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The Significance of New Records of Benthic Red Algae (Rhodophyta) for Hainan Island (and China) between 1990 and 2016

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Abstract: We present an annotated list of new finds of red algae from Hainan Island, Southern China, including those found in 1990 and 1992 during the German-Chinese expeditions to Hainan Island and in 2008–2016 by Titlyanova, Titlyanov, and Li. Between 1990 and 1992, a total of 64 taxa of red algae were newly recorded for Hainan Island. Of these 15 species were new records for China. During the period 2008–2016, a further 54 taxa were newly recorded for Hainan Island, of which 20 were new records for China. The full list of new taxa includes taxonomic forms, dates, and locales, together with known biogeographical distributions. During both periods, the apparent enrichment of red algal marine flora has occurred in a similar way—mainly at the expense of epiphytes with filamentous, thin-filamentous, and finely branched forms. We believe that the changes in the flora of Hainan Island have been influenced by both anthropogenic and natural factors including in particular exploitation of herbivores, nutrient pollution, and coral bleaching.

Keywords: new records; Rhodophyta; Hainan Island; China

1. Introduction

Hainan Island is located at the subtropical northern periphery of the Indo-Pacific in the South China Sea (18°10′–20°9′N, 108°37′–111°1′E) (Figure 1). The island has an area of about 33920 km^2 and a coastline of more than 1000 miles. The annual mean sea surface temperature (SST) is 26 °C with an average seasonal range of 12.1 °C [1]. 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 practical salinity units (PSU). The mean tidal range is mostly less than 1.5 m [2,3]. Shallow areas along Hainan Island coastline are occupied by coral reefs. Seagrass beds and mangroves are also present, but to a lesser extent [4]. The species diversity on the coral reefs appears to have been declining, as does that of the seagrass beds, mainly because of increasing tourism, aquaculture, sediment loads, pollutions from land, and the coastal engineering associated with development [4–11]. The marine algal flora of Hainan Island has been studied by a number of phycologists over the period from 1933 to 2016. The first sampling of marine seaweeds on the island was performed by mainly Chinese algologists [12], from 1933 to the 1980s, at sites covering all coasts of the island (Figure 1).

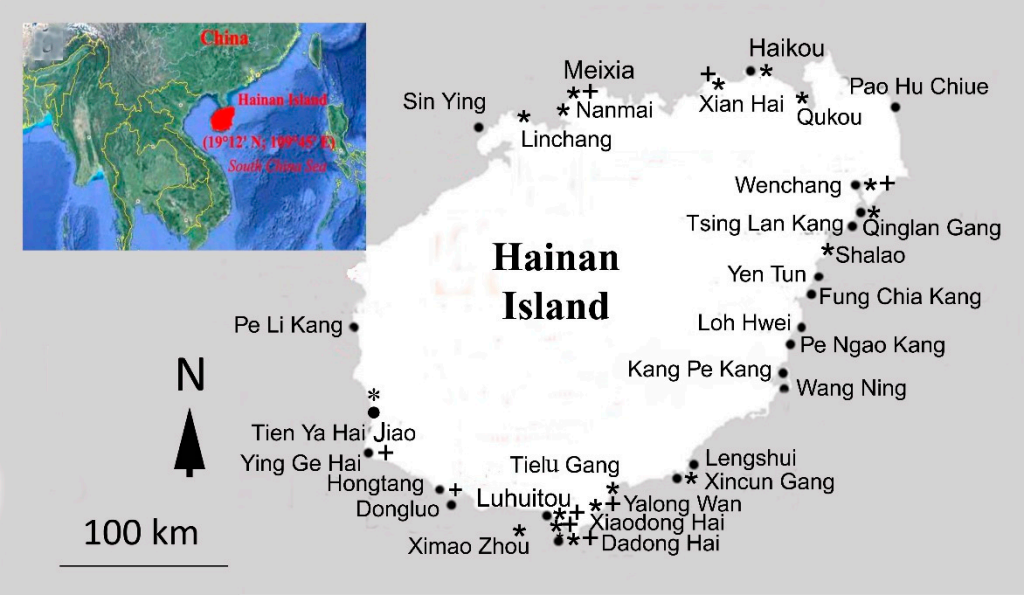

Figure 1. Algal collection sites at Hainan Island: (●)—collection sites of Tseng and coworkers in the 1930s–1980s (old spellings of sites names); (✲)—collection sites of two German-Chinese expeditions during October–December 1990 and March–April 1992; (+)—collection sites of Titlyanova, Titlyanov, and Li between 2008 and 2016.

This collection has been deposited in the herbarium of the Institute of Oceanology of the Chinese Academy of Sciences [12]. All records based on these collections were considered in our previous papers [13–18]. In this early collection (EC), a total of 310 macroalgal taxa and their forms were found, of which 178 species (57%) were Rhodophyta (Rh), 64 (21%) Phaeophyceae (Ph), and 68 (22%) Chlorophyta (Ch). The next major algal sampling on Hainan was conducted in 1990 and 1992 during the German-Chinese expeditions (IC) to Hainan Island (Figure 1). The results of these expeditions were partially published [13,16–18], with 203 taxa collected, including 105 red (52%), 32 brown (16%), and 66 green (32%) algal taxa. A third sampling was performed during 2008–2016 (LC) (Figure 1). Some of the results of this algal inventory have also been published [13–15,17,19,20], with 301 species being recorded including 163 (54%) Rhodophyta, 50 (17%) Phaeophyceae, and 88 (29%) Chlorophyta. This further paper presents an annotated list of new findings of red algae for Hainan Island made during the course of this study. On the basis of this new list with data in the literature, decadal changes in the benthic flora of the island between the 1930s and 2000s are analyzed.

2. Materials and Methods

2.1. Study Sites and Times of Sampling in 1990 and 1992

IC algal sampling was conducted during the German-Chinese expeditions in October–December 1990 and in March–April 1992. During these expeditions, algal samples were processed as herbarium specimens by Xia and Bartsch with colleagues. New findings of red algae were documented from the following sites: Haikou and Qukou on the North coast, Qingnan Gang and Shalao on the East coast, Tielu Gang, Yalong Wan, Dadong Hai, Luhuitou, Xiaodong Hai, Ximao Zhou, and Tian Ya Hai Jiao on the South coast, and Linchang, Meixia, and Nanmai on the North-West coast (Figure 1).

At Linchang, Luhuitou, Dadong Hai, Xiaodong Hai, Yalong Wan, and Tian Ya Hai Jiao, the intertidal/infralittoral reef flat was characterized by mobile blocks of dead corals, typically on a rocky substratum interspersed with sandy areas. Poorly developed mangrove areas with extensive mudflats/seagrass fields were present at Qukou and Qingnan Gang. In Haikou, samples were collected at localities with variable salinity. The *Eucheuma* farm in Shalao was characterized by a sandy bay with an offshore reef flat composed of mostly dead corals. The offshore Ximao Zhou Islet was the only place where the amount of living corals increased with depths in the shallow subtidal

zones and where the reef was generally species-rich. At Meixia, there were extensive stony intertidal areas with an offshore reef flat mostly comprised of dead corals. At Nanmai, there was an extensive reef flat with many living corals on the top of or between dead corals.

2.2. Study Sites and Times of Sampling during 2008–2016

Samplings of benthic macroalgae were carried out in October 2008 at Luhuitou, Dadong Hai, and Xiaodong Hai, in April 2009 at Luhuitou, in December 2010 at Luhuitou, in February–April 2012 at Luhuitou, Meixia, Wenchang, Xian Hai, and Yalong Wan, in April 2014 at Luhuitou, Xiaodong Hai, and Ying Ge Hai, and in March–April 2015 and 2016 at Luhuitou and Xiaodong Hai (Figure 1). In 2008–2016 Luhuitou (Figure 2), Xiaodong Hai (Figure 3) and Dadong Hai (Figure 4) were characterized by damaged coral reefs, estimated cover of live corals being approximately 25%, 10%, and 3–5%, respectively; seaweeds were collected in the intertidal and upper subtidal zones.

Figure 2. Sanya Bay, Luhuitou Peninsula, the intertidal zone at low tide. Inset: The uppersubtidal zone, March 2012.

Figure 3. Xiaodong Hai, *Sargassum* spp. belt along the coast. Inset: The upper subtidal zone. March 2015.

Figure 4. Dadong Hai at low tide, October 2008. Inset: Turf algae among live corals.

The locality Yalong Wan (Xipai, a small rocky islet) was characterized by a sandy bottom with blocks of dead corals, stones, and boulders, and a rocky bottom near the islet; seaweeds were sampled in the intertidal and upper subtidal zones. At the locality Wenchang (Figure 5), algae were collected from the intertidal zone on a damaged coral reef. In Xian Hai, seaweeds were collected from beach cast and fishery nets, which were placed on the coral reef, poor in live corals.

Figure 5. The vicinity of Wenchang City. Inset: *Padina arborescens* in association with turf algae in the middle intertidal zone, March 2012.

Figure 6. Meixia locality. Inset: *Monostroma latissimum* on dead coral block in the low intertidal zone, April 2012.

Meixia was characterized by an extensive stony intertidal area (cape site), above which was a sandy beach and a steeper upper intertidal zone, the coast being fringed by an offshore reef flat mostly composed of dead corals and, rarely, live coral colonies. Seaweeds were collected from this site at depths up to 4 m. Here, we also observed in shallow water a bloom of the green alga *Monostroma latissimum*, which along the coastline formed extensive floating beds, many of which were washed ashore (Figure 6).

Ying Ge Hai was characterized by dead coral reef and seawater heavily polluted by coastal waste. Seaweeds were collected up to 4 m depth (Figure 7).

Figure 7. Ying Ge Hai, *Ulva* spp. belt, the middle intertidal zone, April 2014.

2.3. Collection, Conservation, and Floristic Analysis of Samples

During the German-Chinese expeditions (1990, 1992), sampling was carried out in the intertidal and shallow subtidal. Specimens were catalogued with consecutive numbers and were preserved as herbarium specimens. Duplicate sets of voucher specimens were prepared: one set is deposited at BRM in Bremerhaven, Germany; the other set in Qingdao, at the Institute of Oceanography, Chinese Academy of Sciences. Materials were identified by Xia and Bartsch in 1990–1994 and by Titlyanova and Titlyanov in 2007–2009. Anatomical studies were made using slides prepared from pre-soaked herbarium material and sectioned by hand with a razor blade. During the period from 2008 to 2016, macroalgae were collected in the upper, middle, and lower intertidal, and the upper subtidal (from 0.5 to 4 m depth during low tide) zones by Titlyanova and Titlyanov. In the upper subtidal zone, sampling of the marine plants was carried out via snorkeling and SCUBA diving (by Li) during both low- and hightides. Algae were collected from all types of substrata. The algal collection of 2008–2016 is deposited at the Zhirmunsky Institute of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences.

Fresh and dried specimens were identified by Titlyanova and Titlyanov using monographic publications, floristic studies, and systematic articles cited in previous publications [13,14,16,17]. The systematics and nomenclature followed [21]. Hierarchical classification of the phylum Rhodophyta was assessed according to [22]. All publications concerning studies on Hainan Island have been reviewed in Titlyanova et al. in 2014. 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 [21,23,24]. Results of this study are presented in table form as Table 1 "An annotated list of new records of benthic red algae (Rhodophyta) for Hainan Island coast between 1990 and 2016."

3. Results

Floristic Analysis of New Findings of Red Algae in Hainan Island in 1990/1992 and during the Period 2008–2016

A total of 64 taxa of red algae found in 1990 and 1992 were newly recorded for Hainan Island, and included 15 new records for China. Of the newly recorded red algae for Hainan Island, more than 60% were thin-filamentous, finely branched epiphytes (Table 1).

Table 1. Annotated list of new records of benthic red algae (Rhodophyta) recorded from the shores of Hainan Island between 1990 and 2016.

1	2	3	4	5
List of Species, Varieties and Forms	**Sr**	**Lf**	**Dg**	**Sampling Times and Locations of Finds**
DIVISION RHODOPHYTA				
CLASS STYLONEMATOPHYCEAE				
ORDER STYLONEMATALES				
Family Stylonemataceae				
Bangiopsis dumontioides (P. Crouan & H. Crouan) V. Krishnmurthy	♥♥	Ep	T,S	(♥) Xh
Chroodactylon ornatum (C. Agardh) Basson	♣	Ep	T,S,M	(♣)Dh, Lc, Lh, Ty, Yw, Xh/(♥) Lh, Xh
Stylonema alsidii (Zanardini) K.M. Drew	♣	Ep	T,S,M	(♣)Dh, Lc, Lh, Mx, Nm, Qk, Sl, Ty, Yw, Xh, Xz/(♥)Dh, Mx, Lh, Wc, Yg, Yw, Xh
CLASS COMSPOGONOPHYCEAE				
ORDER ERYTHROPELTALES				
Family Erythrotrichiaceae				

Erythrotrichia carnea (Dillwyn) J. Agardh	♣	Ep	T,S,M,Ar,An	(♣)Dh, Lc, Lh, Nm, Qk, Sl, Ty, Yw, Xc, Xh, Xn, Xz/(♥)Dh, Lh, Mx, Wc, Yg, Yw, Xh
Erythrocladia irregularis Rosenvinge	♣	Ep	T,S,M,Ar,An	(♣)Ty, Xh/(♥)Lh, Wc, Yw, Xn
Porphyrostromium japonicum (Tokida) Kikuchi	♣♣	Ep	T,S,(I-P)	♣Qk
Sahlingia subintegra (Rosenvinge) Kornmann	♣	Ep	T,S,M	(♣)Sl, Ty, Xc, Xh, /(♥)Lh, Mx, Wc, Yg, Yw, Xn
CLASS FLORIDEOPHYCEAE				
ORDER HILDENBRANDIALES				
Family Hildenbrandiaceae				
Hildenbrandia rubra (Sommerfelt) Meneghini	♥	HS, Cr	T,S,M,Ar, An	(♥)Dh, Lh, Mx, Xh
ORDER NEMALIALES				
Family Galaxauraceae				
Dichotomaria falcata (Kjellman) Kurihara & Masuda	♣♣	HS	T,S,(I-P)	(♣)Xz
Tricleocarpa cylindrica (J. Ellis & Solander) Huisman & Borowitzka	♥	HS	T,S	(♥)Lh, Xh
ORDER ACROCHAETIALES				
Family Acrochaetiaceae				
Acrochaetium catenulatum M. Howe	♣♣	Ep	T,S,M	(♣)Xh
Acrochaetium chaetomorphae (Tanaka & Pham-Hoàng Hô) Heerebout	♥♥	Ep	T,S,(I-P)	(♥)Dh, Lh
Acrochaetium secundatum (Lyngbye) Nägeli	♣	Ep	T,S,M	(♣)Nm, Yw/(♥)Lh, Yw
Acrochaetium subseriatum Børgesen	♣♣	Ep	T,S,(I-P)	(♣)Xh
ORDER COLACONEMATALES				
Family Colaconemataceae				
Colaconema bonnemaisoniae Batters	♣	Ep	T,S,M	(♣)Xh
Colaconema daviesii (Dillwyn) Stegenga	♣	Ep	T,S,M,Ar, An	(♣)Xh/(♥)Lh
ORDER CORALLINALES				
Family Corallinaceae				
Amphiroa foliacea J.V. Lamouroux	♣	HS	T,S,(I-P)	(♣)Lh, Sl/(♥)Dh, Lh, Wc, Xh
Hydrolithon boreale (Foslie) Y.M. Chamberlain	♣	Ep	T,S,M	(♣)Sl/(♥)Lh, Yw
Hydrolithon farinosum (J.V. Lamouroux) Penrose & Y.M. Chamberlain	♣	Ep	T,S,M	(♣)Dh, Lh, Qg, Qk, Sl, Ty, Yw Xh, Xz/(♥)Lh, Wc, Yw, Xh
Jania capillacea Harvey	♣	HS	T,S,(I-P)	(♣)Dh, Lh, Mx, Nm, Sl, Ty, Yw, Xh, Xz, /(♥) Lh, Mx, Yg, Yw, Xh
Jania longiarthra E.Y. Dawson	♥	HS	T,S	(♥)Xn
Jania pumila J.V. Lamouroux	♣	HS	T,S	(♣)Dh, Xc, Xh, Xz/(♥)Lh, Yw
Jania ungulata f. *brevior* (Yendo) Yendo	♣	HS	T,S,(I-P)	(♣)Lh, Xh/(♥)Dh, Wc, Yw, Xh
Lithophyllum tumidulum Foslie	♥	HS, Cr	T,S,(I-P)	(♥)Lh, Wc
Neogoniolithon megalocystum (Foslie) Setchell & L.R. Mason	♥	HS, Cr	T,S,M,(I-P)	(♥)Lh
Pneophyllum confervicola (Kützing) Y.M. Chamberlain	♥♥	HS, Cr	T,S,M	*Lh, Wc
Pneophyllum fragile Kützing	♣	HS, Cr	T,S,M	(♣)Dh, Lh, Mx, Nm, Sl, Ty, Yw, Xh, Xz/(♥)Lh, Mx, Wc, Yw
Family Lithothamniaceae				
Lithothamnion intermedium Kjellman	♥	HS, Cr	T,S,M	(♥)Yw
Lithothamnion phymatodeum Foslie	♥	HS, Cr	T,S,M,(I-P)	(♥)Lh
ORDER CERAMIALES				

Family Ceramiaceae				
Antithamnion antillanum Børgesen	♣	Ep	T,S	(♣)Sl/(♥)Dh, Lh
Antithamnionella breviramosa (E.Y. Dawson) Wollaston	♥	Fo	T,S	(♥) Xh
Antithamnionella elegans (Berthold) J.H. Price & D.M. John	♥	Ep	T,S,M	(♥)Lh, Yw, Xn
Antithamnionella spirographidis (Schiffner) E.M. Wollaston	♣	Ep	T,S,M	(♣)Sl
Centroceras japonicum Itono	♥	Ep	T,S,(I-P)	(♥)Lh, Yw
Centroceras minutum Yamada	♣	Ep	T,S,(I-P)	(♣)Sl, Xh, Xz/(♥)Lh
Ceramium aduncum Nakamura	♣	Ep	T,S,(I-P)	(♣)Nm, Xh/(♥)Lh
Ceramium borneense Weber-van Bosse	♣	Ep	T,S,(I-P)	(♣)Xh/(♥)Lh, Yw, Xh
Ceramium camouii E.Y. Dawson	♥	Ep, HS	T,S,(I-P)	(♥)Lh, Xh
Ceramium cimbricum H.E. Petersen	♣	Ep	T,S,M	(♣)Xh/(♥)Lh, Wc, Yg, Xh, Xn
Ceramium cingulatum Weber-van Bosse	♣♣	Ep	T,S	(♣)Dh, Lc, Lh, Nm, Sl, Ty, Yw, Xh, Xz, /(♥)Lh, Yg, Yw
Ceramium codii (H. Richards) Mazoyer	♥♥	Ep	T,S	(♥)Lh
Ceramium comptum Børgesen	♥	Ep	T,S	*Lh
Ceramium macilentum J. Agardh	♣	Ep	T,S,(I-P)	(♣)Sl, Xh, Xz/(♥)Lh, Xh, Xn
Ceramium marshallense E.Y. Dawson	♣♣	Ep, HS	T,S,(I-P)	(♣)Xh, Xz/(♥)Lh, Yg, Yw, Xh
Ceramium procumbens Setchell & N.L. Gardner	♥♥	Ep	T,S,(I- P)	(♥)Lh, Xh
Ceramium serpens Setchell & N.L. Gardner	♥	Ep	T,S	(♥)Xn
Ceramium tenerrimum (G. Martens) Okamura	♣	Ep	T,S	
Ceramium vagans P.C. Silva	♣	Ep	T,S	
Corallophila kleiwegii Weber-van Bosse	♣	Ep, HS	T,S,(I-P)	
Gayliella fimbriata (Setchell & N.L. Gardner) T.O. Cho & S.M. Boo	♥	Ep,	T,S,(I-P)	
Gayliella mazoyerae T.O. Cho, Fredericq & Hommersand	♣	Ep, HS	T,S	
Gayliella taylorii (E.Y. Dawson) T.O. Cho & S.M. Boo	♥	Ep	T,S	
Aglaothamnion cordatum (Børgesen) Feldmann-Mazoyer	♥♥	Ep	T,S	
Crouania attenuata (C. Agardh) J. Agardh	♣	Ep	T,S,M	
Family Delesseriaceae				
Taenioma perpusillum (J. Agardh) J. Agardh	♣	Ep, HS	T,S	
Family Rhodomelaceae				
Acanthophora aokii Okamura	♥	HS	T,S,(I-P)	
Bryocladia cervicornis (Kützing) F. Schmitz	♥♥	Ep	T,S,(I- P)	
Chondria dangeardii E.Y. Dawson	♥♥	Ep	T,S	
Chondria minutula Weber-van Bosse	♥♥	Ep	T,S,(I- P)	
Chondria pygmaea Garbary & Vandermeulen	♥♥	Ep	T,S	
Chondria repens Børgesen	♣	Ep	T,S,(I-P)	
Chondrophycus articulatus (C.K. Tseng) K.W. Nam	♥	HS	T,S,(I-P)	
Herposiphonia insidiosa (Greville ex J. Agardh) Falkenberg	♥	HS	T,S,(I-P)	
Herposiphonia parca Setchell	♣	Ep	T,S,(I-P)	
Herposiphonia secunda (C. Agardh) Ambronn	♣	Ep	T,S	
Herposiphonia secunda f. *tenella* (C. Agardh) M.J. Wynne	♣♣	HS	T,S	
Laurencia decumbens Kützing	♥	HS	T,S	

Laurencia pinnata Yamada	♥	HS	T,S,(I-P)	
Laurencia silvae J.F. Zhang & B.M. Xia	♥	Ep	T,S,(I- P)	
Lophosiphonia cristata Falkenberg	♥♥	Ep	T,S	
Melanothamnus ferulaceus (Suhr ex J. Agardh) Díaz-Tapia & Maggs	♣	Ep	T,S	
Melanothamnus pseudovillum (Hollenberg) Díaz-Tapia & Maggs	♥♥	Ep	T,S	
Melanothamnus savatieri (Hariot) Díaz-Tapia & Maggs	♥♥	Ep	T,S	
Palisada concreta (A.B. Cribb) K.W. Nam	♥	HS	T,S,(I-P)	
Palisada intermedia (Yamada) K.W. Nam	♥	HS	T,S	
Palisada parvipapillata (C.K. Tseng) K.W. Nam	♣	HS	T,S,(I-P)	
Palisada papillosa (C. Agardh) K.W. Nam	♣	HS	T,S,(I-P)	
Pleonosporium borreri (Smith) Nägeli	♥♥	Ep	T,S,M	
Polysiphonia exilis Harvey	♥♥	Ep	T,S	
Polysiphonia scopulorum Harvey	♣	Ep	T,S	
Polysiphonia scopulorum var. *villum* (J. Agardh) Hollenberg	♣♣	Ep	T,S	
Polysiphonia subtilissima Montagne	♣	Ep	T,S	
Tolypiocladia condensata (Weber-van Bosse) P.C. Silva	♣♣	HS	T,S,(I-P)	
Tolypiocladia glomerulata (C. Agardh) F. Schmitz	♣	HS, Ep	T,S,(I-P)	
Vertebrata reptabunda (Suhr) Diaz-Tapia & Maggs	♣	Ep	T,S	
Family Wrangeliaceae				
Gordoniella yonakuniensis (Yamada & T. Tanaka) Itono	♣	Ep	T,S,(I-P)	
Wrangelia argus (Montagne) Montagne	♣	HS, Ep	T,S	
Family Dasyaceae				
Heterosiphonia crispella (C. Agardh) M.J. Wynne	♥♥	Ep	T,S	
ORDER GELIDIALES				
Family Gelidiaceae				
Gelidium crinale (Hare ex Turner) Gaillon	♣	HS	T,S,M,An	
Gelidiophycus divaricatus (G. Martens) G.H. Boo, J.K. Park & S.M. Boo	♣	HS	T,S,(I-P)	(♣)Mx, Sl/(♥)Lh, Wc
Family Gelidiellaceae				
Gelidiella lubrica (Kützing) Feldmann & G. Hamel	♣♣	Ep	T,S	(♣)Xh
Parviphycus adnatus (E.Y. Dawson) B. Santelices	♣♣	Ep	T,S	(♣)Lh, Sl, Xh/(♥)Lh
Parviphycus pannosus (Feldmann) G. Furnari	♣♣	Ep	T,S	♣Lh, Xh, Xz/*Dh, Lh, Wc, Yw, Xh
Family Pterocladiaceae				
Pterocladiella capillacea (S.G. Gmelin) Santelices & Hommersand	♣	HS	T,S,M	(♣)Xh/(♥)Lh, Xn
ORDER GIGARTINALES				
Family Cystocloniaceae				
Hypnea cenomyce J. Agardh	♥	HS	T,S	**(♥)**Lh, Mx, Yw
Hypnea chordacea Kützing	♥	HS	T,S,(I-P)	**(♥)**Yg
Hypnea esperi Bory	♥	HS	T,S,M,An	**(♥)**Lh, Yw
Hypnea musciformis var. *esperi* J. Agardh	♣	Ep	T,S,(I-P)	(♣)Dh, Lc, Nm, Xh

Hypnea nidulans Setchell	♥	HS	T,S,(I-P)	**(♥)**Lh
Hypnea valentiae (Turner) Montagne	♥♥	HS	T,S	**(♥)**Lh, Mx, Yg, Xh, Xn
Family Gigartinaceae				
Chondracanthus intermedius (Suringar) Hommersand	♥	HS, Cr	T,S,(I-P)	**(♥)**Mx, Xn
Chondracanthus tenellus (Harvey) Hommersand	♥	HS	T,S,(I-P)	**(♥)**Xn
Family Rhizophyllidaceae				
Portieria hornemannii (Lyngbye) P.C. Silva	♣	HS	T,S,(I-P)	(♣)Sl
ORDER PEYSSONNELIALES				
Family Peyssonneliaceae				
Peyssonnelia boergesenii Weber-van Bosse	♥♥	HS, Cr	T,S	**(♥)**Lh, Yw
Peyssonnelia inamoena Pilger	♥♥	HS, Cr	T,S	**(♥)**Lh, Yw
Peyssonnelia rubra (Greville) J. Agardh	♣♣	HS, Cr	T,S	(♣)Sl/(♥) Mx, Wc, Yw, Lh
ORDER GRACILARIALES				
Family Gracilariaceae				
Gracilaria changii (B.M. Xia & I.A. Abbott) I.A. Abbott, J. Zhang & B.M. Xia	♣	HS	T,S,(I-P)	(♣)Nm
Gracilaria coronopifolia J. Agardh	♣	HS	T,S,(I-P)	(♣)Xn/(♥)Lh, Xn
Gracilaria textorii (Suringar) De Toni	♥	HS	T,S	**(♥)**Xn
ORDER HALYMENIALES				
Family Halymeniaceae				
Grateloupia asiatica S. Kawaguchi & H.W. Wang	♥	HS	T,S	**(♥)**Yg, Xn
Grateloupia carnosa Yamada & Segawa	♥	HS	T,S,(I-P)	**(♥)**Yg
Grateloupia filicina (J.V. Lamouroux) C. Agardh	♥	HS	T,S,M,An	**(♥)**Lh, Yg, Xn
ORDER RHODYMENIALES				
Family Champiaceae				
Champia parvula (C. Agardh) Harvey	♣	HS	T,S,M	(♣)Yw, Xh, Xz/(♥)Dh, Lh, Yw, Xh
Champia vieillardii Kützing	♣♣	HS	T,S	(♣)Lh/(♥)Dh, Lh, Xh
Family Lomentariaceae				
Ceratodictyon scoparium (Montagne & Millardet) R.E. Norris	♥♥	HS	T,S	**(♥)**Dh, Lh, Wc, Xh
Lomentaria corallicola Børgesen	♣♣	HS	T,S	(♣)Sl, Xh/(♥)Lh, Dh
Family Rhodymeniaceae				
Rhodymenia intricata (Okamura) Okamura	♥	HS	T,S,(I-P)	**(♥)**Xn
Family Hymenocladiaceae				
Asteromenia anastomosans (Weber-van Bosse) G.W. Saunders, C.E. Lane, C.W. Schneider & Kraft	♣	HS	T,S	(♣)Qg

Column 1 lists the new algal records for Hainan Island and for China obtained during the Chinese-German expeditions in 1990 and 1992 and during the more recent investigations undertaken from 2008 to 2016. Column 2 **(Sr)** indicates the status of the species found: In 1990 and 1992, ♣ = new records for Hainan Island; ♣♣ = new records for China. In 2008–2016: ♥ = new records for Hainan Island; ♥♥ = new records for China. Column 3 (**Lf)** indicates the life forms of the different taxa: **Ep** = epiphyte, **HS** = algae growing on hard substrate (epilithic), **Cr** = crust form. Column 4 **(Dg)** shows the known distribution of the species across the various biogeographical zones: **T** = tropical; **S** = subtropical; **M** = temperate; **An** = Antarctic; **Ar** = Arctic; **T,S,M,An** = occurs from the tropics to the Antarctic; **T,S,M,Ar** = occurs from the tropics to the Arctic; **T,S,M** = from the tropics to temperate zones; **T,S** = from tropics to subtropics; **(I-P)** = only in the Indo-Pacific; **(P)** = only in the Pacific. Column 5 indicates the sites of algal finds in 1990 and 1992 (♣) and in 2008–2016 (♥): **Dh** = Dadong Hai; **Lc** = Linchang; **Lj** = Lingao

Jiao; **Lh** = Luhuitou; **Nm** = Nanmai; **Mx** = Meixia; **Qg** = Qinglan Gang; **Qk** = Qukou; **Sl** = Shalao; **Ty** = Tian Ya Hai Jiao; **Wc** = Wenchang; **Yw** = Yalong Wan; **Yg** = Ying Ge Hai; **Xn** = Xian Hai; **Xh** = Xiaodong Hai; **Xc** = Xincun; **Xz** = Ximao Zhou.

Most of the newly reported red algae species (63%) are common to other tropical and subtropical areas. Thirty-seven percent (37%) of these are found only in the Indo-Pacific, 24% restricted to temperate latitudes, and only 6% shared with Arctic and Antarctic floras. Seventy-eight percent (78%) of the species recorded for the first time from Hainan Island in 1990 and 1992 were found again in 2008–2016. In 1990 and 1992, the largest number of new findings were from Xiaodong Hai (43 species), followed by Shalao (25 species), Ximao Zhou Island (24 species), Luhuitou Peninsula (21 species), Yalong Wan (19 species), Dadong Hai (16 species), Tian Ya Hai Jiao (12 species), Nanmai (10 species), Qukou (9 species), Meixia (8 species), Linchang (6 species), and 1–3 species from other areas.

During the period from 2008 to 2016, 54 taxa were newly recorded for Hainan Island of which 20 were new to China. More than 40% of newly recorded taxa were epiphytic. Between 1992 and 2016, the marine flora of red algae on Hainan Island has been increased by 60%, of which 40% of species inhabit the Indo-Pacific, 17% otherwise occur in temperate latitudes and 3 species occur in the Antarctic. During this period, the greatest number of new finds for Hainan Island were recorded for the Luhuitou Peninsula (34 taxa), then for Ying Ge Hai (15 taxa), followed by Xian Hai (11 taxa), Yalong Wan (9 taxa), Xiaodong Hai (9 taxa), Meixia (5 taxa), and Wenchang (3 taxa).

4. Discussion

The records of algal species contained in our previous studies [13–20] suggest that conspicuous changes in the composition and diversity of red algae have occurred between the 1930s and 2012. Counter-intuitively, there has been a decline in total species richness despite the appearance of many newly reported species. The floristic similarity in marine flora of Hainan Island between the two periods, 1930s–1970s and 2008–2012 [17], amounted to 33%. By comparison the floristic similarity in marine flora between the two periods 1990/1992 and 2008–2012 was 65%, i.e., the dissimilarity in the marine flora of Hainan Island between the 1930s and 1990s was two times that between the 1990s and 2008–2012.

At the same time, inspection of the species listed in Table 1 indicates that the enrichment (more than 40%) of the red algal flora of Hainan during both periods occurred at the expense of finely branched, thin-filamentous epiphytes.

We believe that these decadal changes in the flora of the island of Hainan reflects the influence of both local anthropogenic impacts and of global change, including the following factors:

(1) The over-exploitation of the reef ecosystems, especially of algal grazing species of fish and invertebrates, developing from the 1950s–1970s [19].

(2) The eutrophication of shallow waters (bays) in the 1990s–2000s, occurring as a result most obviously of sewage disposal associated with coastal urbanization linked to the increase in tourism, but also with the growth in agriculture and mariculture [13]. This conclusion is supported by the fact that the largest numbers of new finds of red algae in 2008–2016 were from the most polluted areas of the coast, from such localities as Sanya Bay and Ying Ge Hai.

(3) The consequences of wider climate and environmental change, in particular the mass mortality of corals after bleaching such as occurred in the South China Sea in the summer of 1998 [17].

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