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THE BENTHIC MARINE FLORA OF THE PALAU ISLANDS (WCI): NEW RECORDS, MISSING RECORDS AND IMPLICATIONS FOR BIODIVERSITY

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Introduction

The earliest known records of the benthic marine algae from the Palau Islands (Western Caroline Islands) are those of OKAMURA (1904, 1916). TOKIDA (1939) collected 27 taxa of marine algae at the Palau Islands and reported 74 taxa with records of the previous publications. KANDA (1944) investigated the marine algal vegetation around Koror Island for about four months from October of 1938 and recorded 129 taxa of benthic marine algae, of which 56 were Chlorophyta, 15 Phaeophyta, 51 Rhodophyta and 7 Cyanophyta, during his study at the Palao Tropical Biological Station. TRONO (1968, 1969, 1971) reported benthic marine algae of the Caroline Islands and recorded 84 taxa of marine algae from the Palau Islands, of which 28 were Chlorophyta, 11 Phaeophyta, 40 Rhodophyta and 5 Cyanophyta. AJISAKA & ENOMOTO (1987) collected 15 species of Chlorophyta from Peleliu Island in southern Palau Islands. Some marine algae from the Palau Islands have been found in various algal monographs, checklists and short papers (SCHMIDT, 1928; YAMADA, 1930, 1940, 1941, 1944; KANDA, 1940, 1942; HOLLENBERG, 1968a, 1968b, 1968c; SAITO, 1969; TSUDA & WRAY, 1977; GILBERT, 1978; OLSEN-STOJKOVICH, 1985).

In this study, collections of marine plants made in the Palau Islands were compared with previously reported marine floras and checklists published during the last century. Efforts were made to include a broader geographic scale and depth range. The degree to which the presently recognized number of species agrees and differs with previously published studies provides a fresh perspective on the strengths and limitations of these types of investigations. A number of explanations and recommendations are made. In addition, economically important species occurring in relatively high biomass were also noted.

Materials and Methods

Collections of seagrasses (marine angiosperms), seaweeds (benthic marine algae) and cyanobacteria (blue-green algae) were made between 18-29 October 1995 at 11 stations (Fig. 1) ranging from the south coast of Babeldaob Island to the north coast of Peleliu Island. Collection depths ranged from 0-45 meters. Both snorkeling and scuba diving were employed. Specimens were both wet (3.5% formalin) and dry (standard herbarium pressed material) preserved. Specimens are deposited in the Herbarium of Laboratory of Phycology, Tokyo University of Fisheries, Tokyo, Japan (TUF).

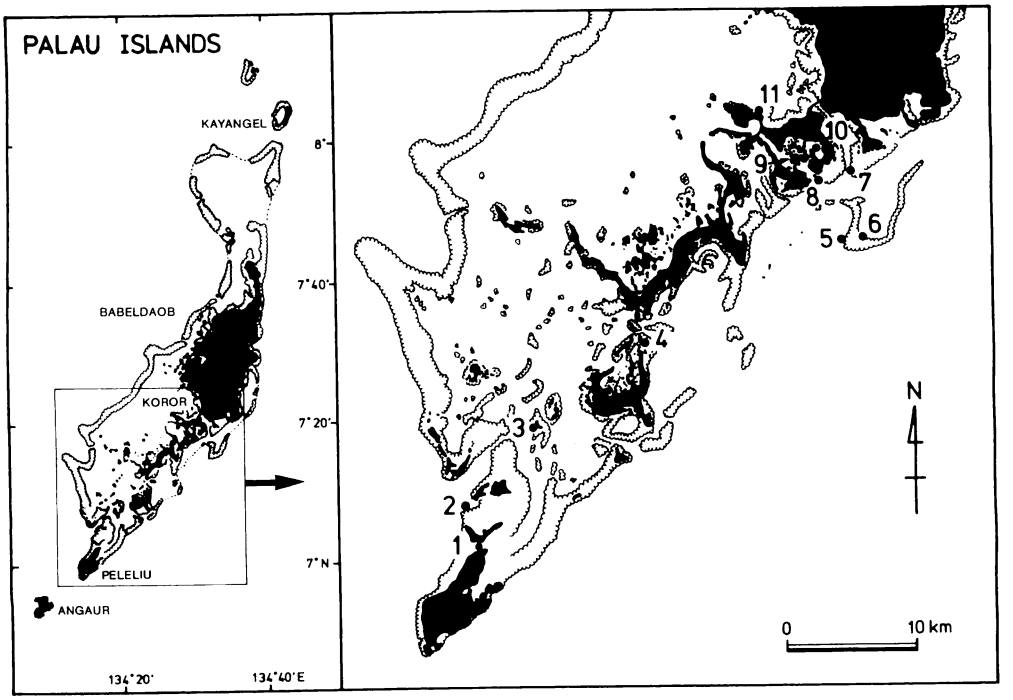

Fig. 1. Map of the Palau Islands showing the stations in which the benthic marine flora was surveyed. Stations: 1. North coast of Peleliu Island, 2. Drop off Ngesebus Island, 3. Omekang Island, 4. Ngermeyaus Island, 5. Drop off Augulpelu Reef off Koror Island, 6. Inner Augulpelu Reef, 7. Toagel Mid Passage off the Babeldaob Island, 8. Arappu Passage, 9. Geruherugairu Passage, 10. Arumizu Bay of Koror Island, 11. Northeast coast of Arakabesan Island.

Results

Some 164 taxa were collected and identified of which 72 were chlorophytes, 18 phaeophytes, 62 rhodophytes, 7 cyanophytes and 5 seagrasses (Table 1). Forty-two species are new records for the Palau Islands.

The floras of eleven stations were grouped into five types based on topography.

Type 1 (Stations 2 and 5)

The steep outer reef slope, drop off, was formed and corals and gravels dominated in these stations. Benthic marine algae were a little except *Caulerpa opposita, Rhipilia sinuosa, Halimeda minima* (?), coralline algae and encrusting algae such as *Peyssonnelia.* Some species belonging to *Cladophora, Cladophoropsis, Valonia, Dictyosphaeria, Halimeda* and *Padina* were found at the reef edge.

Type 2 (Stations 4, 6 and 7)

Large community of the branching coral, *Acropora* spp. was formed in these stations. Relatively small algae such as *Valonia, Chlorodesmis, Halimeda; Dictyota, Lobophora, Padina; Lithophyllum, Amphiroa, Ceramium, Polysiphonia, Laurencia; Lyngbya* and *Symploca* grew

abundantly among branches of *Acropora.*

Type 3 (Stations 8 and 9)

These stations were the shallow and narrow passage where a tidal current flowed relatively strong and whose tidal flat was exposed at spring tide. The number of taxa of seaweeds in these stations were the most abundance of the stations surveyed in this study. Many species belonging to *Cladophoropsis, Bornetella, Neomeris, Caulerpa, Avrainvillea, Halimeda; Dictyota, Padina, Sargassum; Galaxaura, Amphiroa, Hypnea, Gracilaria, Laurencia; Enhalus, Thalassia* and *Halophila* grew luxuriantly at the sunny place of the tidal flat. Especially, *Caulerpa racemosa, Padina pavonica* (?), *Enhalus* and *Thalassia* were formed large association. By contrast, much species belonging to *Cladophora, Valonia, Caulerpa, Rhipilia, Udotea, Halimeda; Dictyopteris; Peyssonnelia, Halymenia, Catenella, Rhodymenia, Amansia* and *Bostrychia* were abundantly distributed at the shady place beside the islets.

Type 4 (Stations 1, 3 and 11)

Seagrass bed was well developed at the shallow and broad sand-bottom lagoon of the Palau Islands. Especially, a vast seagrass bed (about 3 km of east-west x 5 km of north-south), in which *Enhalus* and *Thalassia* dominated, was formed in the northeast coast of Peleliu Island (including Station 1). The algae such as *Cladophora palentiramea* (?), *Caulerpa* spp., *Udotea geppii* and *Halimeda* spp. grew also abundantly in the seagrass bed. This locality had lower diversity of seaweeds but had remarkably high biomass.

Type 5 (Station 10)

This station was a very closed bay. Reef corals which were found in the sheltered place, e.g., *Anacropora, Fungia, Montipora, Pavona* and *Porites,* formed a large community. However, only a few species of seaweeds were found in this station.

Discussion

As is typical for many tropical marine floras, chlorophytes significantly dominated with respect to their diversity over other groups, especially phaeophytes (SEGAWA, 1956). Taxa of *Caulerpa* and *Halimeda* were numerous and accounted for a significant amount of the percent cover and biomass. The seagrasses *Enhalus acoroides* and *Thalassia hemprichii* predominated in a shallow sand-bottom lagoons.

All survey areas appeared to be relatively pristine with respect to absence of shore development and lack of reef damage due to anchor drops and fishing/harvesting pressure. Only Station 4, a heavily impacted resort area, was an exception. Marine floras of Stations 8 and 9 were the richest. This was also noted by KANDA (1942, 1944) who attributed it to increased carbon dioxide carried by strong tidal flow. My observations suggest that this richness may be also due to increased eutrophication since the sites are downstream of a sewage outfall from the city of Koror (pop. 7,000).

The chlorophytes *Caulerpa* spp. which have been eaten at Ryukyu Archipelago (southern Japan), Philippines, Fiji and other countries of Southeast Asia (CHAPMAN & CHAPMAN, 1980; SOUTH, 1993), were abundantly distributed in the Palau Islands but Palauan peoples seemed not to eat them (see TAKEDA, 1996: p. 104 of this report). Marine red algae, *Eucheuma* spp. and *Gracilaria* spp., which have been cultivated actively in the Philippines as materials of carragenan and agar, were not or a little found in this study. It is possible that aquaculture of these useful algae could be achieved in a broad lagoon.

A number of pantropical genera have not so far been found in the Palau Islands. These in-

cluded *Monostroma, Ulva, Chaetomorpha, Valoniopsis, Cymopolia, Halicoryne; Colpomenia, Chnoospora, Zonaria, Hormophysa; Dermonema, Scinaia, Asparagopsis, Dudresnaya, Titanophora, Portieria, Rhodopeltis, Plocamium, Digenea* and *Neurymenia* (See WEBER-VAN BOSSE, 1913; DAWSON, 1954; WOMERSLEY & BAILEY, 1970; EGEROD, 1974; SILVA et al., 1987). Their absence may be due to naturally disjunct biogeographic populations. Several species of seagrasses, for example, which are generally widely distributed throughout the Indo-West Pacific are not found in parts of Micronesia and Polynesia (Den Hartog, 1970).

Here we have reported 42 new records for the Palau Islands. This is very substantial. At the same time, we are not able to account for 130 older records previously reported for the Palau Islands. We were quite surprised at this because we felt that our overall survey strategy was quite good. So what factors might contribute to this?

Four factors influence comparisons among surveys. The first is seasonality. Most surveys are not conducted over the course of a year and so many taxa, particularly those occurring on seasonally exposed reef flats, may be absent. A second factor is the extensiveness of a given survey, with respect to search effort, time, habitat and range of depths. Surveys are seldom identical with previous ones. Since algae are patchily distributed in many cases, it is not unlikely that many species might be missed. A third factor is taxonomic artifacts related to different and changing circumscriptions ("lumpers" and "splitters") used by various workers and taxonomic misidentification over the years. Access to the literature is not always available and cross-comparisons with voucher specimens though desirable, are hardly every made in practice. Finally, we cannot forget human pressure through fishing, harvesting and coastal modifications (resort developments, sewage outfalls, dredging, etc.) which alter natural communities in many different and unpredictable ways.

The obvious question that arises from a study such as this is, "Have 130 species of algae really disappeared, is biodiversity actually decreasing, or might there be alternative explanations?" Clearly, all four of the above factors are playing a role to some extent and I have mentioned them precisely in order to emphasize the need for establishing better field standards and to alert field biologists to the inherent weaknesses of most surveys. The Palau Islands are one of the most biologically diverse regions in the world. Their uniqueness needs to be protected. From the perspective of biodiversity monitoring and coastal management practice, future studies should endevour to sample the same stations, include seasonality in the data set and take note of increased or changing human activity in the area. Only by so doing, can a reliable temporal element be established among studies. This study can provide the starting point for a better understanding of the benthic marine flora of the area.

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Table 1. Systematic list and distribution of seaweeds and seagrasses of the Palau Islands in the western Caroline Islands. The taxa marked with an asterisk (*) are new records for the Palau Islands. The numbers of the stations correspond to those in Figure 1.

Taxa	Stations										
	1	2	3	4	5	6	7	8	9	10	11
CHLOROPHYTA											
Chlorophyceae											
Ulvales											
Ulvaceae											
**Enteromorpha intestinalis* (L.) NEES (?)			+								

Table 1. continued

Taxa	Stations										
	1	2	3	4	5	6	7	8	9	10	11
Cladophorales											
Cladophoraceae											
Rhizoclonium sp.									+		
**Cladophora patentiramea* (MONT.) KÜTZING (?)	+								+		
Cladophora sibogae REINBOLD (?)									+		
Cladophora sp. (1) (thick)					+						
Cladophora sp. (2) (thin)					+						
Cladophora sp. (3)		+	+								
Anadyomenaceae											
Anadyomene wrightii HARVEY				+					+		
Siphonocladales											
Boodleaceae											
Boodlea coacta (DICKIE) MURRAY *et* DE TONI			+								
Boodlea composita (HARV.) BRAND				+							
Struvea (?) sp.									+		
Siphonocladaceae											
Cladophoropsis dichotoma (ZANARD.) PAPENFUSS									+	+	
Cladophoropsis vaucheriaeformis (ARESCH.) PAPENFUSS				+	+						
Cladophoropsis zollingerii (KÜTZ.) REINBOLD		+			+						
Boergesenia sp.	+										
Valonia aegagropila C. AGARDH				+	+				+		
Valonia fastigiata HARVEY *ex* J. AGARDH (?)									+		
Ventricaria ventricosa (J. AG.) OLSEN *et* WEST		+		+	+		+	+	+		
Dictyosphaeria cavernosa (FORSK.) BØRGESEN		+						+	+		+
Dasycladales											
Dasycladaceae											
Bornetella sphaerica (ZANARD.) SOLMS-LAUBACH				+				+	+		+
Neomeris vanbosseae HOWE		+		+				+	+	+	+
**Acetabularia parvula* SOLMS-LAUBACH								+			
Codiales											
Bryopsidaceae											
Bryopsis sp.			+								
**Halicystis ovalis* (LYNGBYE) ARESCHOUG					+						
Caulerpaceae											
Caulerpa verticillata J. AGARDH									+		
Caulerpa webbiana MONTAGNE				+		+		+	+		
Caulerpa brachypus HARVEY	+								+		
**Caulerpa subserrata* OKAMURA				+							
Caulerpa serrulata (FORSK.) J. AGARDH var. *serrulata*	+			+	+			+	+	+	+
Caulerpa cupressoides (VAHL) C. AGARDH var. *lycopodium* (J. AG.) W.-V. BOSSE f. *amicorum* (HARV.) W.-V. BOSSE	+			+							
Caulerpa urvilliana MONTAGNE (?)	+			+				+			
Caulerpa sertularioides (GMEL.) HOWE f. *longipes* J. AGARDH				+					+		
Caulerpa taxifolia (VAHL) C. AGARDH				+							
Caulerpa racemosa (FORSK.) J. AGARDH var. *clavifera* (TURN.) W.-V. BOSSE. f. *macrophysa* (KÜTZ.) W.-V. BOSSE	+			+	+	+		+	+		

Table 1. continued

Taxa	Stations										
	1	2	3	4	5	6	7	8	9	10	11
Caulerpa racemosa (FORSK.) J. AGARDH var. *lamourouxii* (TURN.) W.-V. BOSSE	+				+				+		
Caulerpa racemosa (FORSK.) J. AGARDH var. *peltata* (LAMX.) EUBANK				+		+		+	+		
Caulerpa racemosa (FORSK.) J. AGARDH var. *uvifera* (TURN.) W.-V. BOSSE	+		+	+							
* *Caulerpa macrodisca* DECAISNE (?)									+		
* *Caulerpa nummularia* HARVEY *ex* J. AGARDH				+							
* *Caulerpa opposita* COPPEJANS *et* MEINESZ					+						
Caulerpa lentillifera J. AGARDH var. *condensata* YAMADA									+		
Codiaceae											
* *Chlorodesmis hildebrandtii* A. *et* E. S. GEPP (?)				+	+		+				
Chlorodesmis fastigiata (C. AG.) DUCKER				+		+		+			
* *Avrainvillea amadelpha* (MONT.) A. *et* E. S. GEPP (?)						+			+		
Avrainvillea erecta (BERKEL.) A. *et* E. S. GEPP									+		
Avrainvillea lacerata HARVEY *ex* J. AGARDH	+										
* *Rhipilia orientalis* A. *et* E. S. GEPP									+		
Rhipilia sinuosa GILBERT					+		+				
Rhipilia sp. (1)		+									
Rhipilia sp. (2)									+		
Udotea geppii YAMADA	+			+	+	+			+		
Udotea javensis (MONT.) A. *et* E. S. GEPP								+			
Tydemania expeditionis W.-V. BOSSE				+						+	
* *Halimeda copiosa* GOREAU *et* GRAHAM (?)		+			+	+	+	+			
Halimeda cylindracea DECAISNE	+			+		+		+			
Halimeda discoidea DECAISNE	+				+	+	+		+		
* *Halimeda fragilis* TAYLOR (?)		+					+				
* *Halimeda gigas* TAYLOR (?)				+							
Halimeda gracilis HARVEY *ex* J. AGARDH (?)				+							
* *Halimeda hederacea* (BART.) COLINVAUX (?)					+				+		
Halimeda macroloba DECAISNE	+					+		+	+		+
Halimeda macrophysa ASKENASY				+	+	+	+	+			
Halimeda micronesica YAMADA				+	+	+	+	+			
* *Halimeda minima* (TAYLOR) COLINVAUX (?)		+									
Halimeda opuntia (L.) LAMOUROUX	+	+	+	+				+	+	+	+
Halimeda simulans HOWE	+		+	+		+		+	+		+
* *Halimeda taenicola* TAYLOR					+						
* *Halimeda velasquezii* TAYLOR				+							
Halimeda sp. (1) (= YAMADA's *H. renschii*)					+						
Halimeda sp. (2)						+	+	+			
Codium repens (CROUN) VICKERS (?)		+									
Codium sp.						+					
PHAEOPHYTA											
Phaeophyceae											
Ralfsiales											
Ralfsiaceae											
Ralfsia sp.		+			+				+		

Table 1. continued

Taxa	Stations										
	1	2	3	4	5	6	7	8	9	10	11
Scytosiphonales											
Scytosiphonaceae											
Hydroclathrus clathratus (C. Ag.) Howe								+			
Sphacelariales											
Sphacelariaceae											
Sphacelaria sp.								+			
Dictyotales											
Dictyotaceae											
Dictyota apiculata J. Agardh				+	+	+		+	+		
Dictyota bartayresiana Lamouroux								+	+		
* *Dictyota friabilis* Setchell (?)				+		+					
Dictyota patens J. Agardh (?)								+			
Dictyota sp. (1)						+	+				
Dictyota sp. (2)									+		
Dictyopteris sp.					+		+		+		
Lobophora variegata (Lamx.) Womersley				+		+		+	+		+
Padina australis Hauck				+		+		+	+		+
* *Padina japonica* Yamada				+	+	+					+
Padina pavonica (L.) Thivy (?)	+			+	+		+	+	+	+	+
Fucales											
Sargassaceae											
Turbinaria conoides (J. Ag.) Kützing (?)				+							+
Turbinaria ornata (Turn.) J. Agardh				+		+		+	+		
Sargassum polycystum C. Agardh (?)									+		+
Sargassum sp.				+							
RHODOPHYTA											
Rhodophyceae											
Nemaliales											
Galaxauraceae											
Actinotrichia fragilis (Forsk.) Børgesen		+			+	+			+		
Galaxaura fasciculata Kjellman	+										
* *Galaxaura fastigiata* Decaisne									+		
Galaxaura sp.									+		
Gelidiales											
Gelidiaceae											
Gelidium pusillum (Stackh.) Le Jolis (?)									+		
Corallinales											
Corallinaceae											
* *Neogoniolithon frutescens* (Fosl.) Setchell *et* Mason					+			+			
* *Porolithon onkodes* (Heydr.) Foslie		+			+			+			
* *Hydrolithon reinboldii* (W.-v. Bosse *et* Fosl.) Foslie								+			
* *Mastophora pacifica* (Heydr.) Foslie					+						
* *Lithophyllum kotschyanum* Unger f. *kotschyanum*				+							
Lithophyllum moluccense (Fosl.) Foslie f. *moluccense*				+	+	+		+			+
* *Lithophyllum pallescens* Foslie										+	+

Table 1. continued

Taxa	Stations										
	1	2	3	4	5	6	7	8	9	10	11
Lithophyllum (?) sp.		+									
Amphiroa foliacea LAMOUROUX					+	+					
Amphiroa fragilissima (L.) LAMOUROUX		+	+	+				+	+		+
**Amphiroa zonata* YENDO (?)					+						
Jania capillacea HARVEY	+			+				+			+
Cryptonemiales											
Peyssonneliaceae											
**Peyssonnelia caulifera* OKAMURA									+		
**Peyssonnelia conchicola* PICCONE *et* GRUNOW								+			
**Peyssonnelia obscura* W.-v. BOSSE		+			+		+		+		
Peyssonnelia orientalis (W.-v. BOSSE) CORMACI *et* FURNARI		+			+						
Peyssonnelia sp.								+			+
Halymeniaceae											
Cryptonemia (?) sp.									+		
Halymenia dilatata ZANARDINI									+		
Halymenia durvillae BORY									+		
Halymenia (?) sp.									+		
Carpopeltis (?) sp.		+									
Prionitis (?) sp.					+						
Gigartinales											
Caulacanthaceae											
**Catenella caespitosa* (WITHER.) IRVINE									+		
Hypneaceae											
**Hypnea charoides* LAMOUROUX			+	+				+			
Hypnea pannosa J. AGARDH (?)					+				+		
Hypnea sp.								+			
Gracilariaceae											
**Gracilaria bursa-pastoris* (GMEL.) SILVA (?)								+			
Gracilaria eucheumoides HARVEY (?)									+		
Gracilaria salicornia (C. AG.) DAWSON								+	+		+
Gracilaria sp.								+			
Gelidiopsis intricata (C. AG.) VICKERS	+			+		+					+
**Gelidiopsis repens* (KÜTZ.) SCHMITZ		+									
Ceratodictyon spongiosum ZANARDINI			+						+		+
Rhodymeniales											
Rhodymeniaceae											
Rhodymenia (?) sp. (1)									+		
Rhodymenia (?) sp. (2)									+		
Coelothrix irregularis (HARV.) BØRGESEN	+										
Chrysymenia (?) sp.		+									
Coeloseira (?) sp.			+								
Champiaceae											
Champia (?) sp.								+			
Ceramiales											
Ceramiaceae											
Callithamnion (?) sp.									+		

Table 1. continued

Taxa	Stations										
	1	2	3	4	5	6	7	8	9	10	11
Wrangelia (?) sp.								+			
Euptilota (?) sp.					+						
Spyridia filamentosa (WULF.) HARVEY				+				+			+
Ceramium sp. (1)			+			+			+		
Ceramium sp. (2) (large)			+								
Delesseriaceae											
* *Martensia fragilis* HARVEY							+		+		
Rhodomelaceae											
Polysiphonia sp.	+		+	+				+			+
Tolypiocladia glomerulata (J. AG.) SCHMITZ			+			+					
Tolypiocladia condensata (W.-V. BOSSE) SILVA			+					+			
Chondria sp. (1)			+								
Chondria sp. (2)				+							
* *Laurencia carolinensis* SAITO (?)								+			
* *Laurencia tronoi* GANZON-FORTES (?)			+					+			
* *Laurencia parvipapillata* TSENG				+							
Laurencia sp.				+	+				+		
Acanthophora spicifera (VAHL) BØRGESEN			+					+			+
* *Leveillea jungermannioides* (MART. *et* HER.) HARVEY								+			+
Amansia glomerata C. AGARDH									+		
Bostrychia sp.									+		
CYANOPHYTA											
Cyanophyceae											
Oscillatoriales											
Oscillatoriaceae											
Hydrocoleum (?) sp.	+										
Lyngbya confervoides C. AGARDH				+							
Lyngbya majuscula (DILLW.) HARVEY									+		
* *Lyngbya sordida* (ZANARD.) GOMONT		+			+			+			
Symploca (?) sp.				+	+						
Phormidium (?) sp.				+							
Stigonemataceae											
* *Kyrtuthrix maclans* (GOM.) UMEZAKI									+		
SPERMATOPHYTA											
Monocotyledoneae											
Helobiales											
Potamogetonaceae											
Cymodocea rotundata EHRENBERG *et* HEMPRICH *ex* ASCHERSON				+	+						
Halodule uninervis (FORSK.) ASCHERSON				+							
Hydrocharitaceae											
Enhalus acoroides (L.) ROYLE	+								+	+	+
Thalassia hemprichii (EHRENB.) ASCHERSON	+			+	+				+	+	
Halophila ovalis (R. BR.) HOOKER	+			+	+				+		
(Total number of taxa at each station)	26	23	22	56	41	28	14	53	71	8	26