

First Records of the Invasive “Upside-down Jellyfish”, *Cassiopea* (Cnidaria: Scyphozoa: Rhizostomeae: Cassiopeidae), from Coastal Lakes of New South Wales, Australia

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ABSTRACT. Scyphozoans of the genus *Cassiopea* (Cassiopeidae) are notable for their unusual benthic habit of lying upside-down with tentacles facing upwards, resulting in their common name, “upside-down jellyfish”. In Australia, five named species of *Cassiopea* have been recorded from the tropical north. *Cassiopea* are frequently noted worldwide as invasive species and here, we report the first records of the genus and family from temperate eastern Australia on the basis of specimens collected from two widely separated coastal lakes, Wallis Lake and Lake Illawarra; these specimens represent southern range extensions of the genus by approximately 600 km and 900 km, respectively. *Cassiopea* from Lake Illawarra and Wallis Lake appear to represent different species, which we assign to *C. ndrosia* and *C. cf. maremetens*, respectively, noting morphological discrepancies from published accounts.

KEYWORDS. Introduced species, coastal lake, *Cassiopea*, Wallis Lake, Lake Illawarra, New South Wales

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The medusa stage of the scyphozoan, *Cassiopea* (Cassiopeidae), is a distinctive marine or estuarine jellyfish, notable for its unusual, inverted, largely sedentary and benthic behaviour, imparting the common name “upside-down jellyfish”. This lifestyle typically involves the jellyfish lying in sheltered, shallow water with the aboral surface of the exumbrella facing downward onto sediments and the oral arms above. This posture and niche provides sunlight to algal endosymbionts (zooxanthellae) within the tissues although the jellyfish are also suspension feeding carnivores (Verde & McCloskey, 1998; Schembri *et al.*, 2009; Marsh &

Slack-Smith, 2010). The severity of stings to humans from *Cassiopea* has been variably reported from mild or absent to severe (Southcott, 1982; Marsh & Slack-Smith, 2010).

Although *Cassiopea* is readily recognized, the species level taxonomy is confused and requires reappraisal (Holland *et al.*, 2004). Worldwide, at least 11 species are currently recognized: *Cassiopea andromeda* (Forskål, 1775), *C. depressa* Haeckel, 1880, *C. frondosa* (Pallas, 1774), *C. medusa* Light, 1914, *C. maremetens* Gershwin, Zeidler & Davie, 2010, *C. mertensi* Brandt, 1838, *C. ndrosia* Agassiz & Mayer, 1899, *C. ornata* Haeckel, 1880, *C. xamachana*

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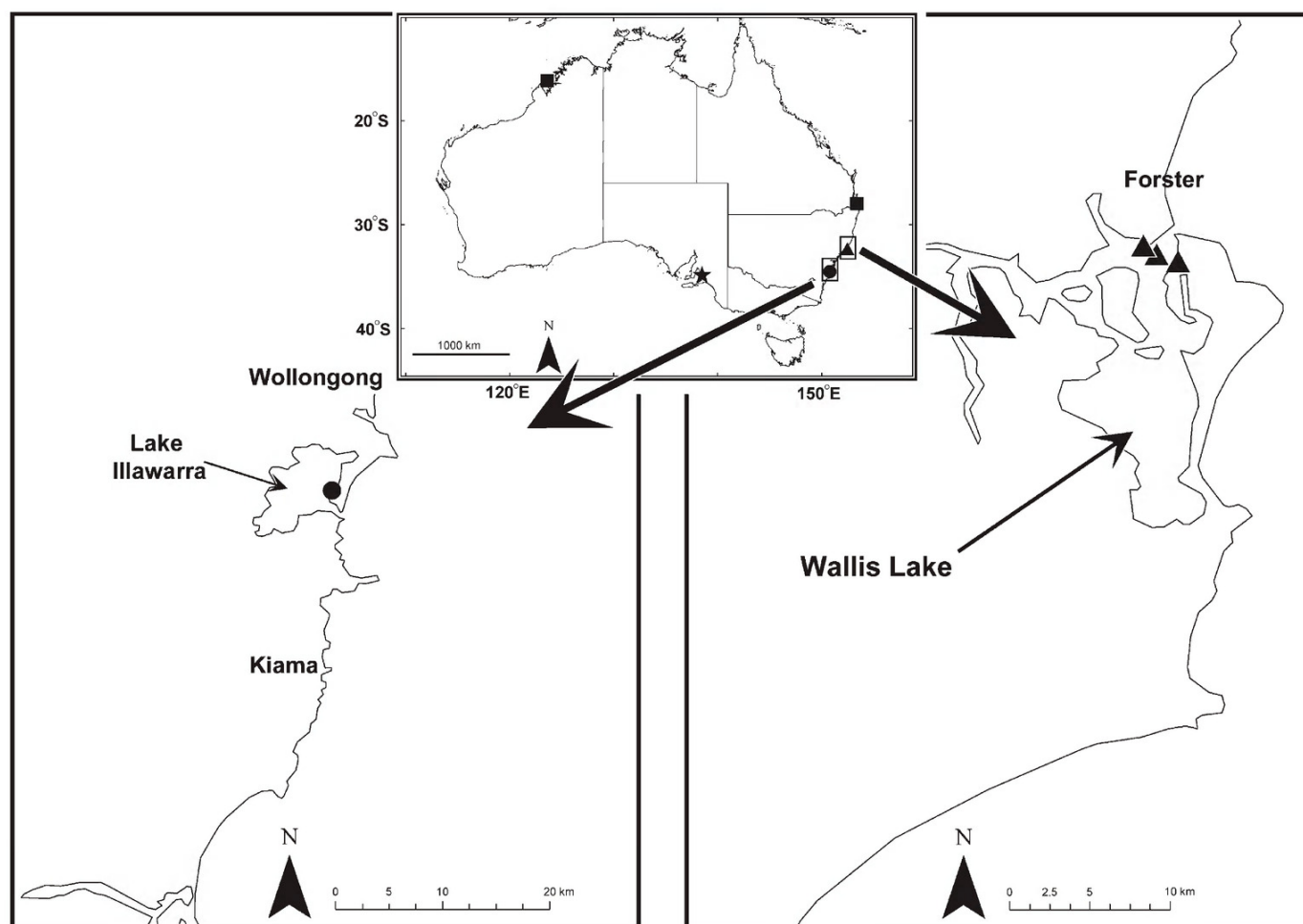


Figure 1. Location of previous southern records of *Cassiopea* from Australia (squares) and new localities reported here (circles and triangles), star represents anomalous record from Torrens Island Power Station.

Bigelow, 1892 (Gershwin *et al.*, 2010; WoRMS, 2014). Unfortunately, the correct name applicable to specimens from various locations is problematic (Holland *et al.*, 2004) and undescribed species are known (Gershwin *et al.*, 2010). Therefore, few species of *Cassiopea* can presently be accurately identified.

The genus is widely distributed in the tropics (Holland *et al.*, 2004) but also acknowledged as globally invasive (Graham & Bayha, 2007). As early as 1886, *C. andromeda* from the Red Sea was recorded in the Suez Canal, and soon after in the Mediterranean Sea off Cyprus; today it is known from the Aegean coast of Turkey (Gülşahin & Tarkan, 2012) and the central Mediterranean Sea off Malta (Schembri *et al.*, 2009). Other incursions are recorded from Hawaii (Holland *et al.*, 2004). In Australia, five named species or subspecies (*C. andromeda andromeda*, *C. andromeda baduensis*, *C. maremetensis*, *C. ndrosia*, *C. ornata*) and two undescribed species have been reported (Gershwin *et al.*, 2010). Péron & Lesueur (1810) described *Cassiopea dieuphila* from northwestern Australia but its taxonomic status is presently indeterminate. Previous southernmost Australian records of *Cassiopea* (Fig. 1) are from Queensland and Western Australia, north of approximately 27°58'S on the east coast and 16°08'S on the west coast (Atlas of Living Australia, 2014). An additional anomalous record of *C. ndrosia* from

Angas Inlet, near Adelaide, South Australia (approximately 34°48'S 138°32'E) is associated with the warm water outlet of the Torrens Island Power Station where temperatures are raised 5–8°C above ambient (Southcott, 1982).

Here, we report the sudden, recent appearance of medusae of *Cassiopea* from two shallow, widely separated, coastal lakes on the central east coast of Australia based on both sightings and preserved specimens. These are the first records of *Cassiopea* and Cassiopeidae from temperate eastern Australia.

Materials and methods

In 2013 and 2014, the authors were contacted through colleagues by concerned members of the public seeking to identify jellyfish that had appeared in large numbers in their local waterways (Lake Illawarra, 2013, and Wallis Lake, 2014; Fig. 1) and considered unusual. Subsequently, examples of these jellyfish were collected and deposited in the collections of the Australian Museum (AM). Whole specimens are fixed in 4–10% formalin but non-formalin fixed frozen tissue samples have also been retained for genetic studies currently in progress. Specimen measurements indicate bell diameter (bd). The synonymy of *C. ndrosia* is restricted to the original citation and Australian records.

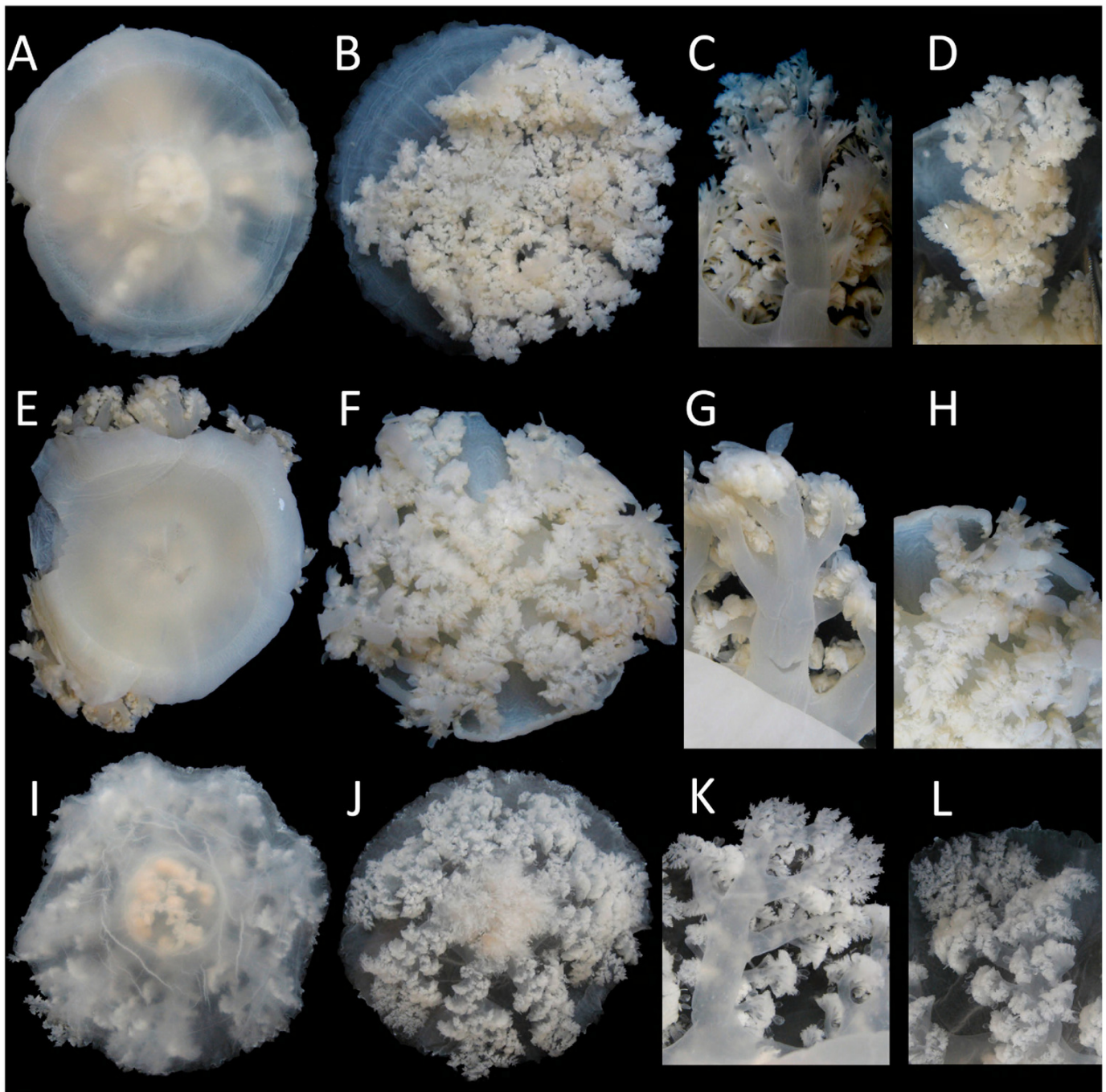


Figure 2. (A–D) *Cassiopea ndrosia*, bd 80 mm, Lake Illawarra, AM G.18075. (E–H) *Cassiopea* cf. *maremetens*, bd 80 mm, Wallis Lake, AM G.18155. (I–L) *Cassiopea maremetens*, bd 110 mm, Moreton Bay, paratype, QM G.6645. A, E, I, aboral surface; B, F, J, oral surface; C, G, K, aboral view of oral arm; D, H, L, oral view of oral arm.

Taxonomy

A taxonomic revision of *Cassiopea* is needed as there are a number of difficulties in recognizing species within the genus with currently used character suites (Holland, 2004; Gershwin *et al.*, 2010; Shapiro, 2014). On the basis, however, of characters highlighted by Mayer (1910) and Gershwin *et al.* (2010) in comparison with paratypes of *C. maremetens* in the Queensland Museum (QM G.6645, Fig. 2I–L) and other specimens in the collections of the Australian Museum (AM), it is apparent that two forms are present in the samples from New South Wales, identified here as *C. ndrosia* (Lake Illawarra) and *C. cf. maremetens* (Wallis Lake).

Cassiopeidae Tilesius, 1831

Cassiopea ndrosia Agassiz & Mayer, 1899

Figs 2A–D, 3A–B

Cassiopea ndrosia Agassiz & Mayer, 1899: 175, pl. 14, figs 45, 46; Stiasny, 1934: 913–921; Kramp, 1965: 265; Southcott, 1982: 159, pls. 15.3, 15.4; Gershwin *et al.*, 2010: 91.

Material examined. AM G.18074, 1 specimen, from bottom of canal through “Jetties By The Lake Lifestyle Village” at Windang Road, Lake Illawarra, New South Wales, Australia,

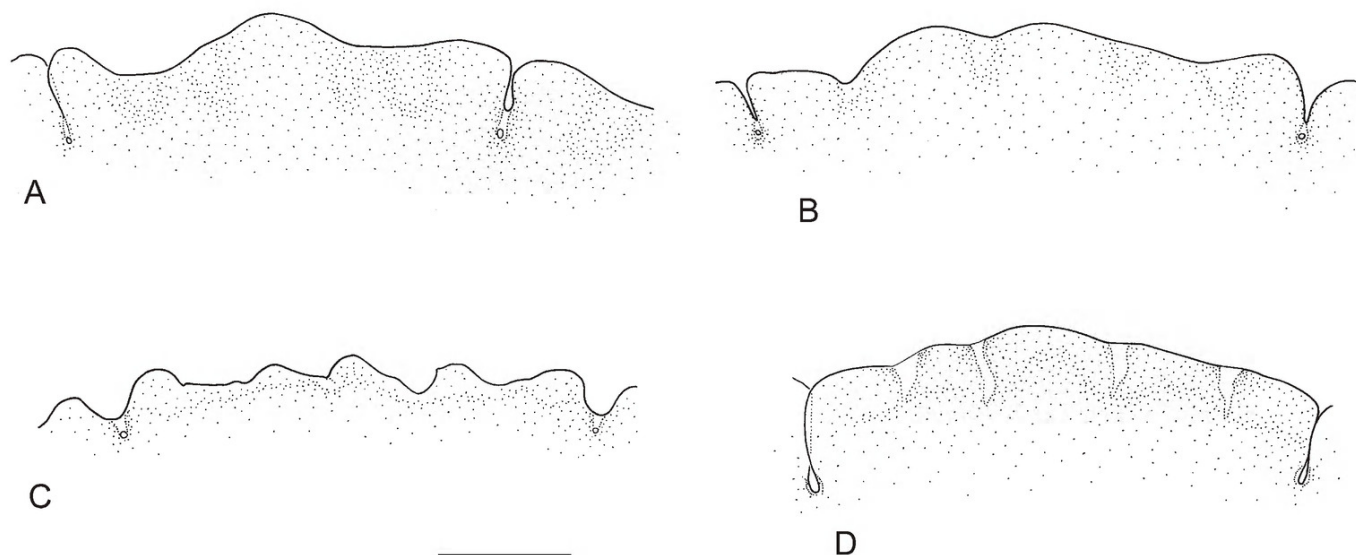


Figure 3. Lappets, oral view. (A) *Cassiopea ndrosia*, Lake Illawarra, bd 80 mm, AM G.18075. (B) *Cassiopea ndrosia*, bd 100 mm, Hayman Island, AM G.13568. (C) *Cassiopea* cf. *maremetens*, bd 90 mm, Wallis Lake, AM G.18156. (D) *Cassiopea maremetens*, paratype, bd 110 mm, Moreton Bay, QM G6645. Scale = 5.0 mm.

34°31'36"S 150°51'53"E, 0–1 m, M. Cameron, 8 May 2013; AM G.18075, 1 specimen (80 mm), locality data as for G.18074; AM G.13568, 3 specimens (90–120 mm), Hayman Island, Whitsunday Passage, Queensland, 20°03'S 148°53'E, tidal flat, coll. F. A. McNeill, January 1933.

Remarks. The Lake Illawarra specimens, collected in 2013, conform well to *C. ndrosia* according to diagnostic characters indicated by Mayer (1910), Southcott (1982), Gershwin *et al.* (2010: tab. 9) and comparative specimens from Queensland (AM P.13568; originally reported by Stiasny, 1934). The “pinnate” branching of the oral arms (i.e., with lateral arms opposing each other on the primary arm) is the most significant distinction from *C. maremetens* in which the lateral arms “alternate” in position along the primary arm (see Fig. 2C for *C. ndrosia* from Lake Illawarra versus Fig. 2K for *C. maremetens*). Additionally, the oral arms are subequally branched just distal of the midpoint of the total arm length in the material from Lake Illawarra, a condition found in *C. maremetens* only on the distal extremity of the oral arms due to the arrangement of alternate branching of the proximal lateral arms. The vesicles are elongate and leaf-shaped, of varying size, and numerous, especially toward the centre. Numbers of these vesicles are relatively small and no longer than the width of the oral arms, however, initially giving the impression that relatively fewer vesicles are present until examined under magnification. The Lake Illawarra and Queensland (Hayman Island) specimens agree closely and correspond to the current concept of *C. ndrosia* (see Mayer, 1910; Gershwin *et al.*, 2010). *Cassiopea ndrosia*, first described from Fiji, is currently attributed a wide distribution in the central and western Pacific, from French Polynesia to Australia and Japan (Kramp, 1965); records, however, require confirmation (Holland *et al.*, 2004; Gershwin *et al.*, 2010). In Australia, *C. ndrosia* has been reported from Queensland (Torres Strait, the Gold Coast, Hayman Island; Stiasny, 1934; Kramp, 1965) and South Australia (Angas Inlet; Southcott, 1982).

Gershwin *et al.* (2010) noted the very close similarity between *C. ndrosia* and *C. maremetens*, with the chief differences recognized in the branching of the oral arms

(pinnate versus alternate), and shape and number of lappets per paramere (1–2 indistinctly lobed versus 4 square, deeply incised); we question the latter distinction below under the account of *C. cf. maremetens*.

The collector of the Lake Illawarra specimens noted this jellyfish started appearing and multiplying two weeks prior to the samples being obtained. Over 100 individuals were observed at this time at the same location—a small, shallow, artificial canal (8–10 m wide, approximately 100 m long, less than 1 m deep) within a residential village on the Lake Illawarra foreshore (Fig. 4A). Water temperatures measured daily within the canal for over a week while the jellyfish were present ranged from 17 to 22°C but within two months of collection, and the onset of cooler winter weather (water temperature not measured), the population disappeared (M. Cameron, pers. comm.). A check of the area in May 2014 and discussion with local residents living next to the canal indicates the jellyfish have not reappeared at this location. Other sites along the shoreline within Lake Illawarra were also inspected in May 2014 without encountering any *Cassiopea*.

Cassiopea cf. *maremetens* Gershwin, Zeidler & Davie, 2010

Figs 2E–H, 3C, 4E,F

Material examined. AM G.18137, 1 specimen, in channel splitting Godwin Island approximately one third distance from southern shore, Breckenridge Channel, Wallis Lake, New South Wales, Australia, 32°11'45"S 152°29'56"E, R. Pearce, 15 August 2014. AM G.18138, 1 specimen, collection data as for G.18137. AM G.18139, 11 specimens, collection data as for G.18137. AM G.18143–18155, single specimens; AM G.18156, 13 specimens, Pipers Creek, behind Smugglers Cove Caravan Park, Wallis Lake, New South Wales, Australia, 32°12'00"S 152°30'39"E, R. Pearce, 18 September 2014. AM G.18181–18183, 4 specimens, inlet on south east side of Mather Island, Wallis Lake, New South Wales, Australia, 32°11'26"S 152°29'36"E, S. J. Keable & A. D. Hegedus, 28 April 2015. AM G.18184, 1 specimen,

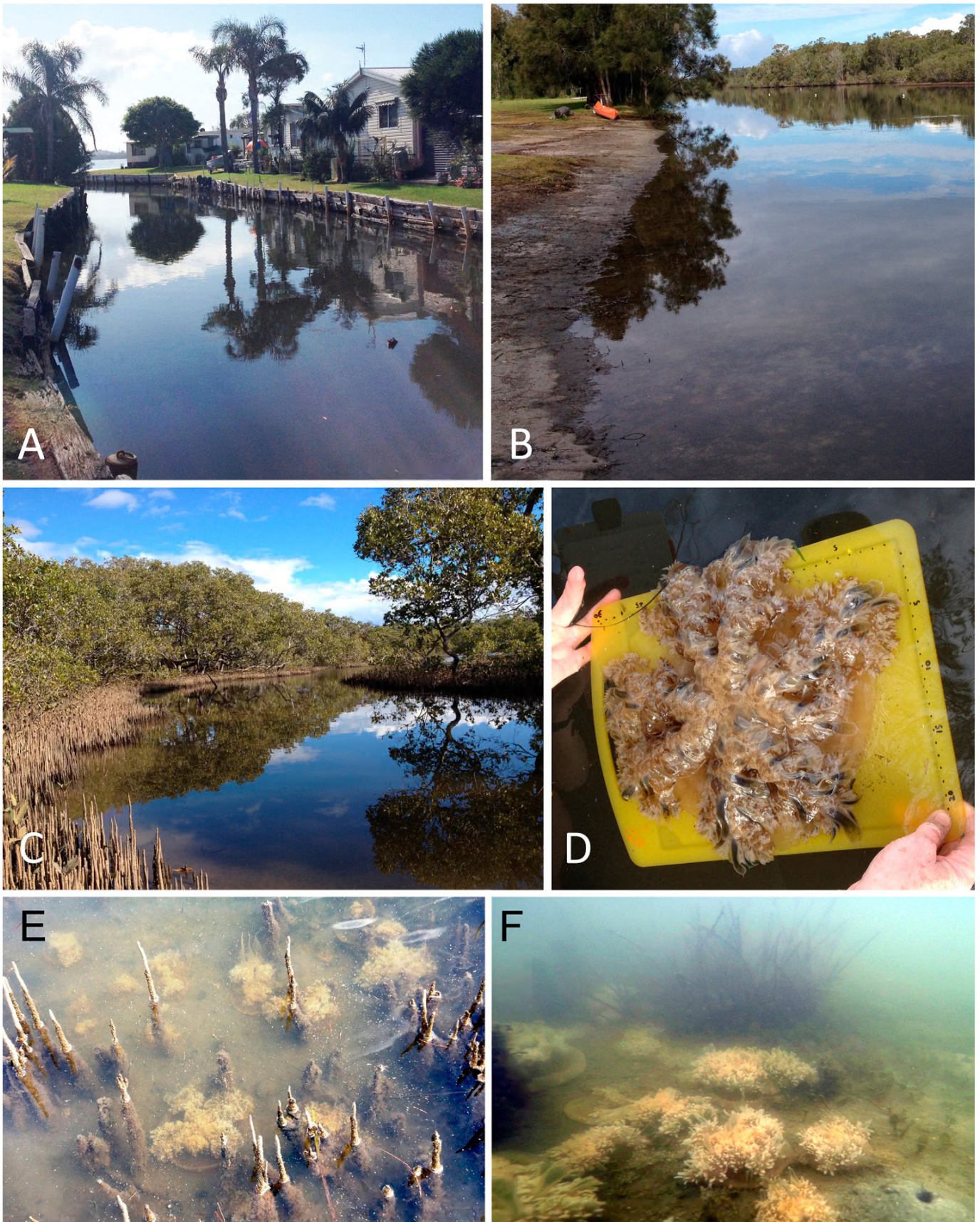


Figure 4. (A) Collection site for *Cassiopea ndrosia* from Lake Illawarra, canal through “Jetties By The Lake Lifestyle Village” looking toward lake. (B) Collection site for *Cassiopea* cf. *maremetens* from Pipers Creek, Wallis Lake, looking toward lake. (C) collection site for *Cassiopea* cf. *maremetens* from inlet on south east side of Mather Island, Wallis Lake, looking toward lake. (D) field measurement of bell diameter of c.210 mm for *Cassiopea* cf. *maremetens* from Pipers Creek, Wallis Lake. (E–F) Aggregation of *Cassiopea* cf. *maremetens* at inlet on southeast side of Mather Island, Wallis Lake from above and below water surface, respectively.

Pipers Creek within Smugglers Cove Caravan Park, Wallis Lake, New South Wales, Australia, 32°11'58"S 152°30'39"E, S. J. Keable & A. Murray, 30 April 2015. Bell diameter 35 mm (AM G.18182) to 210 mm (AM G.18139).

Comparative material of *C. maremetens*. QM G6645, 3 paratypes (110–130 mm), Mud Island, Moreton Bay, Queensland, C. Wallace, 8 April 1972.

Remarks. The Wallis Lake specimens appear to be closest to *C. maremetens* Gershwin, Zeidler & Davie, 2010, from Queensland (Figs 2I–L, 3D) (type locality, Lake Magellan, southwest of Caloundra, 26°49'42"S 153°06'48.6"E), with which they agree in most respects including exumbrella conformation, branching pattern of the oral tentacles and the numbers of rhopalia (19–21) (Gershwin *et al.*, 2010). The material from Wallis Lake (Fig. 2G) agrees with type material of *C. maremetens* (QM G6645; Fig. 2K), and most noticeably differs from the Lake Illawarra specimens (Fig. 2C), in having alternating (i.e., non-opposing) rather than pinnate lateral branches along the length of the oral arms and lacking a distinct subequal bifurcation just distal to the midpoint of the primary arm. They differ, however, from both *C. maremetens* sensu stricto and *C. ndrosia* in the presence of numerous, large, conspicuous vesicles along the length of these arms (compare Fig. 2H and Fig. 2D [*C. ndrosia*, Lake Illawarra] and Fig. 2L [*C. maremetens*]). The vesicles are variably leaf shaped (generally slightly broader in the distal half, maximum width approximately one-third length), and generally as wide as the lateral arm branches. The presence of the numerous large vesicles on the oral arms is the most significant distinction between the Wallis Lake specimens and *C. maremetens* sensu stricto, which has few or no vesicles. Gershwin *et al.* (2010), however, noted they could not adequately assess the significance of the presence or absence of vesicles in their material, whether a polymorphism or indicative of an additional unrecognized species. Just as Gershwin *et al.* (2010) observed no correlation between body size and presence of vesicles on the oral arms in *C. maremetens*, the vesicles in the Wallis Lake specimens are similarly numerous across the size range.

Significantly, our Wallis Lake specimens also differ from the description of *C. maremetens* in the lappet shape and arrangement (Fig. 3C–D). Ocelli are present in the Wallis Lake specimens, absent in *C. maremetens*. The margin of the parameres in the Wallis Lake specimens are sinuous, resulting in 4–5 low, rounded lobes (Fig. 3C). In contrast, the lappets of *C. maremetens* are reported as square and deeply incised, with four per paramere (Gershwin *et al.*, 2010). Close examination of paratypes of *C. maremetens*, however, revealed the squared, apparently deep incisions are bridged by transparent exumbrella membrane (Fig. 3D). Thus, instead of being deeply incised, the outline of the lappets of *C. maremetens* (at least in the paratypes examined) is actually essentially sinuous and indistinctly lobate, much like that of *C. ndrosia*. The lappets in the Wallis Lake material differ from *C. maremetens* in having a more strongly sinuous margin with more numerous lobes per paramere. The differences in lappet shape and vesicle complement in comparison to *C. maremetens* suggest that the Wallis Lake specimens may represent a separate, possibly undescribed species. Pending further study, however, we tentatively identify our material as *C. cf. maremetens* to highlight its similarity to *C. maremetens*. *Cassiopea maremetens* sensu

stricto is presently known from Bentinck Island, Gulf of Carpentaria, Queensland (c. 17°03'34"S 139°29'09"E) to Moreton Bay on the Queensland east coast (27°48'S 153°24'E). Reports of *C. andromeda* from Southport, Queensland (27°58'S 153°25'E), just south of Moreton Bay, may also represent *C. maremetens* (Gershwin *et al.*, 2010).

The original collector of *Cassiopea* cf. *maremetens* from Wallis Lake first observed these jellyfish “in their hundreds” in Pipers Creek in 2009. The 2014 outbreak in the vicinity of Godwin Island (reported as “in large numbers within a small area”), documented here with specimens, was noticed on or near 2 August 2014 although specimens were not collected until 15 August 2014. Specimens of *C. cf. maremetens* were obtained again from the same location in Pipers Creek in September 2014.

Subsequent fieldwork in Wallis Lake in April 2015 confirmed the continued presence of *C. cf. maremetens* in Pipers Creek (Fig. 4B) and at a third locality within the lake adjacent to the shore at Mather Island (Fig. 4C). A 75 m transect line was placed randomly along the shoreline in both these locations and *Cassiopea* within 1 m of the shore along this distance were counted. Five randomly selected individuals from each transect were also measured for bell diameter. At Pipers Creek, 30 individuals were present along the transect, the bell diameter of the individuals measured ranged from 120 to 210 mm (Fig. 4D) with a mean of 170 mm. At Mather Island 24 individuals were present along the transect, those measured ranged in size from 40–70 mm with a mean of 53 mm. Distribution of *Cassiopea* appeared patchy. Outside the transects, dense aggregations were observed (Fig. 4E,F) with up to 35 per square metre at Mather Island. A water temperature of 21.5°C and a salinity of 28.7 parts per thousand was recorded during the Mather Island transect and a salinity of 12.1 parts per thousand at Pipers Creek. *Cassiopea* were observed lying with the aboral surface resting on very soft sediment in depths of 10–100 cm.

Discussion

The impacts (both ecological and economic) and mechanisms behind invasions and population explosions of jellyfish have received considerable recent interest (Graham & Bayha, 2007; Gershwin, 2013; Pitt & Lucas, 2014), influencing, for example, commercial fisheries, tourism and trophic structures. Species of *Cassiopea* feature in these reports as a globally invasive genus (see references cited above).

Cassiopea has not previously been recorded from New South Wales. Pitt *et al.* (2006) note jellyfish as the most conspicuous animals in Lake Illawarra and indicate the three species most commonly seen as *Catostylus mosaicus*, *Phyllorhiza punctata* and *Aurelia aurita* but not *Cassiopea*. Similarly, other scyphozoans such as *Catostylus mosaicus* have been documented from Wallis Lake (Pitt & Kingsford, 2000) but not *Cassiopea*.

The samples reported here, therefore, represent a range extension for *Cassiopea* of approximately 600 km (Wallis Lake) to 900 km (Lake Illawarra) southward of the previous southern instance on the east Australian coast, Southport, Queensland. Given the lack of previous records, the apparently sudden appearance in large numbers is significant.

We do not discount the role of normal environmental change in driving changes in species' ranges. However, *Cassiopea* are not considered to have strong natural dispersal

capabilities (Holland *et al.*, 2004) so it is highly plausible that anthropogenic influences are involved. Given the isolated and significantly disjunct occurrences of the two forms recorded here, that at least one of the present forms does not appear referable to known Australian species, and the genus is conspicuous where it occurs, the new records from New South Wales do appear to represent new introductions. Even if the Wallis Lake form is referable to true *C. maremetens*, the absence of records from intermediate localities in New South Wales is consistent with human mediated translocation. Different factors may also be implicated in the different situations of Wallis Lake compared to Lake Illawarra. Vectors suggested for anthropogenic transport of *Cassiopea* include shipping (through biofouling or ballast water release), intentional or unintentional direct release and via “live rock” from aquaria (Holland *et al.*, 2004; Graham & Bayha, 2007; Schembri *et al.*, 2009). Both lakes have considerable recreational and other domestic vessel traffic, and Lake Illawarra is close to a major population centre, Wollongong and commercial port, Port Kembla. Increased water temperatures associated with global warming or a perturbation of the East Australian Current could also be involved, although one would predict the occurrence of *Cassiopea* from intermediate localities between southern Queensland and Wallis Lake–Lake Illawarra.

The presence of *Cassiopea* medusae in Lake Illawarra currently appears to be ephemeral, but the dormant reproductive potential of the polyp stage of jellyfish (Gershwin, 2013) means another outbreak could occur again in the future. Conversely, *Cassiopea* appears to be established in Wallis Lake where it is continuously present over consecutive seasons. Given the amenity, economic asset and ecological benefits these waterways provide and the possible negative impacts invasive jellyfish are known to have, it is imperative that these outbreaks are studied further, and the vectors for translocation identified. Moreover, taxonomic revision of the genus is urgently required in order that incursions can be accurately recognized and tracked. We hope publication of these initial records will stimulate further investigations.

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