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A SURVEY OF JELLYFISH (CNIDARIA) AROUND ST JOHN'S ISLAND IN THE SINGAPORE STRAITS

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ABSTRACT. — We document seven species of cnidarian jellyfish collected from the waters surrounding St John's Island, located in the Singapore Straits. The seven pelagic cnidarians described here are: *Aequorea pensilis*, *Diphyes bojani*, *Liriope tetraphylla*, *Chrysaora chinensis*, *Aurelia aurita*, *Netrostoma dumokuroa* and *Phyllorhiza punctata*. Most of these cnidarians found here have been reported previously elsewhere in the Indo-Pacific, but it is the first time that *N. dumokuroa* have been documented outside of Fiji. Four other cnidarian jellyfish are recorded in Singapore for the first time: *A. pensilis*, *D. bojani*, *C. chinensis*, and *Au. aurita*. Two species, namely *Liriope tetraphylla* and *Phyllorhiza punctata* have been documented previously from Singapore.

KEY WORDS. — Jellyfish, Cnidaria, Hydrozoa, Scyphozoa, Southeast Asia, Singapore

INTRODUCTION

The cnidarian jellyfish from the waters around the Republic of Singapore are poorly documented and studied. Since Haeckel's (1879) description of *Thamnostoma macrostomum* (Haeckel, 1879) from Singapore, at least 25 different genera of marine jellyfish have been recorded (see Appendix). However, after Searle's (1957) account on local jellyfish, no taxonomic or ecological research has been conducted on pelagic cnidarians here, with the recent exception of a small study on *Cassiopea xamachana* (Lee, 2009; unpub. thesis). Recent accounts of jellyfish occurring locally are primarily in field guides and encyclopedias (see Appendix). Unfortunately these records are difficult to verify. Descriptions given are often insufficient to determine their identities, and voucher specimens are not available. In recent years, Singapore has seen a surge of the public's interest in local wildlife and recreational activities (e.g guided reef-walks, diving, fishing, etc.) held within maritime areas (Chan, 2011) where jellyfish occur. These cnidarians are known to inflict a painful stinging sensation when in contact, that might cause scarring (e.g., Searle, 1957; Sharma, 1973; Burnett, 2001), physiological disorders such as urinary incontinence (Burnett, 2006) and even death (Sharma, 1973). Conversely in Southeast Asia, these pelagic cnidarians are also considered as both a delicacy (Omori & Nakano, 2001; Kitamura & Omori, 2010) and a popular dried snack. To keep up with demand, edible jellyfish fisheries in the region (e.g., Indonesia, Singapore, Malaysia) are expanding (Omori & Nakano, 2001; Kitamura & Omori, 2010). Jellyfish also play important roles in marine ecosystems, maintaining the food webs as both predator and prey (Purcell, 1997; Arai, 2005). Rising global temperatures and increasing habitat degradation have resulted in frequent jellyfish blooms occurring worldwide (Purcell, 2005). This could destabilise complex marine food webs and in addition, impede economic activities such as fish farming (Purcell et al., 2007). Thus, knowledge of the type and seasonality of these medusae are not only of intrinsic value to fisheries management but also to the public's safety and health, as well as in making management decisions concerning the marine environment. The main objective of this study is to provide a preliminary taxonomic record of these pelagic cnidarians found around Singapore.

MATERIAL AND METHODS

Jellyfish specimens examined in this study were collected from the Singapore Straits, around St John's Island jetty over a six-year period, from January 2006 to August 2012. Collections were carried out whenever the opportunity arose. In addition, similar specimens collected from the northern

shores of Singapore were also examined in this study. Most of these specimens were examined live in a tank in the laboratory, fixed in 10% buffered formalin, then dissected on a flat surface with water. To facilitate with the preliminary identification of the specimens, we referred to Mayer (1910), Kramp (1961), Cornelius (1997), Bouillon et al. (2004) and Calder (2009). Thereafter, specific morphological characters of the specimens were compared against available taxonomic literature. Where necessary, foreign language descriptions were translated with Google Translate (Google Inc., 2012). Due to the differences in terminologies of the various anatomical characters for each class of cnidarians, we followed descriptors and methodologies used in Russell (1953, 1970), Bouillon et al. (2004), Morandini & Marques (2010), Bolton & Graham (2004) and Gershwin et al. (2011).

Cnidae were extracted from the fixed specimens via squashing of a small piece of tissue under cover slips. Tentacles or filaments of mouth-arms from each jellyfish were sampled. For each type of cnidae, ten undischarged capsules were measured for both capsule length and width. Measurements of the cnidae were made at 1000x magnification, oil immersion, with a compound microscope (Olympus CX31, Japan). Due to the variability of cnidae nomenclature (Fautin, 2009) and to remain consistent with previously published descriptions, documentation of the cnidae followed that of Russell (1953, 1970), Östman (2000), Bouillon et al. (2004) and Morandini & Marques (2010) for the relevant specimens described here. In addition, photographs were taken, to document the cnidae capsules measured.

Voucher specimens were deposited in the Zoological Reference Collection, Raffles Museum of Biodiversity Research, Department of Biological Sciences, National University of Singapore (ZRC).

SYSTEMATIC ACCOUNT

Class HYDROZOA (Owen, 1843)
Subclass LEPTOMEDUSAE (Haeckel, 1879)
Order CONICA (Broch, 1910)

AEQUOREIDAE (Eschscholtz, 1829)
Aequorea (Péron & Lesuer, 1810)

Aequorea pensilis (Eschscholtz, 1829)
(Fig. 1A & B)

Mesonema coelum pensile — Eschscholtz, 1829: 112
Mesonema pensile — Haeckel, 1879: 226
Aequorea pensilis — Mayer, 1910: 333; Bouillon, 2004: 118;
Taxonomic comparisons from 1910 to 1961 are too numerous to list here; for additional synonyms, please refer to Kramp, 1961

Material examined. — St John's Island Jetty (ZRC.CNI. 0692x3, ZRC.CNI. 0693x2, ZRC.CNI. 0694x1, ZRC.CNI. 0695x8, ZRC. CNI. 0696x1); Beting Bronok (Fig. 1B).

Diagnosis. — Glassy transparent biconvex bell, diameter ranging between 45 mm and 70 mm. Up to 160 or more radial canals, 14 – 22 marginal tentacles. Tentacle bulbs pyramidal with long lateral extensions, without abaxial keel and excretory papillae.

Description of specimens. — Bell: Biconvex. Mesoglea is thick and uniform throughout. Diameter of bell between 45 mm to 70 mm. Height of bell up to 20 mm. Glassy transparent in life and remains so in fixative (Fig. 1A & B).

Stomach and radial canals: Stomach occupies up to 3/5 of the subumbrella. For all specimens, a shallow furrow is present between the stomach and the margin of the bell. Radial canals line the furrow, up to 160 or more is present. These canals are straight, singular and mostly unbranching; although some are forked at either the end closest to the stomach or the bell margin. The width of the radial canals is thin and uniform, milky-white in fixative.

Gonads: For all specimens, gonads are separate from stomach. Gonads are straight, bilamellar and extending the entire length of the radial canal.

Tentacles and tentacular bulbs: Tentacular bulbs plain, without excretory papillae and abaxial keel. Adaxial center of bulb is sometimes sunken. Shape of tentacular bulb is pyramidal/ funnel-shaped, extending laterally to the tentacles. Marginal tentacles are smooth, hollow and unbranching. Specimens typically have 14 to 22 tentacles, regardless of size. Length of tentacles varies. Rudimentary bulbs are present between tentacular bulbs, ranging between 15 and 35 in number, dependent on the size of the jellyfish.

Velum and statocysts: Velum for all specimens is narrow, thin and straight. Statocysts present, numerous as external closed vesicles.

Tentacle cnidae — Large atrichous isorhiza, small atrichous isorhiza and microbasic eurytele (Fig. 2A–C). For size distribution, see Table 1.

Remarks. — The taxonomy of the Aequoreidae is in need of revision, due to varying forms of similar looking species and the difficulty of distinguishing them (Bigelow, 1919; Gershwin et al., 2010). Historically, species identification criteria used differed amongst authors, and earlier descriptions were too brief to be useful (e.g Péron & Lesueur, 1810). Most Aequoreidae workers have often used the number of radial canal to tentacles (e.g Vanhöffen, 1911; Russell, 1953; Bouillon et al., 2004) and tentacle bulb morphology (e.g Browne, 1905; Russell, 1953) for species recognition, although some authors have suggested that these are inadequate (e.g Bigelow, 1919). Despite this, in this present study we have adopted these commonly used character traits to identify the *Aequorea* specimens collected.

Aequorea pensilis is a first record for Singapore. While *A. pensilis* seems to occur from March to July in Singapore (pers. obs.), there is insufficient local data currently to determine

if this hydrozoan does occur during these warmer months. Stiasny (1928) reported two *Aequorea* species occurring in Singapore waters (Appendix A). *Aequorea pensilis* is easily distinguished from *A. conica* and *A. parva* in having up to 160 or more radial canals, few marginal tentacles and plain, pyramidal tentacle bulbs without excretory papillae (Russell, 1953; Kramp, 1961; Bouillon et al., 2004). In contrast, *A. conica* have only 16 radial canals, twice as many marginal tentacles to canals and excretory papillae on the bulbs (Russell, 1953; Kramp, 1961; Bouillon et al., 2004). Similarly, *A. parva* differs from *A. pensilis* in that the former has up to 16 radial canals, up to 8 marginal tentacles and the presence of excretory pores (Kramp, 1961).

The glassy transparent appearance and shape of the *Aequorea* species may also be superficially mistaken for *Aurelia* species that occurs in the same duration. *Aequorea* belongs to the class Hydrozoa, where medusae typically possess a muscular velum, undivided stomach and the lack of nematocysts on its ectoderm (Pearse et al., 1987). *Aurelia* is of the cnidarian class Scyphozoa, its medusae characterised by the absence of the velum, a partitioned gastric cavity with the presence

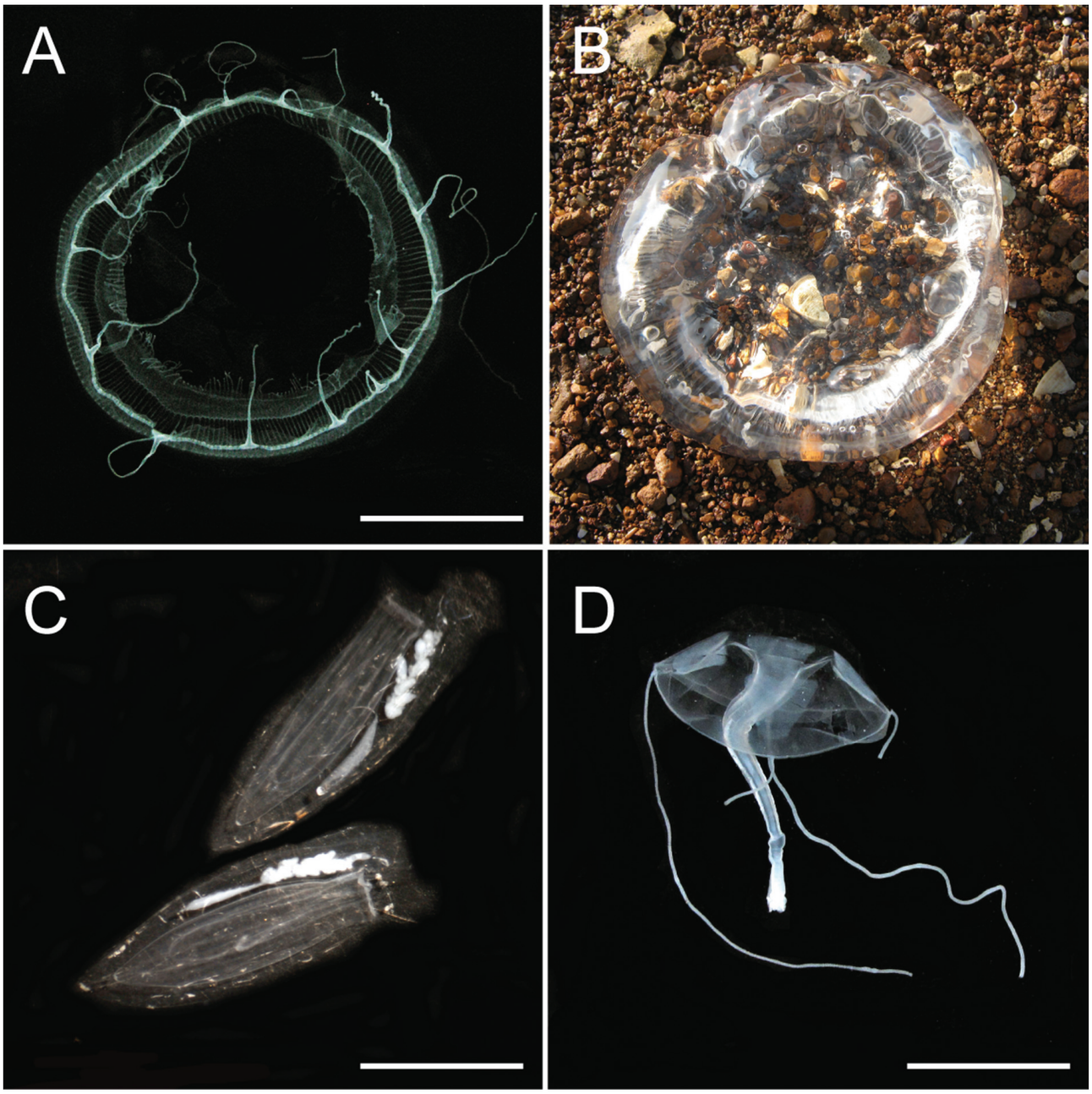

Fig. 1. Hydrozoan jellyfish found from the waters of St John's Island, Singapore, (A) *Aequorea pensilis*: St John's Island (ZRC.CNI.0692). Fixed in 10% formalin. Subumbrella view. Note the numerous radial canals. Scale bar = 2 cm. Photo: N. Yap; (B) Live *A. pensilis*: Beting Bronok, stranded upon the shore. Photo: C. K. Chim; (C) *Diphyes bojani*: St John's Island (ZRC.CNI.0687). Fixed in 10% formalin. Scale bar = 5 mm. Photo: N. Yap; (D) *Liriope tetraphylla*: St John's Island (ZRC.CNI.0690). Fixed in 10% formalin. Note the four distinctive gonads. Scale bar = 5 mm. Photo: J. Y. Ong.

of gastric filaments within it (Pearse et al., 1987). Aequoreid medusae cannot be confused with any other scyphozoans.

Contact with *A. pensilis* may result in a sharp itchy rash with light or intense swelling (pers. ob.) which can persist for several hours. In the water, *A. pensilis* is difficult to spot due to its near transparency. *Aequorea pensilis* are also commonly washed up on our local shores, appearing as thick discs of glassy jellies (Fig. 1B), where the tentacles and radial canals are not immediately obvious. Some authors (Panikkar, 1938; Namikawa & Soyama, 2000) have reported that *Aequroea* medusae are hosts to the parasitic juveniles of the haloclavid anemone, *Peachia* sp. We have not observed any of these parasitic attachments on our specimens.

Distribution. — Atlantic, Indo-Pacific and Mediterrenean (Kramp 1961; Bouillon et al., 2004)

Subclass SIPHONOPHORA (Eshscholtz, 1829)
Order CALYCOPHORAE (Leuckart, 1854)

DIPHYIDAE (Quoy & Gaimard, 1827)
Diphyes (Cuvier, 1817)

***Diphyes bojani* (Eshscholtz, 1829)**
(Fig. 1C)

Diphyes augustata — Eschscholtz, 1829: 136
Doromasia bjoani — Chun, 1892:108, 110
Doromasia pictoides — Lens & Van Riemsdijk, 1908: 3
Diphyes bojani — Bigelow, 1911: 251; Bouillon et al., 2004: 220
Diphyes indica — Lens & Van Riemsdijk, 1908:44
Diphyes malayana — Lens & Van Riemsdijk, 1908: 45
Diphyes gegenbauri — Lens & Van Riemsdijk, 1908:46

Material examined. — St John's Island Jetty (ZRC.CNI. 0687x3).

Diagnosis. — (Based on the polygastric stage) Pointed rocket shaped individuals, up to 10 mm in length. Anterior nectophore bears five complete ridges slightly serrated. Nectosac is generally cylindrical in shape but pointed towards the nectophore apex. Hydroecium narrow and deep, long somatocysts fusiform, extending towards apex. Posterior nectorphore also serrated, with three ostial teeth and prominent apophysis.

Description of specimens. — Nectophore: Up to 10 mm in length and 3 mm at the broadest width. Anterior nectophore with five complete longitudinal ridges slightly serrated. Ridges meet at the apex forming a pointed pyramidal shape. Three ostial teeth are present at the posterior nectophore, similarly sized. Apophysis is present at the posterior, slightly larger than the ostial teeth. Edge of the posterior nectophore serrated.

Nectosac, hydroecium and somatocysts: Nectosac cylindrical, but pointed as it reaches near the nectophore apex. Basal lamellae entire and thin. Hydroecium narrow and deep, approximately 1/3 the length of the nectophore. Somatocysts fusiform and overall longer than the hydroecium, extending to the apex of the nectophore. In fixative, somatocyst is milky-white in colour.

Remarks. — First record for Singapore. Another siphonophore, *D. chamissonis*, has been reported to occur commonly in our local waters, in both polygastric and edoxids stages (Wickstead, 1958; Ng et al., 2011). Chuang (1961) also reported the presence of *D. chamissonis* as part of the zooplankton in Singapore's waters. However, the figure of the animal accompanying the record (Chuang, 1961: 113) is misidentified as *D. chamissonis*. Nor does the author give a useful description of the animal, "… It may exceed 10 mm in length. It has two transparent swimming bells of about equal size." (Chuang, 1961: 114). Due to morphological similarities (both species are transparent and rocket shaped) and diminutive size, it is easy to confuse *D. bojani* for *D. chamissonis*. The pointed apex of *D. bojani* is distinct. *Diphyes chamissonis* has an obtuse apex and with the anterior slightly convex (Huxley, 1859). In addition, the somatocyst of *D. bojani* is longer than the hydroecium, extending towards the nectophore apex, whereas in *D. chamissonis* it is shorter than the hydroecium (Huxley, 1859). It has also been reported that another Didphyidae, *Lensia* spp. (Ng et al., 2011) is also common in these waters. *Lensia* differs from *Diphyes* sp. in that it lacks ostia teeth, has a shallow hydroecium and the number of ridges of the nectophore varies, more than five (Bouillon et al., 2004). Thus *Lensia* cannot also be confused for *Diyphes*.

Distribution. — Tropical and subtropical waters of Atlantic, Pacific and Indian oceans, the Mediterrenean (Alvariño, 1971; Bouillon et al., 2004). In the Mediterranean, *D. bojani* is common and occurs all year-round (Bouillon et al., 2004), and it is likely that it does so in the Indo-Pacific too.

Subclass TRACHYLINA (Haeckel, 1879)
Order TRACHYMEDUSAE (Haeckel, 1879)
GERYONIIDAE (Eschscholtz, 1829)
Liriope (Lesson, 1843)

***Liriope tetraphylla* (Chamisso & Eysenhardt, 1821)**
(Fig. 1D)

Taxonomic literature prior to 1961 too numerous to list here; for complete list of synonyms, refer to Kramp (1961)
Liriope tetraphylla — Bouillon et al., 2004: 238; Gershwin et al., 2010: 51, 83; Namikawa & Soyama, 2010: 64

Material examined. — St John's Island Jetty (ZRC.CNI.0688x3, ZRC.CNI.0690x6).

Diagnosis. — Hemispherical bell up to 15 mm in diameter. Four visible gonads of 'leaf' or 'heart' shapes however, size and shape variable. Long and cylindrical gastric peduncle twice as long as the bell diameter extends below the bell. Mouth with four lips, covered with nematocyst clusters. Four prominent perradial marginal tentatcles, each can be as long as the gastric peduncle.

Description of specimens. — Bell: In life, individuals were glassy transparent. In fixative, the jellyfish turned milky-white. Bell is distinctively hemispherical in shape, with a high apex. Among the specimens examined, bell diameter ranges from 5 mm to 15 mm. Mesoglea within the bell is thicker at the apical region than the margin. Four prominent gonads are visible through the bell. Gonads are of variable sizes and shape, typically of 'leaf' and 'heart' shapes. Velum is well developed, broad and simple.

Gastric peduncle: Elongated and cylindrical gastric peduncle extends below the bell. Peduncle is at least twice as long as the bell diameter; however with larger individuals, peduncle length can be longer. Four simple but slightly crenulated lips surround mouth. Nematocyst clusters stud the edge of these lips.

Radial and ring canal: Four faint straight and non-branching radial canals. For all specimens, up to seven blind centripedal canals are present in each quadrant. Of these, there are usually three to large and three short centripedal canals. Ring canal present.

Tentacles and statocysts: Four perradial marginal tentacles present, hollow and lined with cnidocyst rings, each as long as gastric peduncle. Small interradial tentacles also present, typically one or two present, with cnidocyst clusters present on the adaxial side. Eight statocysts embedded in the mesoglea; four perradial and four interradial.

Tentacle cnidae — Basitrichous haplonemes (Fig. 2D). For size distribution, refer to Table 1.

Remarks. — In his survey of the plankton of the Singapore Straits, Wickstead (1958) documented that *Liriope* sp. were common in our local waters. As of writing, *L. tetraphylla* is the only valid species in its genus. It is unmistakable in its appearance, due to its four distinct gonads and elongated peduncle. Smaller sized individual might be more difficult to recognize as Russell (1953) reports that the characteristic gonads do not appear until the medusae is at least 4 mm in diameter. It is likely that the animals Wickstead (1958) encountered were *L. tetraphylla*.

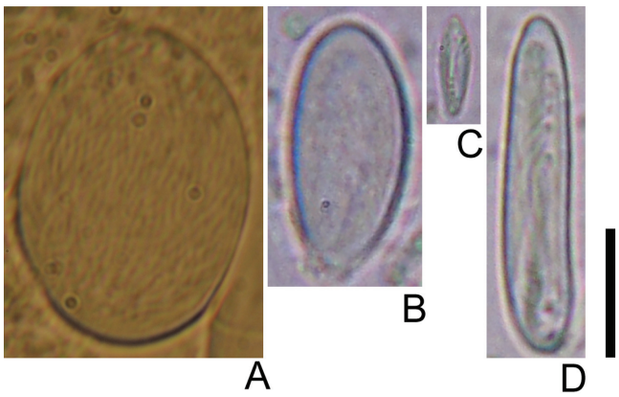

Fig. 2. Nematocysts of Hydrozoan jellyfish. *Aequorea pensilis*: (A) large atrichous isorhiza, (B) microbasic eurytele and (C) small-sized atrichous isorhiza; *Liriope tetraphylla*: (D) basitrichous haploneme. Scale bar = 10 µm. Photos: J. Y. Ong.

In Queensland, Australia, *L. tetraphylla* have been used in recent years as an indicator for the occurance of Irukandji jellyfishes, Nacromedusae and salps (Gershwin et al., 2010).

Distribution. — Atlantic, Indo-Pacific, Mediterranean (Kramp, 1961; Bouillon et al., 2004). While commonly occurring in warmer waters, *L. tetraphylla* have been found in temperate waters; along the coasts of the British Isles (Ranson, 1926; Russell, 1953) and Japan (Namikawa & Soyama, 2010).

Class SCYPHOZOA (Goette, 1887)
Order SEMAEOSTOMEAE (Agassiz, 1862)
PELAGIIDAE (Gegenbaur, 1856)
Chrysaora (Péron & Lesuer, 1809)

***Chrysaora chinensis* (Vanhöffen, 1888)** resurrection by Morandini & Marques (2010)
(Fig. 3A & B)

Chrysaora chinensis — Vanhöffen, 1888: 16, 23, 48; Morandini & Marques, 2010: 13, 54, 55, 58, 64
Chrysaora helvola var. *chinensis* – Mayer, 1910: 580, 582
Chrysaora melanaster — Mayer, 1915: 179; Mayer, 1917: 200; Light, 1921: 26
Chrysaora helvola — Vannucci, 1954: 125; Gao et al., 2002: 6, 33, 201
?*Dactylometra quinquecirrha* — Stiasny, 1940: 22
Chrysaora melanaster — Chuang, 1961: 143; Chou, 1993: 66
Dactylometra quinquecirrha – Light, 1914: 196, 198; Light, 1921: 26, 28, 30; Stiasny, 1919: 75
Dactylometra africana — Mayer, 1915: 180; Mayer, 1917: 201

Material examined. — St John's Island Jetty (ZRC.CNI.0680x1, ZRC.CNI.0684x2, ZRC.CNI.0685x1, ZRC.CNI.0686x1); Beting Bronok (ZRC.CNI.0683x1); Terumbu Semakau (Fig. 3B).

Diagnosis. — Flattened hemispherical bell, up to 65 mm in diameter. Marginal lappets elongated, typically up to 6 per octant. Twenty-four long marginal tentacles, 3 per octant (ontogenetic sequence: 2-1-2). Long trailing oral arms, studded red. Quadralinga absent. Tentacular and rhopalar clefts of similar depth. For larger individuals (adults), exumbrella surface finely granulated; overall light brownish colouration with minute red radiating spots scattered evenly over surface. Edge of lappets with intense reddish-brown colouration.

Description of specimens. — Bell: Flattened hemispherical, with diameter up to 65 mm. Low apex. In life, colouration (adults) of bell is light brown with reddish spots scattered evenly over the surface. In fixative, bell turned yellowish-white. Exumbrella surface is also finely granulated. Mesoglea flexible. Marginal lappets present, elongated and rounded but pointed at the tip. Intense reddish colouration along the edge of the lappets. Up to 6 lappets per octant, typically 2 rhopalar and 2~4 tentacular lappets. Rhopalar lappets broader than tentacular lappets, sometimes overlapping. Tentacular and rhopalar clefts overall of similar depth. Subumbrella and tentacular musculature not prominent.

Table 1. Measurements of undischarged nematocysts capsules of both length and width of selected jellyfish specimens examined. For each type of nematocysts, n = 10 capsules were measured.

Species (Catalogue number)	Nematocyst type	Range (Length x Width) (µm)	Mean length ± S.E (µm)	Mean width ± S.E (µm)
A. pensilis (ZRC.CNI.0692)	Large atrichous isorhiza	25-39 x 15-26	30.85 ± 1.47	19.40 ± 1.28
	Microbasic eurytele	13-16 x 7-8	14.80 ± 0.25	7.55 ± 0.16
	Small-sized atrichous isorhiza	8-10 x 3-4	9.40 ± 0.22	3.25 ± 0.13
L. tetraphylla (ZRC.CNI.0689)	Basitrichous haploneme	27-29 x 4-5.5	28.05 ± 0.22	4.95 ± 0.14
C. chinensis (ZRC.CNI.0683)	Heterotrichous microbasic	9-12 x 6-7	10.35 ± 0.26	6.35 ± 0.15
	Holotrichous O-isorhiza	12-16.5 x 12-16.5	14.65 ± 0.42	14.25 ± 0.38
	Holotrichous A-isorhiza	12.5-15 x 7-10	13.55 ± 0.28	8.45 ± 0.26
	Holotrichous a-isorhiza	4-6 x 2-4	4.85 ± 0.18	2.80 ± 0.20
Au. aurita (ZRC.CNI.0679)	Heterotrichous microbasic	6-11 x 6-8.5	8.15 ± 0.60	6.65 ± 0.33
	Atriches	4-5.5 x 3-4	4.90 ± 0.18	3.35 ± 0.11
N. dumokuroa (ZRC.CNI.0691)	Heterotrichous microbasic	5-9 x 4-6	6.10 ± 0.38	4.50 ± 0.20
	Atriches	3-4.5 x 2-3	3.50 ± 0.18	2.50 ± 0.15
P. punctata (ZRC.CNI.0698)	Heterotrichous microbasic	6-8 x 3-5	6.60 ± 0.21	4.60 ± 0.22

Rhopalia: Eight rhopalar present in clefts, each bending slightly downwards. Rhopalar overall white, ecto- and endodermal ocelli absent. Exumbrellar sensory pit blind-ended, deep. Attached mid-way of rhopalar. Sensory pit is of a teardrop shape when viewed directly above.

Stomach and radial canals: Four subgenital ostia present; horse-shoe shaped. Gastric filaments align the interradial trough of the ostia. Gonads are folded along the edge of the filaments, absent in smaller individuals. Quadralinga absent. Stomach circular, pillars evident. Sixteen stomach pouches of which its bases are of equal width. Towards the bell margin, width of stomach pouches differ; tentacular pouches wider than rhopalar. Radial septae present, thin, translucent. Extends ¼ towards margin, making an 'S' curve (i.e widening width of tentacular pouch) and ending near tentacular base of the rhopalar lappet. Mouth-disc with distinct four corners, sometimes grooved.

Oral arms and tentacles: Oral arms up to 200 mm in length. Four present, studded with reddish spots in life. Oral arms have a fragile and convoluted edge, V-shape in cross section, ending with a slight spiral at the tip. Tentacles up to 3 per octant. Ontogenetic sequence of tentacles is 2-1-2; with 1° tentacles deeper in tentacular clefts than 2° tentacles. Tentacles up to 10 mm, typically 1° tentacles are longer than 2° tentacles.

Tentacle cnidae – Heterotrichous microbasic, holotrichous O-isorhiza, holotrichous A-isorhiza and holotrichous a-isorhiza (Fig. 4A–D). For size distribution, refer to Table 1.

Remarks. — The occurrence of *C. chinensis* appears to be seasonal in Singapore, occurring especially during the warmer months (March – July). However, it has also been observed to occur, although in much fewer numbers, during the Northeast monsoon months (November – January) of Singapore (pers. obs.). At the moment, there is insufficient data to determine the exact seasonal occurrence of these jellyfish. Direct skin contact with this jellyfish should be avoided; an intense painful burning sensation will be felt if stung. Swelling will occur and may take several weeks to heal (pers. obs.).

Records of *Chrysaora* jellyfish in the region have indicated that *C. melanaster* may be present. Prior to authors Morandini & Marques (2010) resurrection of *C. chinensis*, many *Chrysaora* jellyfish encountered in this locale were identified as *C. melanaster* (e.g Chuang, 1961; Chou, 1993; Appendix B). In having a similar reddish colouration and numerous marginal tentacles, *C. chinensis* superficially resembles *C. melanaster*. However, these jellyfishes are two distinct species. Medusae of *C. chinensis* do not have the intense reddish radiating bands on its exumbrella surface of *C. melanaster* (Namikawa & Soyama, 2000; Morandini & Marques, 2010). Instead, faint reddish spots are scattered evenly on the exumbrella surface of *C. chinensis*. The shapes of the subgenital ostia of these two jellyfish also differ. *Chrysaora chinensis* has a horseshoe shaped subgenital ostia, whereas *C. melanaster* may vary between rounded or triangular (Morandini & Marques, 2010). In addition, the radial canals of *C. melanaster* are dark, whereas *C. chinensis* radial canals are almost translucent (Morandini & Marques, 2010). Hence, *C. chinensis* cannot be confused as *C. melanaster*.

While the ecology of *C. chinensis* is not well known, we have observed scad fish swimming among the oral-arms and marginal tentacles, unharmed. There are a few possible explanations of this behaviour. One likely reason is that they might be seeking protection from predators amongst the jellyfish tentacles. Another possibility is that they might be feeding on the remnants of undigested food left behind by the jellyfish.

Distribution. — Likely South China Sea, Indo-Pacific and Northwestern Pacific (Morandini & Marques, 2010).

ULMARIDAE (Haeckel, 1880)
Aurelia **(**Péron & Lesuer, 1809)

***Aurelia aurita* (Linné, 1758)**
(Fig. 3C & D)

Medusae aurita — Linné, 1758: 60
Aurellia flavidula — Peron & Lésueur, 1809: 359
Aurelia aurita — Lamarck, 1816: 513; Russell, 1970: Gershwin, 2001: 115; Dawson, 2003: 369
Taxonomic comparisons from 1816 to 1961 are too numerous to list here; for additional synonyms, please refer to Kramp (1961)

Material examined. — St John's Island Jetty (ZRC. CNI.0679x1).

Diagnosis. — Hemispherical bell with eight broad velar lobes, crenulated. Numerous minute tentacles align the bell margin. Four unbranched paddle-like mouth arms, each approximately the length of bell radii. Inconspicious manubrium. Eight rhopalia, ocelli prominent. Exumbrella sensory pits deep and blind ended. Adradial canals unbranched, perradial and interradial canals branched extensively towards bell margin. Ring canal present. Four subgenital ostia present, horseshoe-shaped. Colour milky-white, transparent.

Description of specimen. — Bell: Hemispherical in shape. Approximately 20 mm in diameter; dome height of 15mm. In life, bell is transparent, milky-white with no coloured markings on its surface. In fixative, colour of the bell remains the same. Exumbrella surface finely granulated. Granulation covers the entire exumbrella surface, up to the velar lobes. Rhopalar lappets thin, and are part of the velarium that runs along the bell margin. The velarium divides into the eight distinct crenulated velar lobes. Slightly above the velarium edge, the bell margin extends into numerous small lappets. Between these lappets, a single marginal tentacle arises from the depression.

Mouth-arms: Four present, paddle-like and V-shaped in cross-section. The length of each mouth arm is approximately 2/3 the bell radii. Mesoglea is thicker at the midpoint than the edge of each mouth-arm. Tentacle-like processes are present on the exposed mouth-arm margin. Brood pouches absent. Mouth-arms are arranged perradially, in a slightly curved clockwise fashion. Manubrium inconspicuous.

Stomach and subgenital ostia: Stomach circular. Four subgenital ostia present, distinctively horseshoe-shaped. Gastric filaments line the central trough of the subgential ostia. Gonads not present, likely not developed yet.

Radial canals: Conspicious. In both life and fixative, these canals are milky-white. Eight unbranched adradial canals present. Both perradial and interradial canals are branched, more extensively towards the bell margin. However, this extensive branching only takes place from the sub-branches of these canals. Ring canal present as a faint white line near the edge of the subumbrella.

Rhopalia: Covered by a hood-like projection of the exumbrella, flanked on each side by the inward folds of the rhopalar lappets. Exumbrella sensory pits are of a teardrop shape when viewed directly above and are blind-ended, deep. Both ecto- and endodermal ocelli are present on the rhopalium. Ocelli are reddish in fixative. Rhopalium is slightly bent upwards at the junction of the bulb and statocysts.

Tentacle cnidae — Heterotrichous microbasic and atriches (Fig. 4E–F). For size distribution, refer to Table 1.

Remarks. — First record for Singapore. Previous reports of *Au. aurita* from this area were based on an account

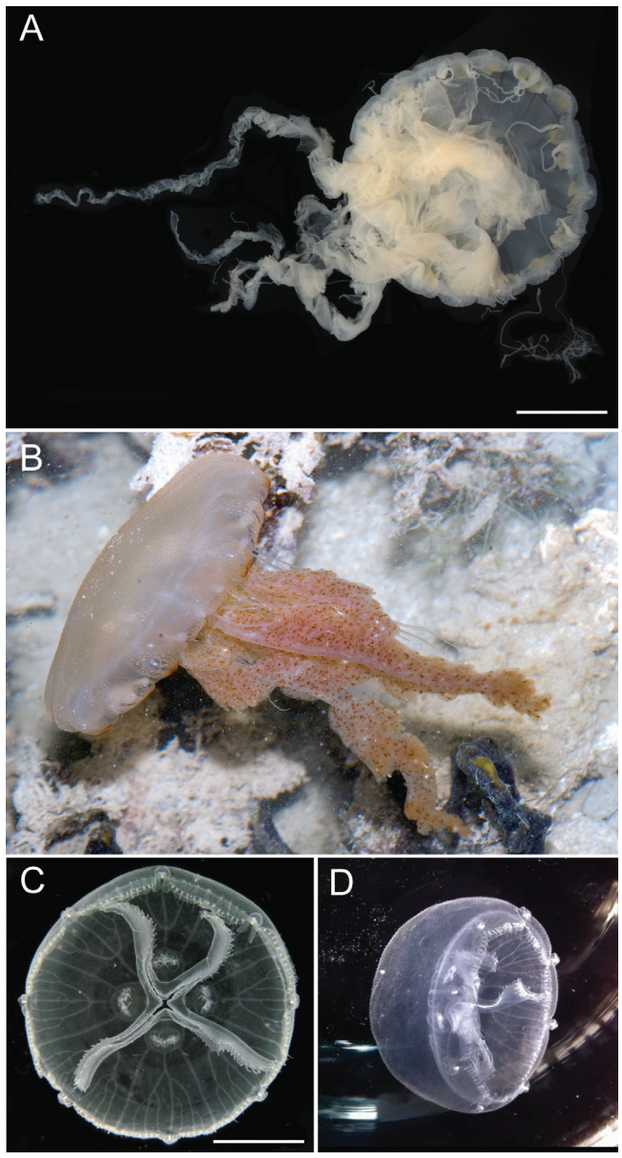

Fig. 3. Semaeostomeae jellyfish from the waters of St John's Island, Singapore, (A) *Chrysaora chinensis*: St John's Island (ZRC. CNI.0684). Fixed in 10% formalin. Subumbrellar view. Scale bar = 2 cm. Photo: J. Y. Ong, (B) Live *C. chinensis*: Terumbu Semakau, swimming. Photo: Ria Tan, (C) *Aurelia aurita*: St John's Island (ZRC.CNI.0679). Fixed in 10% formalin. Subumbrella view. Scale bar = 1 cm. Photo: N. Yap, (D) Live *Au. aurita*: St John's Island (ZRC.CNI.0679), swimming. Photo: N. Yap.

by Searle (1957). In the study, the author discussed the general body plan of the semaeostomeae jellyfish using *Au. aurita* as an example, and notes that it has a worldwide distribution. However, Searle (1957) makes no mention of encountering or collecting the jellyfish in Singapore's waters. Kramp (1961) erroneously lists Searle's account as having observed the jellyfish in Singapore, thereafter local authors have done the same (e.g Chuang, 1961). As of writing, this present study is the first to formally report its presence in Singapore's waters.

Another species of the same genera, *Au. labiata,* have been encountered in waters of the nearby regions (Stiasny, 1919) Due to similarities in its appearance, *Au. labiata* may be confused for *Au. aurita* (Gershwin, 2001). However *Au. aurita* is distinct in that it has a reduced or inconspicuous manubrium and has only 8 broad velar lobes. *Aurelia labiata* on the other hand, has an elongated manubrium that varies in shape amongst individuals and have 16 velar lobes (Gershwin, 2001). In addition, *Au. aurita* may be superficially mistaken for the hydrozoan *Aequorea*. The absence of a muscular velum and a partitioned gastric cavity with filaments, distinguishes *Aurelia* from the *Aequorea* jellyfish (Pearse et al., 1987).

Recent molecular studies and morphological re-examination of *Aurelia* sp. have indicated the actual diversity of this genus may be greater than previously reported, suggesting the presence of cryptic species (Gershwin, 2001; Dawson, 2003). We are aware of the uncertainties concerning the identity of *Aurelia*. Despite this, the identification of *Aurelia* here was based on the taxonomic descriptions by Russell (1970) and Gershwin (2001), of which the morphological features of our specimen corresponded well. We could not compare among specimens collected, due to the elusiveness of this jellyfish here. So far we have managed to obtain one specimen of *Aurelia* from local waters and subsequent attempts during the same season proved fruitless. Further molecular analyses and studies on the biology of the jellyfish have been proposed by other authors to rectify this confusion (Dawson, 2003; Bolton & Graham, 2004). This is beyond the scope of this publication. Any further revisions concerning the taxonomy of *Aurelia* will be addressed in further works of local jellyfish. For now, we assigned the identity of *Aurelia aurita* to our specimen until these uncertainties are cleared up.

Distribution. — Cosmopolitan, from tropical to arctic seas (Russell, 1970; Gershwin, 2001; Dawson, 2003).

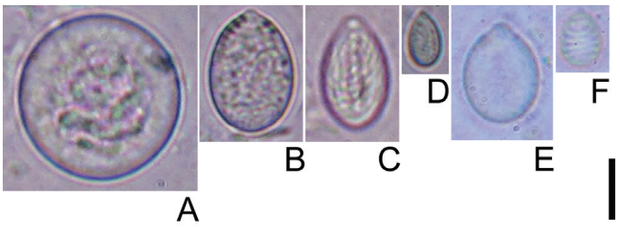

Fig. 4. Nematocysts of Semaeostomeae jellyfish. *Chrysaora chinensis*: (A) holotrichous O-isorhiza, (B) holotrichous A-isorhiza, (C) heterotrichous microbasic, (D) holotrichous a-isorhiza; *Aurelia aurita*: (E) heterotrichous microbasic, (F) atriches . Scale bar = 5 µm. Photos: J. Y. Ong.

Order RHIZOSTOMEAE (Cuvier, 1817)
Suborder KOLPOPHORAE (Stiasny, 1921)
CEPHEIDAE (Agassiz, 1862)
Netrostoma (Schultze, 1898)

***Netrostoma dumokuroa* (Agassiz & Mayer, 1899)**
(Fig. 5A & B)

Cephea dumokuroa — Agassiz & Mayer, 1899: 172
Netrostroma dumokuroa — Maas, 1903: 38; Stiasny, 1921: 75; Gershwin & Zeidler, 2008: 50
Cephea cephea var. *dumokuroa* — Mayer, 1910: 656

Material examined. — St John's Island Jetty (ZRC.CNI.0691x1; ZRC.CNI.0697x3).

Diagnosis. — Flattened and inverted disk, with large central knob and shallow furrow. Two whorls of papillae surround the knob, up to twenty papillae may be present. Three inter-rhopalar canals per octant. Rhopalia 8 present, without ocelli and exumbrellar sensory pit. Up to eight mouth-arms, branching and bifurcate; without filaments or club-like appendages.

Description of specimens. — Bell: Disk shaped and peripheral region inverted. Bell diameter is approximately 65 mm. Prominent smooth large knob on the central dome. Side of knob surrounded by two whorls of short papillae; projections closer to the apex are larger than the lower whorl (Fig. 5B). Eight papillae surround the knob, however in some specimens remnants of the knob and papillae are present, due to damage. Presence of a shallow furrow between knob and margin. Marginal lappets present, scarcely distinguishable. Velar and ocular lappets appear to be flat and roundish. Per octant, there are 7 velar and 2 ocular lappets. In life, jellyfish is whitish-transparent. In fixative, it is milky-white in appearance.

Radial canals and subgenital ostia: Radial canals 32. Three inter-rhopalar canals per octant. Radial canals are interconnected in an anatomisizing network close to the bell margin. Ring canal absent. Four openings on the side of the oral disk lead to the four subgenital ostia. Gonads present, folded on the edge of the ostia.

Rhopalia: Eight present. Located deep in rhopalar clefts. Ocelli absent. Lacking exumbrella sensory pits. Rhopalar is entirely white, in fixative.

Oral disk and mouth-arms: Oral disk thick, with seven to eight corners each corresponding to the mouth arms. Oral disk extends 9 mm below the subumbrella, slightly concave in cross-section. Five papillae present on the oral disk of the specimen, approximately 16 mm in length, all similar in shape and size. Mouth arms seven up to eight, extending as long as bell radii. Branching and bifurcate, with 'feathery' on the edge or tips of the branches. Without filaments or club-shaped appendages. Branching occurs on the adaxial side of the mouth-arms. Adaxial side convex. Mouth-arms triangular in cross-section. Mouths frilled, without obvious appendages.

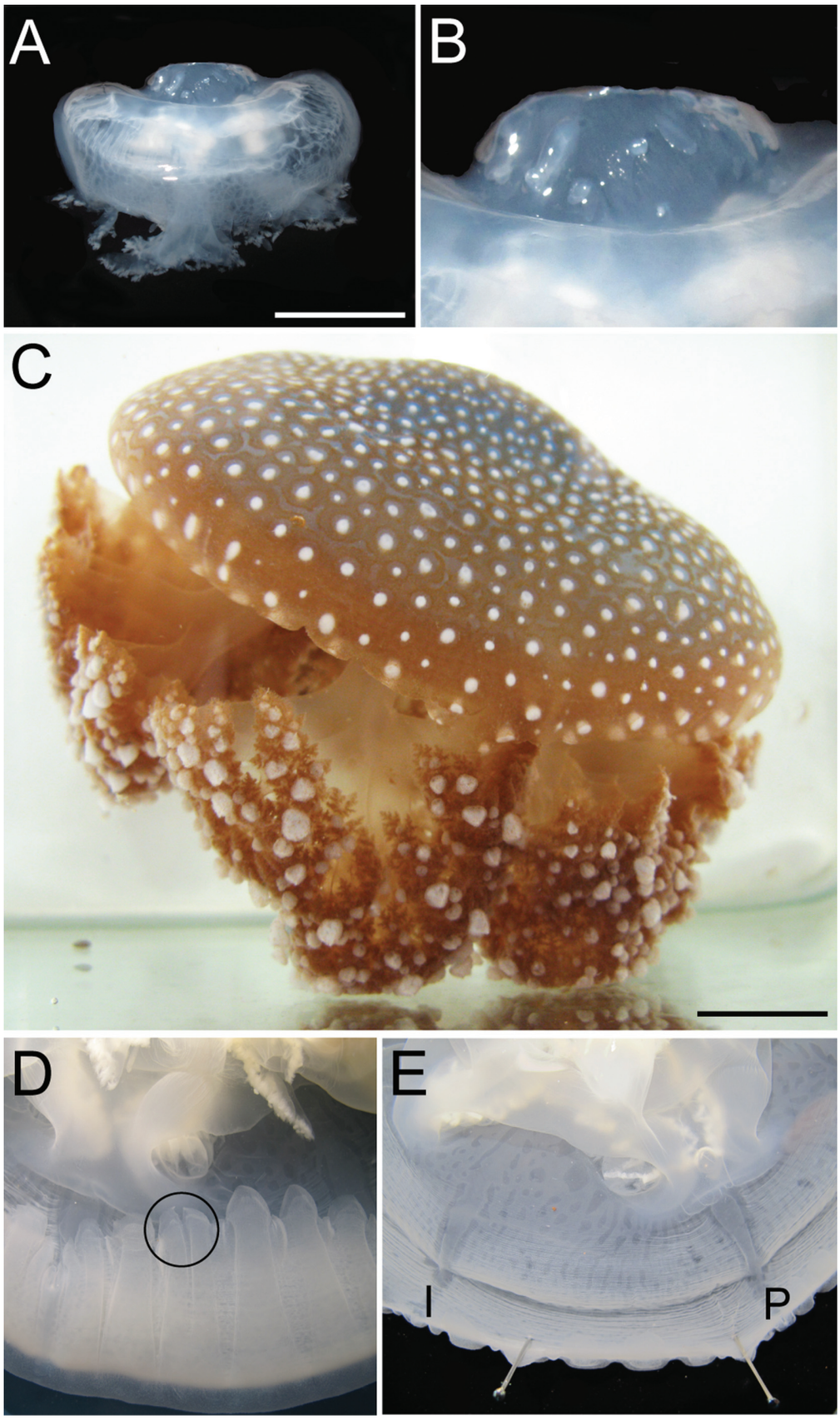

Fig 5. Rhizostomeae jellyfish from the waters of St John's Island, Singapore, (A) *Netrostoma dumokuroa*: St John's Island (ZRC. CNI.0691). Fixed in 10% formalin. Side view. Note the papillae on central knob. Scale bar = 2 cm, (B) close up of papillae on the knob of *N. dumokuroa*. Photos: J. Y. Ong, (C) Live *Phyllorhiza punctata*: St John's Island (ZRC.CNI.0699), swimming. Scale bar = 5 cm, (D) Close up of *P. punctata* velar lappets. Circled: double lappets, (E) Close up of radial canals of *P. punctata*. I = interradial rhopalar canal, P = perradial rhopalar canal. Photos: N. Yap.

Mouth-arm cnidae — Heterotrichous microbasic, atriches and elongated atriches (Fig. 6A–B). For size distribution, refer to Table 1.

Remarks. — New record for Singapore. First documented from the Fiji islands by Agassiz and Mayer (1899), it has not been recorded anywhere else. Another species of the same genus, *N. coerulescens*, have been documented by both Maas (1903) and Stiasny (1929) to occur within the same region. While both these jellyfishes have papillae on its central dome, *N. dumokuroa* can be easily distinguished from *N. coerulescens* by it having fewer papillae (up to 20 or less, in two whorls of different sizes). In addition, tubular and spindle shaped appendages are present on the oral disk of *N. coerulescens*, but it is absent for *N. dumokuroa* (Agassiz & Mayer, 1899; Maas, 1903; Stiasny, 1929). Thus *N. dumokuroa* is morphologically distinct from *N. coerulescens*.

Distribution. — Fiji Islands (Agassiz & Mayer, 1899; Maas, 1903; Mayer, 1910); Stiasny, 1921 and Singapore.

MASTIIGIDAE (Agassiz, 1862)

Phyllorhiza (Agassiz, 1862)

Phyllorhiza punctata (von Lendenfeld, 1884)

(Fig. 4C–E)

Phyllorhiza punctata — von Lendenfeld, 1884: 296, 307; Mayer, 1910: 684; Stiasny, 1924: 56; Stiasny, 1926: 255; Graham et al., 2003: 53; Bolton & Graham, 2004: 125; Morandini et al., 2005: 281; Morandini et al., 2006: 1; Abed-Navandi & Kikinger, 2007: 391; Calder, 2009: 38; Galil et al., 2009: 481; Verity et al., 2011: 2219

Phyllorhiza trifolium — Uchida, 1954: 209

Mastigias scintillae — Moreira, 1961: 5

Material examined. — St John's Island (ZRC.CNI.0698x1, ZRC.CNI.0699x1, ZRC.CNI.0700x1).

Diagnosis. — Large hemispherical bell with granulated exumbrellar surface covered with irregularly spaced white spots. In life, bell is rusty brown in colour with a bluish-tinge concentrated at the apex of the dome. Up to 16 marginal lappets per octant, arranged in a 'big and small' alternating series. Larger lappets are rounded at the tip whereas smaller lappets are pointed. Lappets are interconnected by a thin membrane and occasionally a 'double-lappet' may be present at the mid of the octant. Eight oral arms present, three winged and 'J'-shaped. Adaxial edge of the oral arms highly branched, with feathery and clubbed shaped filaments present. Short terminal appendages may be present. Up to eight rhopalar canals present, radiating from the cruciform stomach. An anastomosing network also extends from the stomach, communicating with the four interradial rhopalar canals. Ring canal present. Circular musculature field visible, interrupted by the eight rhopalar canals. Up to eight rhopalia present, without ocelli.

Description of specimens. — Bell: Hemispherical dome shaped, slightly flattened in fixative. Granulated exumbrellar surface for all individuals. In life, bell of all specimens are rusty brown in colour. A concentrated bluish-tinge colouration is also seen at the apex of the dome of the larger individuals, but not of the smaller specimen. In addition, large white spots irregularly arranged over the exumbrellar surface of the bell of larger specimens, but not on the smaller (Fig. 4C). In fixative, all specimens turn white in colour. Bell diameter up to 180 mm. Marginal lappets present, arranged in a 'big and small' alternating configuration, up to 16 per octant. Larger velar lappets are elongated and rounded at the tip, whereas smaller lappets, including the rhopalar lappets, are pointed at the tip. Lappets are connected via a thin membrane, more obvious in large sized individuals (Bell diameter: >120 mm). In the largest specimen a 'double-lappet', two large velar lappets arranged immediately side by side, may be seen in the mid of the octant (Fig. 4D). In smaller specimens, this feature is not present. Subumbrellar circular musculature is visible in all specimens, interrupted by rhopalar canals.

Stomach and radial canals: Cruciform stomach with gastric filaments aligning the edge. Up to eight rhopalar canals radiate out from the stomach, reaching the rhopalia. An anastomosing network of gastric canals also arises from the stomach, communicating with the interradial rhopalar canals (Fig. 4E). Perradial rhopalar canals are wider than the interradial canals and does not connect with the anastomosing network. Ring canal present, communicating with all eight rhopalar canals.

Rhopalia: Eight present. White in fixative, without ocelli.

Oral disk and mouth-arms: Oral disk quadrate. Mouths frilly with elongated club-shaped filaments extending from the middle of the oral disc. Up to eight mouth arms, each slightly longer than the radius of the bell. Mouth-arms are three-winged and 'J'-shaped, with extensive branching along the adaxial edge. Feathery and club-shaped filaments align these branches. In life, feathery filaments are rusty brown and club-shaped ones are white (Fig. 4C). In fixative, these turn white completely. Apparent holes on the mouth arms, known as 'windows', are more obvious in larger specimens than in the smaller. Pointed and short (>1 cm) terminal clubs are present at the end of the mouth-arms of the smaller individuals. It is absent in the largest specimen. In life, these clubs are transparent; in fixative these remain as such.

Mouth-arm cnidae — Heterotrichous microbasic (Fig. 6C). For size distribution, refer to Table 1.

Remarks. — The invasive distributions of *P. punctata* of both tropical and subtropical habitats have been well documented (Bolton & Graham, 2004; Galil et al., 2009), although the manner of its transferences by human agencies is still vague (Bolton & Graham, 2004). First described from Port Jackson in Australia (von Lendenfeld, 1884), and thereafter in the Indo-Pacific region (Kramp, 1961), this species of jellyfish has since been sighted out of its reported range, from the Mediterranean (Abed-Navandi & Kininger, 2007) to the Caribbean (Bolton & Graham, 2004). It is likely that *P. punctata* is endemic to the Indo-Pacific region, extending

throughout Southeast Asia to Northern Australia; Bolton & Graham, 2004; Verity et al., 2011). With an estimated prey-clearance rate of up to 80 m^3 $individual^{-1}$ d^{-1} (Graham et al., 2003), blooms of *P. punctata* may impact and alter foodwebs in local habitats.

Phyllorhiza spp. most resembles jellyfish from the genus *Mastigias spp*. Similarities include its overall shape, colouration and presence of white spots on the surface of its bell. In addition, extended terminal clubs from the mouth-arms are present on both genera of jellyfish. One morphological trait to distinguish *Phyllorhiza spp*. from *Mastigias spp*. is its arrangement of the radial canals. While both these rhizostomae jellyfish have an anastomosing network of gastric canals radiating from its stomach, in *Mastigias spp*., these canals communicate with all eight rhopalar canals (Kramp, 1961); whereas in *Phyllorhiza spp*. these only communicate with four (Mayer, 1910; Kramp, 1961).

Phyllorhiza punctata have been reported by some authors to be morphologically plastic within populations (Bolton & Graham, 2004; Verity et al., 2011). This includes the presence and absence of colouration and white spots on the exumbrellar surface, shape of oral discs, terminal clubs and perceptibility of its stings (Bolton & Graham, 2004). All three individual examined in this study have exhibited some degree of variation among specimens. White spots and the bluish tinged colouration were absent in the smallest specimen, while in the two larger specimens these were visible. Apart from colouration, terminal clubs were present in the two smaller specimens but absent in the larger. Some authors (Cornelius, 1995; Arai, 1997; Bolton & Graham, 2004) have suggested that the variation in colour could be attributed to the amount of zooxanthellae present in the tissue, while terminal clubs of mouth-arms are known to autotomize during any mechanical disturbance (e.g during collection, predation by fishes). Despite this, most of the morphological traits observed in our specimens are consistent with past taxonomic descriptions by von Lendenfeld (1884), Mayer (1910), Stiasny (1924), Kramp (1961), Moreira (1965), Calder (2009) and that of photographs in Chou (1993), Bolton & Graham (2004), Abed-Navandi et al. (2007) and Galil et al. (2009). Hence, these specimens were identified as *P. punctata*. As of writing,

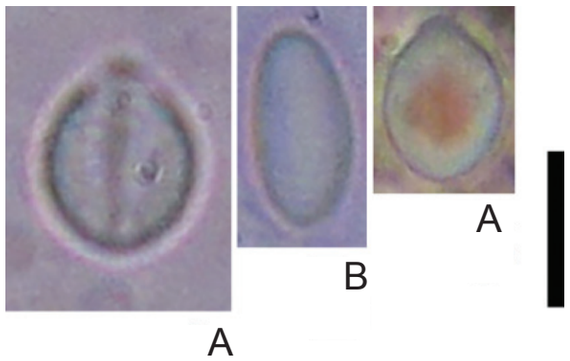

Fig. 6. Nematocysts of Rhizostomeae jellyfish.: (A) *Netrostoma dumokuroa* heterotrichous microbasic; (B) *Netrostoma dumokuroa* elongated atriches; (C) *Phyllorhiza punctata* heterotrichous microbasic. Scale bar = 5 µm. Photos: J. Y. Ong.

the taxonomic designation of *P. punctata* within and among populations of different habitats remains unclear, due to the morphological variation; molecular phylogenic analysis of this rhizostomae jellyfish has been suggested to re-affirm this (Bolton & Graham, 2004; Verity et al., 2011).

Distribution. — Brazil (Morandini et al., 2005; Morandini et al., 2006; Haddad & Nogueira Júnior, 2006), North America East Coast (Graham et al., 2003; Verity, 2011), Gulf of Mexico (Graham et al., 2003; Bolton & Graham, 2004), Mediterranean sea (Navandi & Kikinger, 2007; Galil et al., 2009), Southeast Asia (Chou, 1993; Bolton & Graham, 2004) and Pacific Ocean (Kramp, 1961; Graham et al., 2003).

DISCUSSION

The morphological descriptions of these seven medusae in this study represent a preliminary taxonomic documentation of the cnidarian jellyfish found in the Singapore Straits. With the exception of *Netrostoma dumokuroa*, the other six jellyfish have been reported elsewhere from the Indo-Pacific and are likely to be common and endemic to this region. Originally documented from the Fiji islands in the western Pacific Rim (Agassiz & Mayer, 1899; Mass, 1903; Mayer, 1910), the Singapore Straits represents the westernmost region of which *N. dumokuroa* occurs. We are uncertain if the presence of *N. dumokuroa* is endemic or invasive to this area; while it had not been previously reported from Singapore, to assume that it might have been transported from Fiji Islands could be potentially spurious due to the lack of proper historical and taxonomic records of local jellyfish here.

In recent years, taxonomical confusion surrounding the identities of some pelagic cnidarians has been reported by workers in the field (Gershwin, 2001; Bolton & Graham, 2003; Dawson, 2003; Gershwin et al., 2010; Verity et al., 2011). Morphological variation within jellyfish populations, subjective interpretations of available taxonomic descriptions and the lack of qualitative traits further exacerbate this confusion (Gershwin, 2001; Bolton & Graham, 2003; Dawson, 2003). For three of the seven species of jellyfish documented here, *Aequoeria pensilis*, *Aurelia aurita* and *Phylloriza punctata*, are known to be morphologically variable (see Bouillon et al., 2004, Gershwin et al., 2010; Bolton & Graham, 2003; Dawson, 2003). Apart from slight morphological variations seen in specimens of *P. punctata*, all other specimens examined here did not deviate much morphologically from past taxonomic descriptions or among samples. Ontogenetic, developmental and molecular studies can complement morphological descriptions, thus rectifying the confusion (Bolton & Graham, 2003; Dawson, 2003; Morandini & Marques, 2010). However our main focus here was to present a much needed taxonomic inventory of the medusae within this locality, as a result of the limited marine fauna records present. The use of these other complementary analyses to clarify taxonomical doubts could not be justified within the timeframe, budget and scope of this project. Until the systematics of these invertebrates is further revised, the identities of the documented jellyfishes here are established

from descriptions of past taxonomic records. Any revisions concerning these seven jellyfish will be addressed in future publications.

Much of the available records from Singapore, as mentioned at the onset, have been largely restricted to anecdotal observations (see Appendices A–C), with few descriptions, photographs and voucher specimens to verify their identities. Four other species of jellyfish apart from the seven species described in this study have been collected elsewhere (e.g., Johor Straits) since 2006, more specimens and further taxonomic evaluations are required to accurately determine their identities. However this is further hindered by the unpredictability due to the jellyfish seasonality abundance, elusiveness, and the state of available preserved specimens. Until more specimens can be obtained for their verification, these four species will be documented in subsequent publications on cnidarian jellyfish from Singapore.

The effects of global warming, increased influx of shipping, and extensive coastal developments along Singapore's coastline, could have altered the local community of pelagic cnidarians over the past 55 years since Searle's (1957) account. Alien species might extend its distribution as a result of global warming (Kideys & GüGü, 1995; Avsar, 1999; Bouillon et al., 2004), be translocated via ballast or fouling communities on ships (Carlton et al., 1990; Grosholz & Ruiz, 1995; Graham et al., 2003), or local species might proliferate, and decline, in the presence of increased marine eutrophication due to coastal developments (Arai, 2001). The present taxonomic documentation thus serves as an inventory to the cnidarian jellyfish community found here, facilitating any future research on them or the local marine habitats.

In conclusion while this paper provides a taxonomic record of some jellyfish found in the modern Singapore Straits, rigorous inventories of these invertebrates are still required, as at least 25 different genera have been reported and sighted here. Extensive investigations into the life-cycle and ecology of these jellyfish are also essential, in order to understand their roles in local pelagic food-webs, the cause of its seasonal blooms and possible impact on neighbouring regions.

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Appendix A. List of published literature, and type of reference mentioning the nine families of Hydrozoan jellyfish reported from Singapore specifically. Species highlighted in **BOLD** are taxonomically described in this study.

Class HYDROZOA Owen, 1843				
Family	**Species**	**References**	**Reference Type**	**Remarks**
Subclass ANTHOMEDUSAE Haeckel, 1879 **Order FILIFERA Kühn, 1913**				
Bougainvilliidae	*Thamnostoma macrostomum*	Haeckel, 1879	Primary scientific literature	Taxonomic description.
Subclass LEPTOMEDUSAE Haeckel, 1879 **Order CONICA Broch, 1910**				
Aequoreidae	*Aequorea conica*	Stiasny, 1928	Primary scientific literature	Taxonomic description.
	Aequorea parva	Stiasny, 1928	Primary scientific literature	As *Aequorea parva* var. *buitendijki*, taxonomic description.
	Aequorea pensilis	Present study	Primary scientific literature	New record for Singapore, taxonomic description.
Eirenidae	*Eirene hexanemalis*	Stiasny, 1928	Primary scientific literature	As *Irenopsis hexanemalis*, taxonomic description.
Order PROBOSCOIDA Broch, 1910				
Malagazziidae	*Malagazzia carolinae*	Stiasny, 1928	Primary scientific literature	As *Phialucium mbenga*, taxonomic description.
Subclass SIPHONOPHORA Eschscholtz, 1829 **Order CALYCOPHORAE Leuckart, 1854**				
Diphyidae	***Diphyes bojani***	Present study	Primary scientific literature	New record for Singapore, taxonomic description.
	Diphyes chamissonis	Wickstead, 1958	Primary scientific literature	Brief mention on its occurrence in Singapore.
		Chuang, 1961	Book chapter	Erroneous identification by Chuang (1961). See text for details.
		Ng et al., 2011	Encyclopedic entry	Brief mention on its occurrence in Singapore.\
	Diphyes spp.	Ng et al., 2011	Encyclopedic entry	Brief mention on its occurrence in Singapore.
	Lensia spp.	Ng et al., 2011	Encyclopedic entry	Brief mention on its occurrence in Singapore.
Order CYSTONECTAE Haeckel, 1888				
Physaliidae	*Physalia* sp.	Sharma, 1973	Book chapter	Brief mention on its occurrence in Singapore.
	Physalia utriculus	Sharma, 1973	Book chapter	Brief mention on its occurrence in Singapore.
Subclass TRACHYLINA Haeckel, 1879 **Order TRACHYMEDUSAE Haeckel, 1879**				
Geryoniidae	***Liriope tetraphylla***	Wickstead, 1958	Primary scientific literature	Brief mention in a single sentence as *Liriope sp*., likely *L. tetraphylla*. See text for more details.
		Present study	Primary scientific literature	Taxonomic description.
Order NARCOMEDUSAE Haeckel, 1879				
Aeginidae	*Solmundella* spp.	Wickstead, 1958	Primary scientific literature	Brief mention on its occurrence in Singapore, no mention of the type of species encountered.
Cuninidae	*Cunina duplicata*	Haeckel, 1879	Primary scientific literature	As *Cunissa polyporpa* (nomen dubium), taxonomic description.

Appendix B. List of published literature, and type of reference mentioning the 10 families of Scyphozoan jellyfish reported from Singapore specifically. Species highlighted in **BOLD** are taxonomically described in this study.

Class SCYPHOZOA Goette, 1887				
Family	**Species**	**References**	**Reference Type**	**Remarks**
Order CORONATAE Vanöffen, 1892				
Nausithoidae	*Nausithoe punctata*	Searle, 1957	Primary scientific literature	Brief mention on its occurrence in Singapore.
Linuchidae	*Linuche unguiculata*	Mayer, 1917	Primary scientific literature	Taxonomic description.
		Searle, 1957	Primary scientific literature	Brief mention on its occurrence in Singapore.
		Ng et al., 2011	Encyclopedic entry	As *Linerges draco,* brief mention on its occurrence in Singapore.
Order SEMAEOSTOMEAE Agassiz, 1862				
Pelagiidae	***Chrysaora chinensis***	Present study	Primary scientific literature	New record for Singapore, taxonomic description. However, in Chou (1988) a photo of the jellyfish is included, unidentified.
	Chrysaora melanaster	Chuang, 1963	Book chapter	Brief mention on its occurrence in Singapore, however there is the possibility that photographed jellyfish is *Chrysaora chinensis*.
		Chou,1993	Field guide entry	Brief mention on its occurrence in Singapore, however there is the possibility that photographed jellyfish is *Chrysaora chinensis*.
	Sanderia malayensis	Goette, 1886	Primary scientific literature	Taxonomic descriptions.
		Mayer, 1917	Primary scientific literature	
		Searle, 1957	Primary scientific literature	Brief mention on its occurrence in Singapore in these references.
		Ng et al., 2011	Encyclopedic entry	
Cyaneidae	*Cyanea lamarcki*	Chou, 1993	Field guide entry	Brief mention on its occurrence in Singapore in these references.
		Ng et al., 2011	Encyclopedic entry	
Ulmaridae	***Aurelia aurita***	Searle, 1957	Primary scientific literature	Erroneous record of occurrence by the authors. See text for more details.
		Sharma, 1973	Book chapter	
		Chou, 1993	Field guide entry	
		Present study	Primary scientific literature	Taxonomic description.
Order RHIZOSTOMEAE Cuvier, 1817 Suborder KOLPOPHORAE Stiasny, 1921				
Cassiopeidae	*Cassiopea andromeda*	Searle, 1957	Primary scientific literature	Brief mention on its occurrence in Singapore in these references.
		Chuang, 1961	Book chapter	
	Cassiopea xamachana	Lee, 2009	Honours thesis	Unpublished, ecology of the jellyfish documented.
	Cassiopea sp.	Chuang, 1961	Book chapter	Brief mention on its occurrence in Singapore with no mention of species in these references.
		Chou, 1993	Field guide entry	
		Wang & Yeo, 2011	Field guide entry	
		Ng et al., 2011	Encyclopedic entry	
Cepheidae	*Cephea octostyla*	Haeckel, 1880	Primary scientific literature	As *Stylorhiza octostyla*, taxonomic description.
	Netrostoma dumokuroa	Present study	Primary scientific literature	New record for Singapore, taxonomic description.

Appendix B. Cont'd.

Class SCYPHOZOA Goette, 1887				
Family	**Species**	**References**	**Reference Type**	**Remarks**
Order RHIZOSTOMEAE Cuvier, 1817 **Suborder KOLPOPHORAE Stiasny, 1921**				
Mastigiidae	*Mastigias ocellatus*	Ng et al., 2011	Encyclopedic entry	As *Versura palmata,* brief mention on its occurrence in Singapore.
	Mastigias papua	Searle, 1957	Primary scientific literature	Brief mention on its occurrence in Singapore in all references.
		Chuang, 1961	Book chapter	
		Ng et al., 2011	Encyclopedic entry	
	Mastigias siderea	Stiasny, 1920, 1921	Primary scientific literature	As taxonomic descriptions in both references.
	Phyllorhiza punctata	Chou, 1993	Field guide entry	Brief mention on its occurrence in Singapore.
		Present study	Primary scientific literature	Taxonomic description.
Thysanostomatidae'	*Thysanostoma* spp.	Tan, 2008	Primary scientific literature	As *Thyanostoma* spp. Brief mention on the possibility of a local marine fish mimicking it.
Suborder DAKTYLIOPHORAE Stiasny, 1921				
Catostylidae	*Acromitus spp*	Chuang, 1961	Field guide entry	Brief mention on its occurrence in Singapore with no mention of species in these references.
		Ng et al., 2011	Encyclopedic entry	
	Catostylus spp.	Chuang, 1961	Book chapter	Brief mention on its occurrence in Singapore with no mention of species in these references.
		Ng et al., 2011	Encyclopedic entry	

Appendix C. List of published literature, and type of reference mentioning the two families of Cubozoan jellyfish reported from Singapore specifically.

CLASS CUBOZOA Werner 1973				
Family	**Species**	**References**	**Reference Type**	**Remarks**
Order CARYBDEIDA Gegenbaur, 1856 (sensu Werner, 1984)				
Carybdeidae	*Carybdea sp.*	Sharma, 1973	Book chapter	Brief mention on its occurrence in Singapore with no mention of species in these references.
Order CHIRODROPIDA Haeckel, 1880				
Chiropsalmidae	*Chiropsoides quadrigatus*	Searle, 1957; Sharma, 1973	Primary scientific literature	As *Chiropsalmus quadrigatus.* Mention of collection and specific locality found in Singapore; brief taxonomic description. Specimens missing, actual identity of jellyfish is uncertain. *Chiropsalmus quadrigatus* is now synonymised as *Chiropsoides quadrigatus* however, unresolved taxonomic issues for this genus still persists (see Gershwin, 2006).