The mushroom coral fauna (Scleractinia: Fungiidae) of Brunei Darussalam (South China Sea) and its relation to the Coral Triangle

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Abstract. Brunei Darussalam is situated on the northwest coast of Borneo, just outside the westernmost boundary of the area presently recognised as the centre of maximum marine biodiversity, the so-called Coral Triangle. This diversity is particularly quantified with regard to numbers of reef coral species. Most coral reefs of Brunei are offshore, submerged patch reefs, which makes them hard to discern from the water surface. Few coral studies have been carried out here, although recently an extensive reef coral inventory has been published for Brunei. The present study builds on this inventory by presenting a focus on the mushroom coral fauna of Brunei, based on a survey of the family Fungiidae at 17 sites varying in distance offshore. The purpose of this study is to compare the mushroom coral fauna of Brunei with other faunas in the region, which have been surveyed in a similar manner. A total of 33 species has been recorded, which is similar to various locations in the Coral Triangle and other areas around northern Borneo.

Key words. Reef corals, species richness, submerged reefs, Borneo

INTRODUCTION

Brunei Darussalam has numerous submerged patch reefs, which together are less than 100 km² in extent and situated on the continental shelf in the South China Sea at the northwest coast of Borneo (DeVantier & Turak, 2009; Lane, 2011). Despite their proximity to the Coral Triangle (Hoeksema, 2007; Veron et al., 2009), little was known about these reefs until a few years ago, except for one study that was carried out several decades earlier (Chua et al., 1987). This lack of information in the past was not extraordinary when compared to many other reef areas in the South China Sea (Huang et al., 2014). However, reef surveys have been carried out lately to assess the reef environments and reef coral diversity of Brunei (DeVantier & Turak, 2009; Turak & DeVantier, 2011), and also to monitor threats to its coral fauna, such as coral bleaching and coral predator outbreaks (Lane, 2011, 2012).

In order to compare Brunei’s reef coral assemblages with other coral faunas in Southeast Asia, in particular northern Borneo and the Coral Triangle, the mushroom coral family Fungiidae was selected as a proxy. Fungiid scleractinians have been included in previous studies for Brunei waters (Turak & DeVantier, 2011; Lane & Lim, 2013) but they never been surveyed comprehensively at this location. This family of over 50 species (Hoeksema, 1989, 2014; Gittenberger et al., 2011; Benzoni et al., 2012) has also been targeted in contemporaneous reef coral studies in nearby Sabah, eastern Malaysia (Waheed & Hoeksema, 2013, 2014; Waheed et al., subm), and in areas like Singapore (Hoeksema, 2009; Hoeksema & Koh, 2009) and Berau, East Kalimantan (Hoeksema et al., 2004).

This comparison will show how closely Brunei may be related to other areas in Southeast Asia and the Coral Triangle with regard to its mushroom coral fauna, which is of interest because the Coral Triangle receives much attention with regard to coral reef management (Cliftton, 2009; Mills et al., 2010; Carpenter et al., 2011; White et al., 2014). The species richness of Brunei is also of biogeographical importance because this country is situated near the westernmost boundary of the Coral Triangle, which has shifted over recent years (Green & Mous, 2004, 2008; Hoeksema, 2007; Veron et al., 2009, 2011).

MATERIAL AND METHODS

Data sampling. Presence/absence of mushroom coral species (Scleractinia: Fungiidae) was recorded on water proof paper during SCUBA diving at 17 localities in April 2011 (Fig. 1, Table 1). The roving diving technique was employed from a maximum of approximately 30 m depth upward, which gives better results regarding species richness than other survey methods (Schmitt et al., 2002; Hoeksema & Koh, 2009). Most reefs were submerged, some with their shallowest point at 12 m depth. Species identifications were carried out according to Hoeksema (1989) with an updated classification by Gittenberger et al. (2011) and Benzoni et al. (2012). Photographs were taken as reference for identification. A selection of pictures was made and is presented in plates.
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Table 1. Localities visited during mushroom coral field survey off Brunei in 2011.

<table>
<thead>
<tr>
<th>Site no.</th>
<th>Date</th>
<th>Location</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19 April</td>
<td>Abana Rock, southwest</td>
<td>05°06'24&quot;N 115°04'10&quot;E</td>
</tr>
<tr>
<td>2</td>
<td>19 April</td>
<td>Pelong Rocks, southwest</td>
<td>05°04'44&quot;N 115°03'05&quot;E</td>
</tr>
<tr>
<td>3</td>
<td>19 April</td>
<td>Pelong Rocks, south-southwest</td>
<td>05°04'41&quot;N 115°03'06&quot;E</td>
</tr>
<tr>
<td>4</td>
<td>20 April</td>
<td>Colombo Reef, Champion Shoal</td>
<td>05°12'28&quot;N 114°43'35&quot;E</td>
</tr>
<tr>
<td>5</td>
<td>20 April</td>
<td>Otterspool Rock</td>
<td>05°04'12&quot;N 114°39'03&quot;E</td>
</tr>
<tr>
<td>6</td>
<td>21 April</td>
<td>Littledale Shoal, south</td>
<td>05°06'10&quot;N 114°45'51&quot;E</td>
</tr>
<tr>
<td>7</td>
<td>21 April</td>
<td>Littledale Shoal, north</td>
<td>05°06'27&quot;N 114°45'36&quot;E</td>
</tr>
<tr>
<td>8</td>
<td>23 April</td>
<td>Abana rock, north</td>
<td>05°06'28&quot;N 115°04'13&quot;E</td>
</tr>
<tr>
<td>9</td>
<td>23 April</td>
<td>Two Fathom</td>
<td>05°05'45&quot;N 114°58'12&quot;E</td>
</tr>
<tr>
<td>10</td>
<td>25 April</td>
<td>Nankivell Rock</td>
<td>05°05'24&quot;N 114°32'44&quot;E</td>
</tr>
<tr>
<td>11</td>
<td>25 April</td>
<td>Hornet Reef (Brunei Patches)</td>
<td>05°01'13&quot;N 114°43'54&quot;E</td>
</tr>
<tr>
<td>12</td>
<td>27 April</td>
<td>Littledale Shoal, east</td>
<td>05°06'06&quot;N 114°45'59&quot;E</td>
</tr>
<tr>
<td>13</td>
<td>27 April</td>
<td>Littledale Shoal, north</td>
<td>05°06'27&quot;N 114°45'36&quot;E</td>
</tr>
<tr>
<td>14</td>
<td>28 April</td>
<td>Chearnley Shoal</td>
<td>04°52'05&quot;N 114°19'10&quot;E</td>
</tr>
<tr>
<td>15</td>
<td>28 April</td>
<td>Porter Patch</td>
<td>04°53'32&quot;N 114°24'08&quot;E</td>
</tr>
<tr>
<td>16</td>
<td>29 April</td>
<td>Pelong Rocks, northeast</td>
<td>05°04'56&quot;N 115°03'13&quot;E</td>
</tr>
<tr>
<td>17</td>
<td>29 April</td>
<td>Pelong Rocks, north</td>
<td>05°04'59&quot;N 115°03'12&quot;E</td>
</tr>
</tbody>
</table>

(Figs. 3–6) for species comparison. Four other sites were visited but excluded from the analysis because they were either shipwrecks or a 13 m deep sandy shoal with only a thin cover of solitary zoantharians of the genus *Sphenopus* (Reimer et al., 2012).

**Analysis.** In order to verify whether sampling was sufficient for obtaining a representative indication of the mushroom coral fauna for the whole area, species richness estimators were calculated using EstimateS 8.20 (Colwell, 2009). These estimators are illustrated as species accumulation curves in which the sample order has been randomised and the values have been averaged. The calculated mean values and standard deviations of the species richness at the sample numbers show an averaged rate at which additional species were found in the course of consecutive dives with an asymptote that indicates the expected total species richness (Magurran, 2004). The species richness estimators used for incidence data (presence/absence) are Chao 2 and ICE (Colwell, 2009). Presence/absence data for two *Cycloseris* species that previously belonged to the Siderastreidae (Benzioni et al., 2007, 2012), were recorded for Brunei but not for each separate site. These taxa were therefore excluded from the species richness analysis. Regarding the total of 17 survey sites, species were considered rare (when found at 1–3 sites), uncommon (at 4–6 sites), moderately common (at 7–11 sites), common (at 12–14 sites), and very common (at 15–17 sites). The present results are compared with those of previous studies dealing with the mushroom coral fauna of Brunei (Chou et al., 1987; Turak & DeVantier, 2011) and with those in other areas where the same method was used. Some specimens sampled by Turak & DeVantier (2011) have been deposited at the Fisheries Department Marine Biodiversity Centre, Brunei Darussalam. This collection was examined for partial verification of earlier species records that were not obtained by the present survey.

**RESULTS**

Thirty-two mushroom coral species were recorded at the 17 sites sampled in the field (Table 2). An additional one, *Zoopilus echinatus*, was found during the earlier survey by Turak & DeVantier (2011), which could be confirmed during the present study, giving a total of 33 Fungiidae species for Brunei. The number of species per site varied from 11 to 26 species (Table 2). The species accumulation curves (Fig. 2) showed that the expected number of 33 species (ICE, Chao 2) for Fungiidae is close to the observed number of 32 species, and that with additional sampling, one more species is to be expected. This additional one is represented by *Zoopilus echinatus* (Table 2; Fig. 7). The 33 species are listed below, while earlier records that could not be confirmed are also mentioned.
This free-living species is common at Brunei: recorded at all 17 sites (Table 2).

**Ctenactis albitentaculata** (Turak & DeVantier, 2011: 140).

*Ctenactis albitentaculata* – Turak & DeVantier, 2011: 140.

This free-living species is common at Brunei: recorded at 13 out of 17 sites (Table 2). Occasionally, clusters of 3–6 specimens were observed, all with tentacles extended.

**Ctenactis crassa** (Dana, 1846)

(Fig. 6B)

*Ctenactis crassa* – Turak & DeVantier, 2011: 140.

This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

**Ctenactis echinata** (Pallas, 1766)

(Fig. 6C)

*Fungia echinata* – Chou et al., 1987: 47.

**Ctenactis echinata** – Turak & DeVantier, 2011: 141.

This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

**Cycloseris costulata** (Ortmann, 1889)

(Fig. 3I)


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**SPECIES ACCOUNT**

*Ctenactis albitentaculata* Hoeksema, 1989

(Fig. 6A)

This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

**Ctenactis echinata** (Pallas, 1766)

(Fig. 6C)

*Fungia echinata* – Chou et al., 1987: 47.

**Ctenactis echinata** – Turak & DeVantier, 2011: 141.

This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

**Cycloseris costulata** (Ortmann, 1889)

(Fig. 3I)


This free-living species is common at Brunei: recorded at 14 out of 17 sites (Table 2). It was not observed in fragmenting shape. Although the illustrated specimen has a violet margin (Fig. 3i), the usual colour of this species is even brown (Gittenberger & Hoeksema, 2006). It has also been recorded as C. erosa (Döderlein, 1901) (see Turak & DeVantier, 2011), which actually is a synonym for C. tenuis (see Hoeksema, 1989). The colouration of a specimen illustrated and identified as C. vaughani by Turak & DeVantier (2011) is typical for C. costulata (compare Hoeksema, 1989; Hoeksema & Van Ofwegen, 2004; Gittenberger & Hoeksema, 2006). The costa of another specimen illustrated and identified as C. vaughani by Turak & DeVantier (2011) resembles those of C. boschmai Hoeksema, 2014, which has not been found during the present study, although it has been recorded at the reefs of Kota Kinabalu, located 150 km away in a NE direction (Waheed & Hoeksema, 2014). In comparison to C. boschmai and C. vaughani, C. costulata has less pronounced lower order costae.

*Cycloseris cyclolites* (Lamarck, 1816)

(Fig. 3D-F)


This free-living species is rare at Brunei: recorded at 3 out of 17 sites (Table 2). It was observed in complete (Fig. 3D) and in fragmenting shape (Fig. 3E, F), the so-called *Diaseris* form (see Hoeksema, 1989: Figs. 83, 84).

*Cycloseris explanulata* (Van der Horst, 1922)

(Fig. 4A)


This encrusting species is uncommon at Brunei (Turak & DeVantier, 2011). At the time of this survey it was considered to belong to the Siderastreidae, but based on morphological and molecular evidence (Benzioni et al., 2007), it was moved to the Fungiidae (Benzioni et al., 2012). Although this species was noted in the field, sites for this taxon were not recorded in the presence/absence survey.

*Cycloseris fragilis* (Alcock, 1893)

(Fig. 3A, B)


Not *Diaseris fragilis* – Turak & DeVantier, 2011: 131 (= *C. sinensis*).

This free-living species is moderately common at Brunei: recorded at 7 out of 17 sites (Table 2). It was observed in complete and in fragmenting shape. It has also been recorded as *C. patelliformis* (Boschma, 1923) (see Turak & DeVantier, 2011), which actually is a synonym of *C. fragilis* (see Hoeksema, 1989). Live specimens photographed in Indonesia and identified as *D. distorta* by Turak & DeVantier (2011) show thin septa, which are typical for *C. fragilis* and not for *C. distorta* (compare Hoeksema, 1989). *Diaseris* is considered a synonym of *Cycloseris* (Hoeksema, 1989; Hoeksema & Waheed, 2011, 2012).

*Cycloseris mokai* (Hoeksema, 1989)

(Fig. 4C)


This encrusting species is uncommon at Brunei: recorded at 6 out of 17 sites (Table 2).

*Cycloseris sinensis* Milne Edwards & Haime, 1851

(Fig. 3C)


This free-living species is common at Brunei: recorded at 6 out of 17 sites (Table 2). It was observed in complete and in fragmenting shape, the so-called *Diaseris* form (see Hoeksema, 1989: Figs. 48–54). A fragmented specimen identified as *Diaseris distorta* and shown in a black and white photograph by Turak & DeVantier (2011) is actually a specimen of *C. sinensis*.

*Cycloseris somervillei* (Gardiner, 1909)

(Fig. 3G, H)

Not *Cycloseris somervillei* – Turak & DeVantier, 2011: 131 (= *Lobactis scutaria*).

This free-living species is rare at Brunei: recorded at 3 out of 17 sites (Table 2). The prominent lower order costae (Fig. 3H) are characteristic for this oval and relatively large *Cycloseris* species.

This free-living species is common at Brunei: recorded at 14 out of 17 sites (Table 2). It was not observed in fragmenting shape. Although the illustrated specimen has a violet margin (Fig. 3i), the usual colour of this species is even brown (Gittenberger & Hoeksema, 2006). It has also been recorded as *C. erosa* (Döderlein, 1901) (see Turak & DeVantier, 2011), which actually is a synonym for *C. tenuis* (see Hoeksema, 1989). The colouration of a specimen illustrated and identified as *C. vaughani* by Turak & DeVantier (2011) is typical for *C. costulata* (compare Hoeksema, 1989; Hoeksema & Van Ofwegen, 2004; Gittenberger & Hoeksema, 2006). The costa of another specimen illustrated and identified as *C. vaughani* by Turak & DeVantier (2011) resembles those of *C. boschmai* Hoeksema, 2014, which has not been found during the present study, although it has been recorded at the reefs of Kota Kinabalu, located 150 km away in a NE direction (Waheed & Hoeksema, 2014). In comparison to *C. boschmai* and *C. vaughani*, *C. costulata* has less pronounced lower order costae.

![Species richness estimators (Colwell, 2009) for Fungiidae recorded at 17 sites off Brunei. The curves indicate that the occurrence of one additional species is possible when the maximum number of observed species (S Obs = 32) is compared to the maximum expected numbers (ICE, Chao 2 = 33). Only two species (Uniques) are each represented by a single individual.](image-url)
Table 3. Mushroom coral records from Indo-Pacific areas as comparison to the present results from Brunei (33 species), with a distinction between records from inside and outside the Coral Triangle.

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of Species</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coral Triangle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kudat, Sabah</td>
<td>39</td>
<td>Waheed et al., subm</td>
</tr>
<tr>
<td>Semporna</td>
<td>44</td>
<td>Waheed &amp; Hoeksema, 2013</td>
</tr>
<tr>
<td>East Kalimantan</td>
<td>40</td>
<td>Hoeksema et al., 2004</td>
</tr>
<tr>
<td>Cebu, Philippines</td>
<td>37</td>
<td>Hoeksema, 2007</td>
</tr>
<tr>
<td>North Sulawesi</td>
<td>33</td>
<td>Hoeksema, 2007</td>
</tr>
<tr>
<td>South Sulawesi</td>
<td>38</td>
<td>Hoeksema, 2007, 2012b, c</td>
</tr>
<tr>
<td>Wakatobi, SE Sulawesi</td>
<td>31</td>
<td>Hoeksema, 2003</td>
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<tr>
<td>Togian Bay</td>
<td>28</td>
<td>Wallace et al., 2000</td>
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<tr>
<td>Bali</td>
<td>36</td>
<td>Hoeksema &amp; Putra, 2000</td>
</tr>
<tr>
<td>Komodo</td>
<td>39</td>
<td>Hoeksema, 2007</td>
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<tr>
<td>Ambon</td>
<td>36</td>
<td>Hoeksema, 2007</td>
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<tr>
<td>West Halmahera</td>
<td>36</td>
<td>Hoeksema, 2010</td>
</tr>
<tr>
<td>Raja Ampat, West Papua</td>
<td>40</td>
<td>Hoeksema, 2008</td>
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<tr>
<td>Outside Coral Triangle</td>
<td></td>
<td></td>
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<tr>
<td>Kota Kinabalu, Sabah</td>
<td>35</td>
<td>Waheed &amp; Hoeksema, 2014</td>
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<td>Seychelles</td>
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<td>Hoeksema, 1994</td>
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<td>Red Sea</td>
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<td>Hoeksema, 1989</td>
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<td>Hoeksema, 1989, Riegl et al., 2012</td>
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<td>Hoeksema, 2007</td>
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<td>Hoeksema, 2007</td>
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<td>Koh Tao, Thailand</td>
<td>20</td>
<td>Hoeksema et al., 2012</td>
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<td>Singapore</td>
<td>19</td>
<td>Hoeksema &amp; Koh, 2009</td>
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<td>Jakarta, NW Java</td>
<td>29</td>
<td>Hoeksema, 2007</td>
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<td>Central Java Sea</td>
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<td>Hoeksema, 2007</td>
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<td>Taiwan</td>
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<td>Hoeksema &amp; Dai, 1991; Hoeksema, 2007</td>
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<td>Vanuatu</td>
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<td>Gambier Islands</td>
<td>6</td>
<td>Hoeksema &amp; Benzoni, 2012</td>
</tr>
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</table>

*Cycloseris tenuis* (Dana, 1846)

(Fig. 3J)

Not *Cycloseris tenuis* – Turak & DeVantier, 2011: 129 (= *Pleuractis granulosa*, *Cycloseris* spp.).

This free-living species is moderately common at Brunei: recorded at 9 out of 17 sites (Table 2). The lower order costae are large and roughly ornamented. The species has a typical greyish-brown colour with dark brown around its mouth and white lips (Gittenberger & Hoeksema, 2006). The specimens from Indonesia illustrated by Turak & DeVantier (2011) are wrongly identified.

*Cycloseris vaughani* (Boschma, 1923)

(Fig. 3K)

Not *Cycloseris vaughani* – Turak & DeVantier, 2011: 129 (= *Cycloseris costulata*).

This free-living species is rare at Brunei: recorded only at Colombo Reef, Champion Shoal (Table 2). The lower order costae are larger and sharper than in its congeners. The species has a patchy greyish-brown colour, usually with a radiating pattern (Fig. 2K; Hoeksema, 1989; Hoeksema & Van Ofwegen, 2004). The specimens illustrated by Turak & DeVantier (2011) are wrongly identified.

*Cycloseris wellsi* (Veron & Pichon, 1980)

(Fig. 4B)


This encrusting species is rare at Brunei (Turak & DeVantier, 2011). Previously it was considered to belong to the Siderastreidae but based on morphological and molecular evidence (Benzoni et al., 2007) this species was moved to the Fungiidae (Benzoni et al., 2012). Although this species was noted in the field, sites for this taxon were not recorded in the presence/absence survey.

*Danafungia horrida* (Dana, 1846)

(Fig. 4I)

Fig. 3. A, B, *Cycloseris fragilis*, complete coral at Hornet Reef (Brunei Patches), fragmenting coral at Abana Rock, north; C, *Cycloseris sinensis*, fragmenting coral at Abana Rock, north; D–F, *Cycloseris cyclolites* at Hornet Reef (Brunei Patches), complete coral, fragmenting coral upper and lower side; G, H, *Cycloseris somervillei* at Chearnley Shoal, upper and lower side of a coral; I, *Cycloseris costulata* at Pelong Rocks, northeast; J, *Cycloseris tenuis* at Hornet Reef (Brunei Patches); K, *Cycloseris vaughani* at Colombo Reef (Champion Shoal).
This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

_Danafungia scruposa_ (Klunzinger, 1879)  
(Fig. 4J)

_Fungia danai_ – Turak & DeVantier, 2011: 133.  

This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

_Fungia fungites_ (Linnaeus, 1758)  
(Fig. 4K)

_Fungia fungites_ – Chou et al., 1987: 47; Turak & DeVantier, 2011: 133.

This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

_Halomitra pileus_ (Linnaeus, 1758)  
(Fig. 4H)


This free-living species is common at Brunei: recorded at 11 out of 17 sites (Table 2). High numbers of very large specimens (diameter > 50 cm) were observed at various localities.

_Heliofungia actiniformis_ (Quoy & Gaimard, 1833)  
(Fig. 5A)


This free-living species is common at Brunei: recorded at 13 out of 17 sites (Table 2).

_Herpolitha limax_ (Esper, 1797)  
(Fig. 6D)


This free-living species is very common at Brunei: recorded at 16 out of 17 sites (Table 2). _H. weberi_ is a junior synonym of _H. limax_ (see Hoeksema, 1989).

_Lithophyllum concinna_ (Verrill, 1864)  
(Fig. 4E)


This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

_Lithophyllum repanda_ (Dana, 1846)  
(Fig. 4F)


This free-living species is very common at Brunei: recorded at all 17 sites (Table 2).

_Lithophyllum scabra_ (Döderlein, 1901)  
(Fig. 4D)


This free-living species is rare at Brunei: recorded at 3 out of 17 sites (Table 2).

_Lithophyllum undulatum_ Rehberg, 1892  
(Fig. 4G)


This free-living species is common at Brunei: recorded at 14 out of 17 sites (Table 2).

_Lobactis scutaria_ (Lamarck, 1801)  
(Fig. 5H)


This free-living species is common at Brunei: recorded at 14 out of 17 sites (Table 2).

_Pleuractis granulosa_ (Klunzinger, 1879)  
(Fig. 5C)


This free-living species is very common at Brunei: recorded at 16 out of 17 sites (Table 2).

_Pleuractis gravis_ (Nemenzo, 1955)  
(Fig. 5D)


This free-living species is very common at Brunei: recorded at 15 out of 17 sites (Table 2).

_Pleuractis moluccensis_ (Van der Horst, 1919)  
(Fig. 5E)


This free-living species is common at Brunei: recorded at 14 out of 17 sites (Table 2).

_Pleuractis paumotensis_ (Stutchbury, 1833)  
(Fig. 5F)

Fig. 5. A, Heliofungia actiniformis at Littledale Shoal, north; B, Polyphyllia talpina at Pelong Rocks, southwest; C, Pleuractis granulosa at Littledale Shoal, south; D, Pleuractis gravis at Littledale Shoal, south; E, Pleuractis moluccensis at Pelong Rocks, southwest; F, Pleuractis paumotensis at Abana Rock, south; G, Pleuractis taiwanensis at Pelong Rocks, north; H, Lobactis scutaria at Pelong Rocks, northeast.
Fig. 6. A, Ctenactis albitentaculata at Littledale Shoal, north; B, Ctenactis crassa at Otterspool Rock; C, Ctenactis echinata at Abana Rock, south; D, Herpolitha limax at Littledale Shoal, south; E, Sandalolitha dentata at Porter Patch; F, Sandalolitha robusta at Littledale Shoal, south; G, Podabacia crustacea at Pelong Rocks, south-southwest; H, Podabacia motuporensis at Two Fathom Rock.
This free-living species is very common at Brunei: recorded at all 17 sites (Table 2). Several specimens were infested by acoel flatworms of the genus *Waminoa* (see Hoeksema & Farenzena, 2012).

**Pleuractis taiwanensis** Hoeksema & Dai, 1991  
(Fig. 5G)

*Pleuractis taiwanensis* – Turak & DeVantier, 2011: 139.

This free-living species is rare at Brunei: recorded only at north Pelong Rocks (Table 2).

**Pleuractis taiwanensis**  
(Turak & DeVantier, 2011: 139.)

This free-living species is very common at Brunei: recorded at 14 out of 17 sites (Table 2).

**Sandalolitha dentata** Quelch, 1884  
(Fig. 6E)


This free-living species is common at Brunei: recorded at 14 out of 17 sites (Table 2).

**Sandalolitha dentata** (Quelch, 1886)  
(Fig. 6F)


This free-living species is very common at Brunei: recorded at 15 out of 17 sites (Table 2).

**Zoopilus echinatus** Dana, 1846  
(Fig. 7A, B)


This free-living species is rare at Brunei (Turak & DeVantier, 2011). It was not recorded during our survey (Table 2), but photographs taken at Silk Rock (Turak & DeVantier, 2011) and a specimen fragment in the collection of the Brunei Fisheries Department (Fig. 7A, B) leave no doubt about the occurrence of this species at Brunei, which underlines the importance of museum specimens as reference material in biodiversity studies (Hoeksema et al., 2011).

**UNCONFIRMED RECORDS**

The following four species were not recorded during our survey (Table 2). Their presence at Brunei was reported by Turak & Devantier (2011), but without photographic evidence (photographs of live animals were taken outside Fig. 7.

**Fig. 7. Zoopilus echinatus.** A fragment with regenerated margins from Silk Rock, 10 m depth, 21 October 2008, Coll. L. Devantier. A, upper surface; B, lower surface. Scale bar = 0.5 cm.
in the present study.

_Cycloseris distorta_ (Michelin, 1842)


A fragmented coral identified as _Diaseris distorta_, shown in a black and white photograph by Turak & DeVantier (2011), is actually a specimen of _C. sinensis_. Colour photographs of live specimens taken in Indonesia (Turak & DeVantier, 2011) actually represent _C. fragilis_, which can be recognised because of its very thin septa (see Hoeksema, 1989).

_Cycloseris hexagonalis_ (Milne Edwards & Haime, 1848)


One colour photograph of a live specimen published by Turak & DeVantier (2011) was taken in Indonesia; the origin of the other one is not mentioned. The identity and origin of a third coral (diameter 6 cm) showing the aboral side in a black and white photograph is unclear. This specimen shows prominent lower order costae, while _C. hexagonalis_ of that size usually shows a nearly smooth aboral side with costae that are almost invariable in size (Hoeksema, 1989). Because Turak & DeVantier (2011) state that _C. hexagonalis_ may resemble _C. temuis_, which has very coarsely ornamented lower order costae, the occurrence of _C. hexagonalis_ at Brunei remains uncertain.

_Lithophyllum ranjithi_ Ditlev, 2003


One colour photograph of a live specimen published by Turak & DeVantier (2011) was taken in Indonesia; the origin of other photographs is unclear. They present this species as _L. lobata_, a junior synonym of _L. undulatum_ (see Hoeksema, 1989). The syntypes of _L. lobata_ are large, thin, twirled foliaceous corals with thin septa and mouths scattered over the whole upper surface, whereas specimens of _L. ranjithi_ are thick laminar corals in one plane with folded margins, thick septa, and mouths concentrated at the centre of the upper surface. _L. ranjithi_ is known from East Sabah and East Kalimantan (Ditlev, 2003; Hoeksema et al., 2004; Waheed & Hoeksema, 2013), and it has also been observed in the Kudat area at north Sabah and at Layang-Layang atoll in the South China Sea (Waheed & Hoeksema, in prep.). It was not found at the reefs of Kota Kinabalu (Waheed & Hoeksema, 2014), which are only about 150 km away from Brunei in a NE direction.

_Lithophyllum spinifer_ (Claereboudt & Hoeksema, 1987)


Colour photographs of a live specimen published by Turak & DeVantier (2011) were taken in Indonesia. An additional black and white photograph (locality not indicated) only shows a quarter portion of the upper surface of a thin, coral, which could be a juvenile specimen of _L. spinifer_ or belong to _Cycloseris fragilis_. Specimens of _L. spinifer_ are shaped like a saucer, usually with a thick, bulging central area, a corallum margin turning upward, and strongly developed lower order costae (Claereboudt & Hoeksema, 1987; Hoeksema, 1989, 1993).

**DISCUSSION**

The present result of 33 confirmed mushroom coral species records ( _Cycloseris explanulata_ and _C. wellsii_ excluded) is less than the 44 counted by Turak & DeVantier (2011). This difference is partly based on the inclusion of various synonyms by the latter. Moreover, several of the earlier species records could not be confirmed because they were not found during the present survey and because hardly any voucher specimens or photographic evidence from the earlier study were available for these species.

The number of 33 Fungiidae species found at Brunei is close to the total of 35 recorded at Kota Kinabalu, which is in close proximity to Brunei, but distinctly less than the 39 found in the Kudat area at the northernmost tip of Borneo, the 44 of Semporna at the eastern coast of Sabah, and the 40 species recorded at East Kalimantan (Table 3). Southeast Asian areas outside the Coral Triangle have records that range from 19 at Singapore to, 20 at Koh Tao in the Gulf of Thailand, 21 at West Sumatra, 23 at Phuket, Andaman Sea, 26 in the central Java Sea, 29 at NW Java, and 26 at Taiwan (Table 3). Vanuatu in the West Pacific has 35 species of recorded mushroom coral species, Palau 30, and the remote Gambier Islands only six. Furthermore, 20 species of Fungiidae were recorded in the Seychelles, western Indian Ocean, and 19 in the Red Sea (Table 3). Overall, there is a distinct decrease in mushroom coral species numbers from the central Indo-Pacific towards the periphery of the Indo-Pacific (Hoeksema, 1989).

Indo-West Pacific areas inside the Coral Triangle (other than those already mentioned) have recorded numbers like 40 at West Papua, 40 in northern Papua New Guinea, 39 at Komodo, 36 at Ambon, 33 at North Sulawesi, 37 at central Philippines, 38 at South Sulawesi, 36 at West Halmahera, and 36 at Bali (Table 3). On the other hand, some areas inside the Coral Triangle may also show low species numbers, which may be related to low habitat diversity: for example, 31 species in the Wakatobi Islands off SE Sulawesi and 28 species in the Togian Bay of central Sulawesi. Other areas in eastern Indonesia have species numbers ranging from 26 to 33, but these were only visited briefly (Hoeksema & Moka, 1989). Regardless, all these numbers indicate that the total number of 33 mushroom coral species found at Brunei is comparable to the species richness of various areas in the Coral Triangle.

Although there is variation in recorded species diversity among areas within the Coral Triangle, there are no clear species diversity gradients (Hoeksema, 2007, 2013; Veron et
al. 2009), such as the latitudinal gradient in the adjacent South China Sea (Huang et al., 2014). This CT variation shown by mushroom corals in particular and all reef corals together can be attributed to differences in habitat diversity and sampling effort (Best et al., 1989; Hoeksema & Moka, 1989; Wallace et al., 2000; Bellwood & Hughes, 2001; Hoeksema, 2007). On the other hand, there are clear diversity gradients from the Coral Triangle away towards the margins of the IWP (Hoeksema, 1989; Bellwood & Meyer, 2009a). Therefore, owing to its close proximity to the Coral Triangle, Brunei is not expected to have a much lower species richness than areas within the Coral Triangle (but see Huang et al., 2014).

The present northwestern boundary of the Coral Triangle would exclude Brunei. Its position is based on scleractinian species richness in ecoregions as defined by Veron et al. (2009, 2011), Earlier, this northwestern boundary was located more westward, situated along the continental shelf in the South China Sea and delimited by the large river outlets of Sarawak, to the southwest of Brunei (Green & Mous, 2004; Hoeksema, 2007; Spalding et al., 2007). The eastward shift of the northwestern boundary (Veron et al., 2009, 2011) implies that the boundary would start from the northernmost tip of Borneo. The ecoregion “Palawan/north Borneo” indicated by Spalding et al. (2007) has been replaced by the “Sulu Sea” ecoregion by Veron et al. (2009, 2011), which excludes the northwest coast of Borneo in the South China Sea. The present results based on the mushroom coral species richness of Brunei (n=33), but also those from Kota Kinabalu (n=35), comprising an even smaller research area (Waheed & Hoeksema, 2014), suggest that the position of the northwestern boundary of the Coral Triangle needs to be reconsidered.

Precise data on the species richness pattern in and around the Coral Triangle and the exact position of its boundaries may help to explain which processes in the past resulted in the present-day concentration of species here (Hoeksema, 2007, 2013; Barber, 2009; Bellwood & Meyer, 2009b; Briggs, 2009). In the present study the family Fungiidae is used as a proxy subset of scleractinian reef corals to compare the coral diversity of Brunei with coral faunas of adjacent areas. The results show that the use of such an exemplar taxon in short-term surveys using presence/absence data may serve well in comparisons of species numbers among small study areas. The results can be tested for accuracy by the application of species richness estimators and can serve as a substitute for data obtained during labour-intensive studies involving all reef coral species present, in which the maximum number of species remains uncertain.

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LITERATURE CITED


