around Hainan (among the Chinese provinces) is close to that found around Taiwan (Zhang, 1996). This similarity is probably influenced by both the geographical location of Hainan and the Taiwan Islands and by the intensity of study of their underwater floras.

A total of 156 taxa, including 143 macroalgae (90%), 12 blue–green algae (10%) and one species of seagrass (*Thalassia hemprichii*), were found in the upper subtidal zone at the Luhuitou reef (Sanya Bay) in front of the Marine Biological Station during this study. Among the macroalgae, 79 red (55%), 38 green (25%) and 26 brown algae (20%) were found. The floristic composition of the marine coastal ecosystem at Hainan Island (Luhuitou coral reef) is similar to that of coral reefs in the Indo-Pacific that are situated in regions with insignificant pollution, where the proportion of benthic macroalgal groups has been shown to be 50–60% red, 20–30% green and 10–20% brown (Lewis & Norris, 1987; Silva *et al.*, 1987; Zhang, 1996; Tsuda, 2003, 2006; Huisman & Borowitzka, 2003). In spite of significant pollution with dissolved inorganic nitrogen and phosphorus (Titlyanov *et al.*, 2011a), the subtidal flora of Sanya Bay did not show dramatic changes in macroalgal species composition.

Investigations conducted in other tropical regions of the world have shown that the following changes occur in the marine flora of eutrophicated waters: (1) an increase in species diversity and biomass of ephemeral fast-growing green algae and displacement of slow-growing macroalgae (Burrows, 1971; Barile, 2004; Titlyanov *et al.*, 2011c); (2) overgrowth by epiphytes of frondose and fleshy algae (Morand & Briand, 1996; Morand & Merceron, 2004; Lapointe *et al.*, 2005a, b); and (3) 'blooms' of local or invasive species (Smith *et al.*, 1981; Bell, 1992; Done, 1992; Hughes, 1994; Lapointe, 1997). At Sanya Bay, only the overgrowing of large forms of brown and red algae by epiphytes was observed. In particular, cyanobacterial overgrowth occurred in the low intertidal and upper subtidal zones during the dry season.

Why has eutrophication had no further impact on the flora of Sanya Bay? There are two possible explanations: (1) average concentration of dissolved organic and inorganic compounds of nitrogen and phosphorus in Sanya Bay is not enough for blooms of highly productive green macroalgae that have a high surface to volume ratio; (2) dissolved inorganic matter containing nitrogen and phosphorus is inaccessible to the majority of potentially highly productive macroalgal forms.

Evidence consistent with the first explanation is a local bloom of green macrophytes at a site where seawater runs out of pools used in the cultivation of marine animals (Titlyanov *et al.*, in press). These cultivation pools (1 ha) for crabs, fish and shrimps are situated about 100 m from the Marine Biological Station. Evidence consistent with the second explanation can be seen in the analyses of the molar C:N ratio in the tissues of macroalgae inhabiting the Luhuitou reef. The algae were nitrogen limited even with a high concentration of dissolved inorganic nitrogen in the surrounding seawater. This suggests either a difficulty in nitrogen uptake, caused by the nitrogenous compounds themselves or by the complementary compounds necessary for their absorption, or it may suggest the presence of nitrogen assimilation inhibitors in the polluted waters of Sanya Bay (Titlyanov *et al.*, 2011b).

Seasonal changes in species diversity and algal communities' structure in the subtidal zone

In total, in the subtidal zone during the dry season at Luhuitou Peninsula, 114 species of macroalgae, Cyanobacteria and seagrass were collected; whilst during the rainy season, 98 species were found (15% less).

In the intertidal zone (the same coastal site) during the rainy season, algal species number was 29% less than during the dry season. Species compositions of macroalgae in the intertidal zone during both the dry and rainy seasons were not significantly different: red (58% and 60%), green (22% and 24%) and brown algae (20% and 16%), respectively. During the dry season, blue–green algae were common (seven species) (Titlyanov *et al.*, in press).

In the subtidal zone, 80% of macroalgae recorded were common during both seasons, 15% of macroalgae were found only during the dry season and 2% were found only during the rainy season. In the intertidal zone, 60% of macroalgae were common during both seasons, 30% of macroalgae were found only in the dry season and 10% were found only in the rainy season.

Thus, in the upper subtidal zone of Sanya Bay, changes in species number and their composition were insignificant from season to season. Nevertheless, in the intertidal zone (especially in the upper and middle zones), seasonal changes in flora were significant. The absence of significant changes in the subtidal flora was connected with gradual changes in factors determining species diversity (seawater temperature, light intensity and salinity). In the upper subtidal zone during the transition from the dry to the rainy season, seawater temperature decreases by 4° C to 5° C, salinity decreases by about 2‰ and light intensity decreases by 30% (Li, 2011; Table 1). Such fluctuations in environmental factors cannot evoke serious changes in the subtidal flora (Lüning, 1990). However, the occurrence of new species (mainly ephemeral and blue–green algae, 15% of all algae found in the subtidal area) during the dry season is likely to be a response to the increased temperature of seawater.

In the intertidal zone, with the change of season, marine plants are exposed to rapid changes in environmental factors (in comparison with subtidal conditions) resulting in partial or complete algal replacement. As has been shown in a previous study (Titlyanov *et al.*, in press), in the intertidal zone at the Luhuitou reef, the greatest species number occurs during the winter–spring (dry) season, which in our opinion relates to optimal conditions for the occurrence and development of ephemeral and epiphytic algae (especially blue–green) and mass occurrence of young plants of annual vegetation. During the rainy season, depletion in species composition was observed, which was most likely related to the decrease in water temperature and salinity (especially in the upper and middle intertidal zones). These conditions do not promote the occurrence and growth of ephemeral algae and the majority of annual species are coming to the end of their vegetative growth period by that time.

Subtidal flora mainly represented by polydominant algal turf communities and to a lesser degree by associations of large foliose, fleshy, articulate and coriaceous algae. During the research period (5 years), species composition of algal communities was relatively constant. Seasonality in the algal turf community was generally characterized by changes in the dominant species, which formed the basis of the algal turf. For example, during the rainy season (October 2008), *Amphiroa fragilissima, Jania capillacea, Hypnea pannosa* (Rh) and *Lobophora variegata* (Ph) dominated the turf-forming species. During the dry season (April 2009) at the same site, *Hypnea pannosa* and *Jania capillacea* continued to dominate, but new dominants, such as *Amphiroa foliacea, Hypnea valentiae*, *Acanthophora muscoides* and *Tolypiocladia glomerulata*, also appeared. In the rainy season of November 2010, turf communities were dominated by *Amphiroa fragilissima*, *A. foliacea*, *Jania capillacea* and *Lobophora variegata* as in the previous seasons but *Jania adhaerens* also became a dominant species. In the dry season of 2012, previous dominants, such as *H. pannosa*, *H. valentiae* and *A. muscoides*, predominated but certain new inhabitants, *Spyridia filamentosa*, *Gayliella flaccida* and *Centroceras clavulatum* (Rh), appeared.

Thus, changes in the predominant species composition of long-living and ephemeral algae occur annually in subtidal algal turf communities. It seems likely that these changes in predominant and accompanying species reflect the natural process of species succession in the community. Algal community succession begins immediately on newly formed substratum after detachment of old macroalgae. Detached algae are annually found cast ashore in Sanya Bay from February to April.

The subtidal community structure can be changed by the appearance of ephemeral species (especially Cyanobacteria growing abundantly on larger algae) with increasing seawater temperature in the dry season.

In the upper intertidal zone, changes in dominant species occur more than once during the year not only because of the detachment of thalli from the substratum and the subsequent community succession in the newly formed space, but also because of frequent changes in ephemeral dominant species.

Studies of seasonal changes in macroalgal species composition in other tropical and subtropical regions of the World Ocean do not contradict the results found here or the conclusions drawn regarding the factors promoting these changes. For example, investigations in Nanwan Bay (southern Taiwan) showed insignificant seasonal variations in species diversity and evenness on the reef slope (upper subtidal). However, species diversity on the upper reef flat (intertidal) decreased in August–October (Tsai *et al.*, 2004). Seasonal changes in species diversity and composition at shallow sites were found in Brazilian coral reefs (Costa *et al.*, 2000). On the rocky intertidal shores in the Colombian Caribbean, the macroalgal community was most diverse (23 taxa) in October, which historically has been the rainiest and calmest month of the year (García & Díaz-Pulido, 2006). Extensive ephemeral blooms of smaller, fleshy brown macroalgae, such as *Chnoospora* and *Hydroclathrus*, have been observed on shallow reef (Great Barrier Reef of Australia) predominantly during winter and early spring; large seaweeds, such as *Sargassum*, have peaks in biomass and reproduction during the summer and lowest biomass during the winter (Diaz-Pulido *et al.*, 2007).

The above mentioned authors consider that changes in algal communities at shallow sites are evoked by sharp changes in climatic factors occurring from season to season. However, Thakur *et al.* (2008) found that seasonal variation in species composition of stranded seaweeds on the north-west coast of India (Port Okha) was correlated with species succession in the natural seaweed habitat of the coast. The seaweed growth season on the Okha coast is spread over seven months, from November to May. During this period, the coast witnesses extensive growth and succession of seaweeds.

In summary, in the subtidal zone along the Luhuitou coast during October 2008, April 2009, November–December 2010 and March 2012, 156 species of marine algae and plants were collected in total, including 143 taxa (90%) of macroalgae, 12 (10%) of Cyanobacteria and one species of seagrass, *Thalassia hemprichii*. The macroalgae comprised 79 red (55%), 38 green (25%) and 26 brown (20%) algal species. According to species number and composition of algal communities, benthic subtidal flora in Sanya Bay (polluted with urban and mariculture waste) is close to that of relatively unpolluted regions of the Indo-Pacific. Species number and composition varied insignificantly depending on season (dry, rainy). The upper subtidal communities were characterized by a mosaic polydominant algal turf community and by a bidominant community of *Sargassum* species. In the polydominant community, changes in dominant species occurred mainly among annual fleshy, calcareous articulated and leathery forms. It is considered that these changes were caused by periodic annual changes in the community due to thalli detachment from hard substratum and formation and succession of new algal communities on the available substratum.

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