Distribution and Abundance of Octocoral (Octocorallia, Alcyonacea) Communities at Three Southern Islands of Singapore

Jason Zhi Sheng Seah, Nicholas Wei Liang Yap, Lik Tong Tan* and Beverly Pi Lee Goh
Natural Sciences and Science Education, National Institute of Education, 1 Nanyang Walk, Singapore 637616

Abstract - Studies concerning subtidal octocoral species from Singapore reefs are few. This study documents the diversity and abundance of octocoral communities from fringing reefs at Singapore's Southern Islands, namely, Pulau Semakau, P. Hantu and Kusu Island. Belt transects of 20 m (× 5) were employed to survey the octocoral communities at these reef sites. Morphology and sclerites of a number of collected octocoral samples were compared with paratypes obtained from the Raffles Museum of Biodiversity Research, National University of Singapore, for species identification. A total of 16 morphotypes, belonging to five octocoral genera, including *Cladiella*, *Lobophytum*, *Nephthea*, *Sarcophyton* and *Sinularia*, were identified in this study. Statistical analysis revealed octocoral abundance and diversity at Kusu Island reefs were higher than those around P. Hantu and P. Semakau. Conversely, octocoral community structures encountered along P. Semakau and Kusu Island were more similar than those of P. Hantu. The preliminary data presented in this study could serve as the baseline data for long term biomonitoring programs in assessing the state of coral reefs in Singapore.

Key words – Octocorallia, alcyonacea, tropical ecology, soft coral communities, Singapore coral reefs

***Corresponding authors. E-mails: liktong.tan@nie.edu.sg; beverly.goh@nie.edu.sg**

Running Title : Distribution and Abundance of Octocorals in Singapore-------------

1. Introduction

The Republic of Singapore comprises an area of 710 km^2 and is located off the tip of Peninsular Malaysia. Historically, the marine environment has played a vital role in Singapore's economic development and the island is one of the largest and busiest ports in the world (Chou, 2006). Surrounding the mainland are 60 smaller islands of which the Southern Islands are surrounded by coral reefs (Chou 2006). However, due to rapid coastal developments, the state of coral reefs around Singapore has been declining steadily over the years (Chou et al. 1994; Chou 2002). Suggested reasons for this decline include the decreasing quality of the seabed due to large scale land reclamation during the 1960's to increase land area (Wong 1992) and marine pollution from suspended material from land reclamation and dredging of shipping lanes (Dikou and van Woesik 2006). Approximately 60% of total coral reefs in Singapore have been lost as a result of these anthropogenic activities and surviving reefs are subjected to stress due to high sediment loads (Chou 1996; Dikou and van Woesik 2006). Currently, the majority of the coral reefs around the Southern Islands exist as either patch reefs or fringing reefs (Ng et al. 2011).

While alcyonaceans are found in Singapore's reefs (Dikou and van Woesik 2006; Benayahu and Chou 2010), studies concerning their diversity and ecology are few. In contrast, studies on shallow reef organisms, such as scleractinian corals and associated reef fishes, in Singapore are well known (Huang et al. 2009; Low 2013). The available literature concerning octocorals from Singapore is largely taxonomic in nature and there have been few ecological investigations. Octocorals, such as *Mopsella elongata* and *Juncella gemmacea*, were first described in Singapore waters in the 19th century (Verrill 1864; Studer 1880). The early 20th century saw 11 Alcyonarian species being documented by Shann (1912) belonging to the following families: Alcyoniidae, Melitodidae, Nephthyidae, Siphonogorgiidae, Sclerogorgiidae and Telestidae. Following an absence of octocoral studies for nearly a century, Goh and Chou (1994) published a preliminary survey of gorgonian octocoral fauna in Singapore in the mid 1990s. Thereafter an annotated checklist (Goh and Chou 1996) and several others taxonomic descriptions of octocorals encountered in Singapore were published (Ofwegen et al. 2000; Benayahu and Chou 2010; Benayahu and Ofwegen 2011). For instance, Benayahu and Chou (2010) reported 25 octocoral species from Singapore based on a collection of about 170 specimens obtained between 1993 and 1999. Apart from these taxonomic studies, other aspects such as the distribution and zonation of gorgonians (Goh and Chou 1994; Goh et al. 1997), its growth rate (Goh and Chou 1995) and associated fauna (Goh et al. 1999) were investigated. In addition, preliminary studies conducted by Goh and Chou (1998), Koh et al. (2002) and Goh et al. (2009) had screened members of this invertebrate group for bioactivity and revealed high levels of biological properties.

The main reason for the lack of ecological studies on local octocorals is due to the lack of local taxonomists specializing in octocoral taxonomy. Apart from genetic analysis and examining the external morphology of octocorals, determination to species level is also dependent on the evaluation of sclerites (Haverkort-Yeh et al. 2013; Joseph et al. 2014; McFadden and Sánchez 2010; West 1997). Sclerites are calcite aggregates present in octocorals which are thought to provide both structural support and defense (West 1997) and its morphology plays an important role in the classification and identification of octocorals specimens. In spite of its importance in octocoral taxonomy, only intraspecific variations of sclerite forms have been documented due to various environmental factors, such as difference in depths (West et al. 1993) and geographical occurrence (Gutiérrez-Rodríguez et al. 2009). Such intraspecific variations of sclerite forms could hinder the accurate identification of octocorals (Joseph et al. 2014).

In this study, we aim to provide an updated list of alcyonacean species diversity at three fringing reefs located at the Southern Islands of Singapore, namely Pulau (P = Island) Semakau, P. Hantu and Kusu Island. The study will also analyze both univariate and multivariate parameters of species diversity to determine patterns of octocoral community assemblages at the study sites. To circumvent the taxonomic challenge of identifying the octocorals to species level, apart from colony morphology, we also compared the sclerites of octocoral samples collected in this study to octocoral paratypes maintained at the Raffles Museum of Biodiversity Research (RMBR), Singapore. The present study contributes to a growing body of octocoral research in Southeast Asia and highlights the importance of using natural history information and community characteristics for the purpose of marine conservation in Singapore.

2. Materials and Methods

Study area

Octocoral surveys were conducted at fringing coral reefs located at three Southern Islands of Singapore, namely P. Semakau (01º 11.851'N, 103º 45.543'E. 01º 12. 543'N, 103º 45.212'E), Kusu Island (01º13.588′N, 103º51.561′E. 01º13.524′N, 103º51.677′E) and P. Hantu (01º13.645′N, 103º44.780′E. 01º13.534′N, 103º44.715′E), over a two month duration from January to February 2014. These sites were selected based on previous reports on the occurrence of octocorals at these reef systems (Goh et al. 2009). A total of six sites were surveyed using SCUBA, with two sites from each island (Fig. 1).

Octocoral survey method

At each survey site, a total of five replicate belt transects of 20 m each were established along the reef (English et al. 1994) and octocoral communities were surveyed at a maximal depth of 9 m. The length of each octocoral colony (in cm) encountered along the transects was recorded and the colony photographed. In addition to the measuring of colony lengths, tissues of all octocorals found along the transects were collected for the purpose of species identification. Briefly, octocoral samples were obtained via sectioning *in situ*, placed in separate ziplog bags and transported to the laboratory at the National Institute of Education (NIE), Singapore, to be frozen. In total, 68 octocoral samples were obtained from all three locations.

Octocoral identification

To obtain the sclerites for identification, small pieces of tissue from the collected samples were dissolved in 10 % sodium hypochlorite. Obtained sclerites were viewed under a light microscope at magnifications of 100× and 400×. Dimensions of sclerites were measured and photographs were also taken. Genera of the Octocorals encountered were confirmed with the use of taxonomic keys from the Australian Institute of Marine Science (Fabricius and Aldeslade 2001).

To further identify the octocorals to species level, paratypes from the Zoological Reference Collection (ZRC) of the Raffles Museum of Biodiversity Research (RMBR), National University of Singapore, were examined. All paratypes used in this study were previously examined by Dr Benayahu during his work in Singapore (for the full list of paratypes examined, see: Benayahu and Chou 2010; Benayahu and Ofwegen 2011). Sclerites from surface lobe and base as well as interior lobe and base of collected samples were compared with sclerites prepared from paratype samples under the magnifications of 100× and 400×. In addition, colony morphologies of the octocorals photographed during the survey were compared against available photographs published in Erhardt and Knop (2005), Benayahu and Chou (2010) and Benayahu and Ofwegen (2011) to confirm octocoral identities.

Statistical analysis

Abundance of octocoral species encountered along each transect was calculated based on the total colony length (in metres) of each specific colony of octocoral. Octocoral diversity for each site surveyed was represented by the Shannon-Wiener index of diversity (Hutcheson 1970). This index of diversity was computed for each replicate belt transect based on species richness and abundance (colony length, in metres) of octocoral species.

One-way Analysis of Variance (ANOVA) was conducted on abundance and Shannon Diversity Index data to determine if octocoral abundance and species diversity varied between survey sites (Quinn and Keough 2002). *Post-hoc* REGWF (Ryan-Einot-Gabriel-Welsch F) and Games-Howell tests were used to further determine significant differences between sites in terms of species diversity and abundance, respectively (Zar 2010). Univariate analysis of data was conducted using MINITAB (MINITAB, Inc. Release 2007).

Multivariate tests were also used to carry out a large scale analysis of octocoral community structure at the survey sites. Octocoral community composition at the species level was assessed using the PRIMER v6 (Plymouth Routines in Multivariate Ecological Research) software package (Clarke and Green 1988; Clarke 1993). Octocoral species abundance for each belt transect was fourth root transformed, prior to the application of the Bray–Curtis similarity matrices. The Bray–Curtis similarity results were illustrated using hierarchical clustering with group-average linkage and a non-parametric multi-dimensional scaling (nMDS) ordination plot. A one-way Analysis of Similarity (ANOSIM) was then performed to determine if the octocoral community structures among the three survey sites were statistically dissimilar. In cases where the pairwise R value (statistic) determined for the survey sites was greater than the Global R, it indicated significant dissimilarity in community structure between the sites ($P<0.02$). Multivariate statistical analysis was conducted using PRIMER v6.0.

3. Results

Octocoral identification

All octocorals that we encountered at the three reefs surveyed consisted of members from the genera *Cladiella*, *Lobophytum*, *Nephthea*, *Sarcophyton* and *Sinularia*. Of a total of 16 distinct octocoral species, nine were identified to species level (Table 1). The remaining seven octocorals were identified down to the genus level, as we were unable to determine their identities at species level based on comparisons of the sclerites and morphology of the paratypes.

Abundance and diversity of octocorals

Abundance and diversity of octocorals was highest at Kusu Island followed by P. Semakau and P. Hantu (Figs. 2 and 3). Kusu Island had the largest coverage of octocorals with a total of 17.35 m (based on total colony lengths) while the lowest octocorals coverage was observed at P. Hantu at 1.70 m (based on total colony lengths). ANOVA analysis of abundance and diversity data indicated significant differences between the three locations. The *post-hoc* Games Howell test indicated that octocoral abundance at Kusu Island was significantly higher than that at P. Semakau and P. Hantu at $P<0.05$ (Fig. 3). Similarly, the REGW F test applied to diversity indices of octocorals showed that the reefs of Kusu Island were significantly higher in diversity compared to the reefs of P. Semakau and P. Hantu (Fig. 3, $P <0.05$).

nMDS analysis of octocoral communities

The 2D MDS plot indicated that P. Hantu soft coral communities were distinct from those at Kusu Island and P. Semakau (Fig. 4). Additionally, the Analysis of Similarities (ANOSIM) test results indicated that there were significant dissimilarities in octocoral community structure between P. Hantu and Kusu Island, and also between P. Hantu and P. Semakau ($P<0.02$; Table 2). Conversely, ANOSIM results indicated that the octocoral community structures between Kusu Isand and P. Semakau were not significantly dissimilar ($P>0.1$; Table 2).

4. Discussion

The present study surveyed the octocoral communities encountered at fringing reefs of three Southern Islands, including P. Hantu, P. Semakau and Kusu Island, of Singapore. Overall, 16 distinct octocoral morpho-species were identified based on colony morphologies as well as comparison of sclerites prepared from paratypes (Table 1). Many of the octocorals identified in this study had been previously recorded from Singapore (Benayahu and Chou 2010). Of a total of 29 alcyonacean species recorded from Singapore waters, nine species have been identified in the present study. Octocorals encountered in this study comprised members from Alcyoniidae (*Sarcophyton*, *Cladiella*, *Lobophyton* and *Sinularia*) and Neptheidae (*Nepthea*) and are considered widespread in the Indo-Pacific region (Fabricius and Aldeslade 2001; Goh et al. 2009; Chanmethakul et al. 2010). In addition, members of the aforementioned genera were found to be cosmopolitan, present at different habitats ranging from true reefs, rocky shores and shallow waters with low visibility. Among the *Sarcophyton* specimens that were documented in this study, *S. tenuispiculatum* was previously reported to be absent from P. Semakau and Kusu Island, which Benayahu and Chou (2010) suggested was due to the mass coral bleaching event in 1998. In this study, specimens of *S. tenuispiculatum* were once again encountered from the fringing reefs of P. Semakau and Kusu Island (Table 1). Possible explanations for its reappearance at these sites could be due to the *S. tenuispiculatum* colonies recovering from the 1998 bleaching event or the seasonal appearance of these octocorals. However, the lack of long term biomonitoring data of local octocorals hinders any further interpretation of this reappearance of *S. tenuispiculatum* at these Southern Islands. As with most publications of octocorals from Singapore (e.g. Goh et al. 2009; Benayahu and Chou 2010; Benayahu and Ofwegen 2011), the identities of species encountered in this study will form part of the historical records for local octocorals.

In the analysis of octocoral abundance, diversity and community structures using nMDS, both the identified and unidentified species were used in the computation. A recent study has shown that the inclusion of a large number of unidentified morpho-species in such an ecological analysis would not affect overall conclusions compared to just using identified morpho-species (Pos et al. 2014). Univariate data analyses suggested that Kusu Island has a significantly higher octocoral abundance and diversity compared to reef sites at both P. Hantu and P. Semakau (Fig. 2). Interestingly, in terms of community structure, multivariate analyses revealed that Kusu Island and P. Semakau octocoral communities were not significantly dissimilar. Based on nMDS analysis, only P. Hantu octocoral communities were significantly dissimilar from Kusu Island. Despite the close proximity of survey sites

(Fig. 1), localized environmental factors at these study sites may have influenced the octocoral diversity, abundance and community structures. Anthropogenic stresses could perhaps be one contributing factor for the observed differences, particularly in community structures. Pulau Hantu and P. Semakau lie in close proximity to each other (Fig. 1), with the latter presently functioning as a landfill for the Republic (Ng et al. 2011). During the development of this landfill in the 1990s, the resulting dredged spoils and silt layer formation may have caused a degradation of benthic biodiversity around P. Semakau (Chou and Loo 1994). In addition, the construction of an extensive rock bund along the eastern coast of P. Semakau may have raised levels of sedimentation in the surrounding water column and altered substrate composition, nutrient concentration and organic input in surrounding marine habitats (Chou et al. 2004). For instance, sedimentation rates (mostly sand and some silt) around P. Semakau had fluctuated between10 to 90 mg cm^{-2} day^{-1} (Chou et al. 2004). This rate is much higher than those postulated by Rogers (1990). Coupled with a busy shipping route around these Southern Islands, loose sediments are constantly being stirred up due to currents from high-speed vessels (Ng et al. 2011). An increase in sedimentation within the water column reduces light penetration, leading to low photosynthetic rates of zooxanthellae (*Symbiodinium* sp.) associated with anthozoans, such as these octocorals, resulting in its eventual denudation (Chua and Chou 1992). Conversely, while Kusu Island was subjected to massive land reclamation in 1975, any further developments near or at Kusu Island have since been minimal (Santosh et al. 2014). This would have allowed reef communities surrounding Kusu Island to possibly recover from that reclamation event over time, resulting in the re-establishment of a diverse community of benthic organisms, such as octocorals.

In elucidating the identities of the octocorals, sclerites were useful additional traits to distinguish among the known species collected. Of the 16 distinct octocoral samples, the sclerites of seven samples did not match with those prepared from paratypes. The taxonomy of these unidentified species requires further investigation and work is currently underway to ascertain their identity. Among the morphological traits of the sclerites examined, the surface lobe and base varied the most in appearance among octocoral species. On the other hand, the appearance of sclerites from the interior lobe and base were found to be similar, and therefore not useful for distinguishing species in this study. In their identification of *Sinularia* specimens from Singapore, Benayahu and Ofwegen (2011) had also examined the interior lobe and base of the sclerites through the use of electron microscope. They found that these two traits do vary in appearance among *Sinularia* species. While the use of electron microscopy might yield more details from the sclerites examined, a light microscope would suffice to allow more sclerites to be examined efficiently for taxonomic purposes.

5. Conclusions

The present study is first of its kind to assess octocoral diversity, abundance, and communities at three reef sites, namely P. Semakau, P. Hantu and Kusu Island, in Singapore. Of a total of 16 distinct octocoral morpho-species, nine have been identified to the species level based on sclerites comparision with paratypes maintained at RMBR. In addition, among the three sites surveyed, octocoral diversity and abundance were found to vary while communities were similar between Kusu Island and P. Semakau. Preliminary community data presented in this study could be part of a long term biomonitoring program to assess the state of coral reefs in Singapore.

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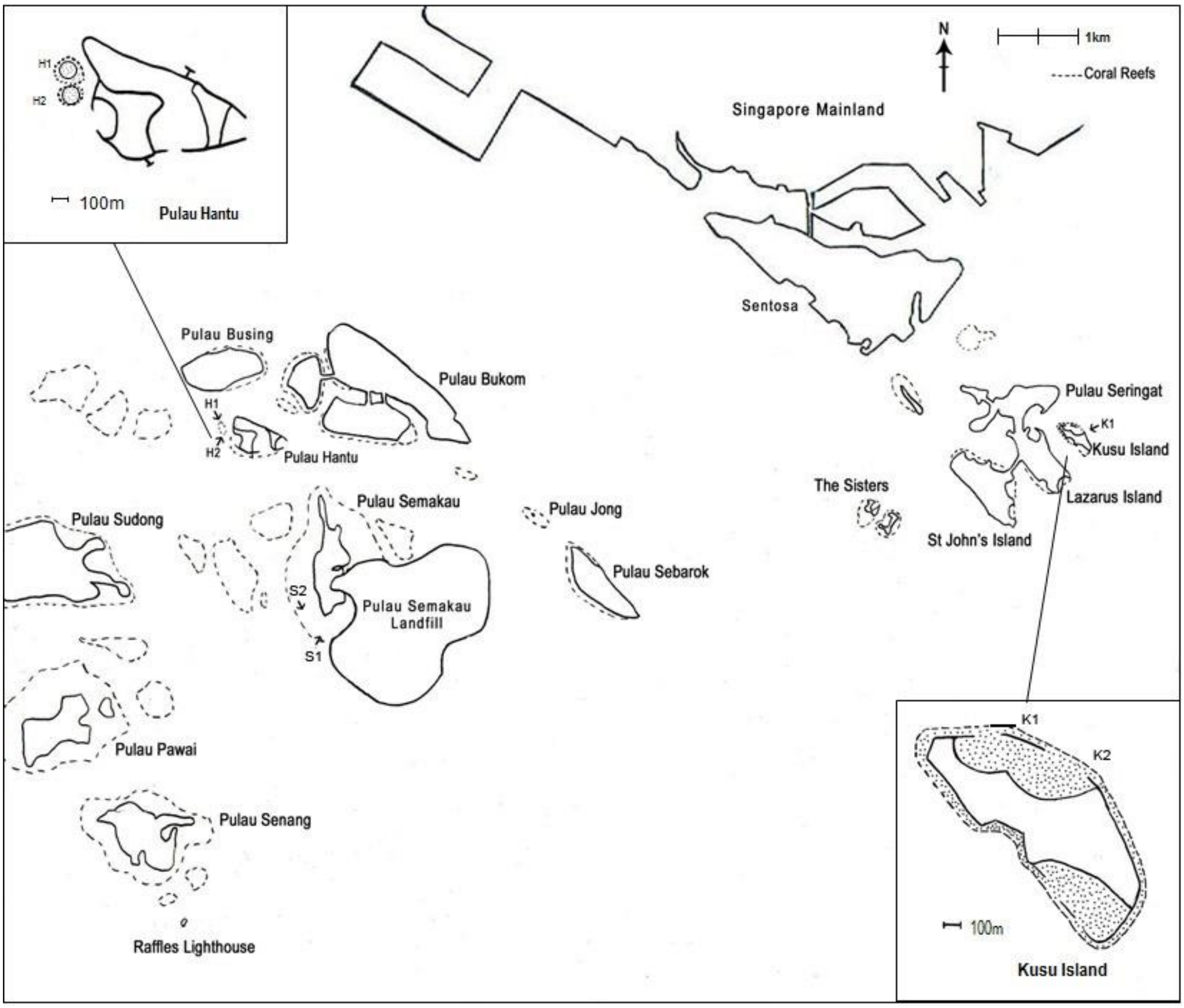

Fig. 1. Map of Southern Islands of Singapore illustrating the survey site locations. Inset: Enlarged maps of Kusu Island and Pulau Hantu indicating transect sites (H1 = P. Hantu 1, H2 = P. Hantu 2, K1 = Kusu Island 1, K2 = Kusu Island 2, S1 = P. Semakau 1, S2 = P. Semakau 2)

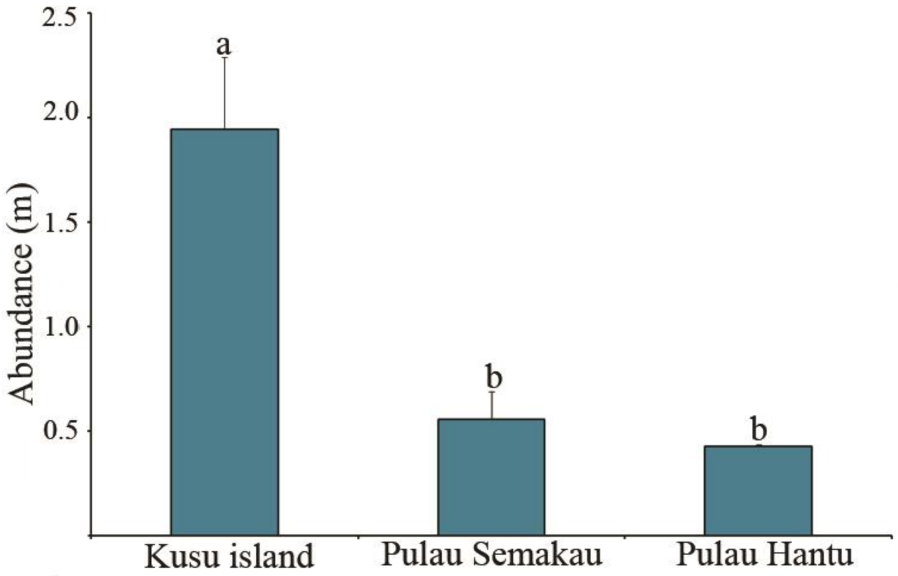

Fig. 2. Mean (± S.E.) abundance (colony diameter, m) of soft corals at survey sites. Different letters (a,b) indicate significance differences ($P < 0.05$)

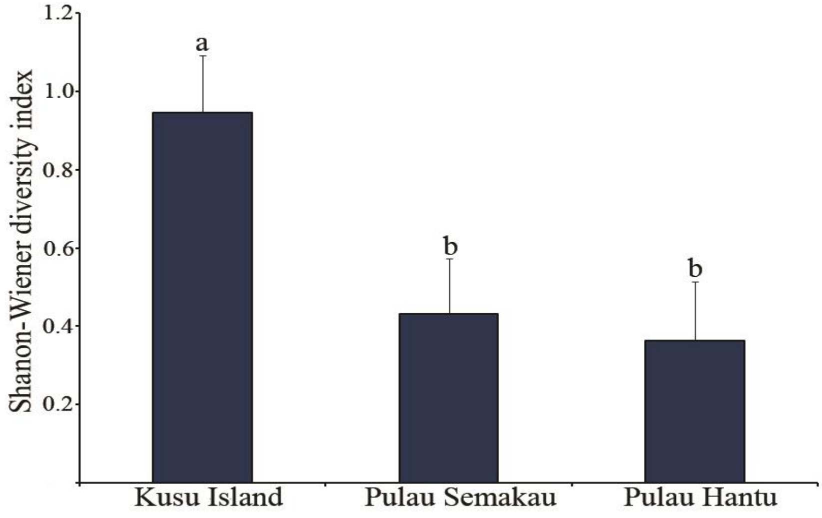

Fig. 3. Mean (± S.E.) Shannon-Wiener diversity index of soft corals at survey sites. Different letters (a,b) indicate significance differences (P < 0.05)

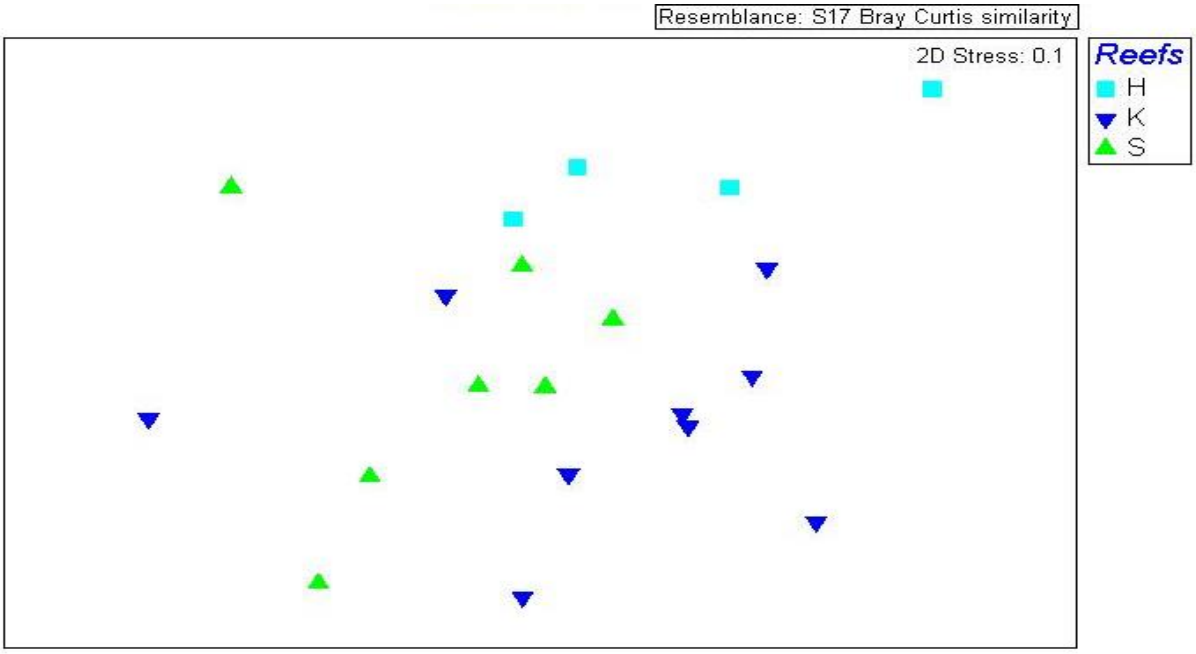

Fig. 4. Two-dimensional (2D) MDS configuration of soft corals communities at Pulau Hantu (H), Kusu Island (K) and Pulau Semakau (S). A stress value of 0.1 gave a good representation of the data

Table 1. Abundance (colony length in metres) of each soft coral species sampled in this study. (H1 = P. Hantu 1, H2 = P. Hantu 2, K1 = Kusu Island 1, K2 = Kusu Island 2, S1 = P. Semakau 1, S2 = P. Semakau 2)

Species List	**H1**	**H2**	**K1**	**K2**	**S1**	**S2**	**Total**
Cladiella hartogi Benayahu & Chou, 2010			0.50				0.50
C. pachyclados (Klunzinger, 1887)		0.45	0.50				0.95
Lobophytum crissum von Marenzeller, 1886				0.40			0.40
L. pauciflorum (Ehrenberg, 1834)				0.50		0.30	0.80
Nephthea sp. 1			2.55		0.60	0.50	3.65
Nephthea sp. 2		0.30	1.85	0.65	1.35		4.15
Nephthea sp. 3			1.00				1.00
Nephthea sp. 4			3.50	1.55			5.05
Sarcophyton ehrenbergi von Marenzeller, 1886	0.30	0.25	0.35				0.90
S. glaucum (Quoy & Gaimard, 1833)				0.35			0.35
S. tenuispiculatum Thomson & Dean, 1931			1.35	0.40	0.80		2.55
S. trocheliophorum von Marenzeller, 1886				0.50		0.35	0.85
Sinularia acuta Manuputty & van Ofwegen, 2007	0.40						0.40
Sinularia sp. 1			0.30				0.30
Sinularia sp. 2			0.70				0.70
Sinularia sp. 3			0.40				0.40
Total	**0.70**	**1.00**	**13.00**	**4.35**	**2.75**	**1.15**	

Table 2. R statistics derived from pairwise tests using ANOSIM to compare dissimilarities of soft coral communities among the three reefs. *Values above the Global R (0.189) indicate significant dissimilarities between sites ($P < 0.02$)

	Kusu Island	Pulau Semakau
Pulau Semakau	0.108	-
Pulau Hantu	0.294*	0.261*