SPONGES AND ASCIDIANS OF WALLIS & SMITHS LAKES:

2002 – 2022

The sponge, *Tetilla* sp., Smiths Lake

REPORT

PREPARED BY THE UNIVERSITY OF WOLLONGONG

FOR

MIDCOAST COUNCIL, NEW SOUTH WALES

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UNIVERSITY OF WOLLONGONG AUSTRALIA

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Executive Summary

This project provided an opportunity to (i) resample Wallis and Smiths Lakes, consolidating a 20-year dataset (2002- 2022) with a total of 18 times of sampling at numerous sites within these lakes, and (ii) demonstrate that the fauna was readily identifiable and could be successfully sampled by a group of competent volunteers in a cost-effective manner.

The seagrass and macroalgal meadows of the southern basin of Wallis Lake continue to be a hotspot for sponge diversity compared to other coastal lakes and lagoons in New South Wales. In the long term, species composition has remained similar with six of the ten species recorded in 2002, recorded again in the most recent sampling (2019-2021). Over time, ascidian diversity appears to have declined with the only species, the introduced solitary ascidian *Styela plicata*, encountered since 2009 and this species was not recorded in the most recent sampling (November, 2021). In 2017 a new sponge taxon was recorded in Wallis Lake, *Pseudospongosorites* sp.. Subsequently, it has been recorded in every sample and was regarded as common in some sites. *Suberites* cf. *diversicolor* continued to be the most commonly encountered sponge in both Lakes. *Suberites* were at highest recorded abundances in Smiths Lake in 2017. Since 2017 the abundance of *Suberites* became highly variable near Pacific Palms which had up until 2007 been the most reliable region of Wallis Lake to encounter them. Necrotic individuals of *Suberites* and *Pseudospongosorites* sp. were observed during sampling in 2021, coincident with very heavy rainfall. The trend of decreasing cover of the habitat forming charophyte *Lamprothamnion* sp. near Pacific Palms continued, with less than 5% cover in the most recent sampling. This represents an 80% reduction in cover since the mid 2000's.

Patterns of boom and bust for many ascidians and sponges were apparent over the 20-year time frame of sampling. Striking increases in the abundance of the previously rarely encountered sponges *Tetilla* sp., *Dysidea* sp. and *Aplysilla* cf. *sulphurea* were particularly notable. For *Tetilla* sp increases exceeded two orders of magnitude in Smiths Lake. Periodic booms coupled with the typically patchy distributions among sites and habitats suggest there may be a number of abiotic and biotic processes driving these complex changes. While it is difficult to identify with confidence individual factors responsible for booms and busts, processes including the release from predation pressure by fish, availability of food, availability of suitable habitat (in particular structure of seagrass and macroalgal meadows), recruitment, water quality (including temperature and sediment loads) and changes caused by blooms of other species such as the jellyfish, *Catostylus mosaicus* should be considered for targeted research.

The paucity of information regarding the biology and ecology of the invertebrate taxa associated with these Lakes continues to inhibit a more informed approach to their conservation and the management of the Lakes more broadly. Indeed, many of the sponge taxa in these Lakes are likely to be undescribed and new to science. In order to better support catchment management we recommend that:

(i) Council continues to monitor sponges and ascidians to better understand their complex patterns of distribution and abundance.

(ii) Council considers the broad ecosystem including sponges, ascidians and habitat forming biota such as algal and seagrass meadows, in assessments of proposed developments in catchments.

(iii) More detailed ecological studies of the processes driving complex changes be undertaken.

1 | INTRODUCTION

The coastal Lakes and Lagoons of the Australian eastern seaboard are often focal points for development and human recreational activities. One would expect the fauna and flora of these habitats to be well known, but unfortunately there is a paucity of research on some important taxa. For example, relatively little is known about the sponges and ascidians in these saline coastal lakes and lagoons. Before 2002, sponges and ascidians had rarely been studied in these systems (but see Barnes *et al.* 2006; Barnes *et al.* 2013; de Mestre *et al.* 2012). Recent studies, however, suggest there are at least 20 species of sponges associated with the seagrass and algal meadows in New South Wales coastal lakes and lagoons, the majority of which are likely to be undescribed and new to science (Barnes 2009; Barnes *et al.* 2013). The seagrass and algal meadows of Wallis Lake have been identified as a hotspot for sponge diversity among these environments in New South Wales. In 2002, the seagrass and algal meadows of Wallis Lake had the largest diversity of sponges (10 species) of 20 New South Wales lakes and lagoons (Barnes 2009). In comparison, the majority of other lakes generally had fewer than half this number of species and in the case of smaller and temporally closed systems were typically devoid of sponges and ascidians (Barnes *et al*. 2013). It is worth noting that the nearby coastal reefs of the Sydney region are regarded a global hotspot for sponge diversity (Van Soest et al. 2012).

Some species growing on rocky outcrops in Wallis Lake (e.g. *Chondrilla australiensis*) are typically associated with rocky reefs on the open coast. However, because many of the sponges in Wallis Lake are yet to be identified at the species level and are likely to be new to science, it is very difficult to determine their broader range of distribution. That is, whether they also occur on the open coast or in large estuarine systems. Indeed, sampling within a large south-coast marine embayment has failed to find many of these sponge taxa adding weight to the notion that they are highly restricted in their distribution (Demers *et al.* 2016). With no other known records of these sponges (with the exception of the surprisingly widespread *Suberites* cf. *diversicolor*), it is possible they may be restricted in range to coastal lakes and lagoons and may occur in only a very small subset of these habitats in New South Wales (Barnes 2009). For example, four of the ten species of sponge previously recorded in Wallis Lake have only been recorded from Wallis Lake and most other species have only been recorded from a handful of other lakes.

With little known of the biology and ecology of these sponges, they may be under threat from a range of natural and anthropogenic sources of environmental disturbance. Many of the sponges may be restricted to a small number of lakes (Barnes 2009) and many species may be restricted to particular habitats (e.g. macroalgal or seagrass meadows) within those lakes (Barnes 2009). Small and isolated geographical ranges can make species particularly vulnerable to extinction from catastrophic events because if a population is made locally extinct, it is unlikely new populations will be able to recolonise rapidly, if at all. The nature of these saline lakes and lagoons may further reduce the likelihood of recovery as a consequence of impeded connectivity, including the separation of saline lakes by many kilometres of open ocean, narrow inlet channels, periodic entrance openings and the vagaries of tides and currents. While some authors have suggested birds may play an important role in the dispersal of sponges among isolated systems, this mechanism does not appear to have been investigated for wholly marine sponges (Harrison 1971; Racek & Harrison 1975). Recolonisation by sponges from other lakes may be further limited by many species having larvae that remain in the water column for only relatively short periods of time and disperse only short distances from the parent (Maldonado 2006). These concepts are supported by the evidence that smaller lakes and lagoons which experience rapid and large changes in water chemistry (e.g. salinity) due to heavy rainfall or the opening of sand bars and influx of seawater, do not support populations of sponges (Barnes et al. 2013).

In this study we assessed the current state of sponges and ascidians in Wallis and Smiths Lake and changes in these assemblages from 2002 to 2022 to support coastal managers in understanding the health of the lake and effectiveness of management in conserving the local environment. It can be difficult to distinguish changes in populations caused by environmental impacts or effective management from natural variation which is often large and unpredictable (Chapman 1998; Underwood 1991). Ideally, changes in an assemblage in the system of interest (in this case Wallis Lake) would be compared to natural changes in similar systems with similar assemblages but which were unaffected by environmental impacts or environmental management – usually called 'Control' or 'Reference' locations (Chapman 1998; Underwood 1991). Ideal control locations do not always exist, however, particularly for large and unique systems such as Wallis Lake. This study, therefore used two approaches to understand changes in assemblages of sponges and ascidians in Wallis Lake. First, the four recent surveys of Wallis Lake in 2019-2021 were compared to fourteen previous surveys. These included surveys from 2002 to 2005 (Barnes, unpublished data), along with surveys from 2007 and 2009 (Barnes 2010), and surveys undertaken in January and April 2017 (Barnes et al. 2017). All surveys used identical field sampling techniques and a similar arrangement of sites. Second, to understand potential changes in a broader geographical context, changes in assemblages in Wallis Lake were compared to surveys in nearby Smiths Lake in 2019-2022 and twelve preceding surveys. This included surveys from 2002 to 2005 (Barnes, unpublished data) and more recently January and April 2017 (Barnes et al. 2017). The resultant twenty-year data set provides significant insights into population dynamics of sponge and ascidian assemblages. Such long-term data sets are extremely rare and are therefore tremendously valuable to help understand patterns of variability, change and environmental impacts.

2 | METHODS

2.1 | Field sampling in 2019-2022

Sponges, ascidians, and other conspicuous invertebrates (e.g., nudibranchs, seahares and octopus) were sampled in thirteen to seventeen sites in the southern basin of Wallis Lake on four occasions between 2019-2021 (Time 1 – 9th & 10th December 2019; Time 2 - 30th November to 4th December; Time 3 – 16th and 17th March 2021 and 14th and 21st April 2021; Time 4 – 18th & 19th November 2021). Sites were chosen over this time period following the rationale of Barnes (2010) to provide a good representation of the invertebrate assemblages and habitats in the southern portion of Wallis Lake (**Figure 1**). Similarly, eight sites were sampled in Smiths Lake on four occasions in 2019 to 2022 (Time 1 – 11th and 12th December 2019; Time 2 – 3rd December 2020; Time 3 - 15th and 20th April 2021; Time 4 - 5th April 2022). Sites in Smiths Lake were chosen for comparison to sites sampled from 2002 to 2005 by Barnes unpublished data (Barnes *et al.* 2009) and resampled in 2017 (Barnes et al. 2017) (**Figure 2**). Historically, twenty-two sites were established in Wallis Lake, with subsets of these sites being sampled over the course of the last twenty years (see Supplemental

Figure 1 in the Appendices). In the most recent surveys, emphasis was placed on targeting three accessible locations (Pacific Palms, Booti Booti and Tiona, **Figure 1**) each containing several sites, providing opportunities to examine temporal patterns of abundance.

Assemblages of invertebrates and benthic vegetation were sampled in each site using two methods:

1. Transects were used to quantify the relatively abundant species of sponges and ascidians. Individual sponges, solitary and colonial ascidians, nudibranchs and seahares were counted by a snorkeller in each of six replicate 10 x 2 m transects haphazardly placed in each site. In addition to counting invertebrates, the percentage cover of different types of aquatic vegetation (seagrasses and macroalgae) and bare substratum were estimated in each transect to provide a qualitative description of the habitats in each site.

2. Timed searches were used to determine the presence or absence of species of invertebrates. Because many species of sponge and ascidian are very uncommon and sparsely distributed in NSW coastal lakes (Barnes *et al*. 2006) and are therefore unlikely to be found in relatively small transects, timed searches in which a snorkeller swam haphazardly for five minutes within a site allowed more area to be searched than within transects and hence greatly increased the probability of finding the less common species. Four replicate five minute timed searches were done at each site (See Barnes *et al*. 2006 for optimisation of sampling design).

Sites were approximately 60 metres in diameter.

2.2 | Examining changes in sponges and ascidians through time: 2002 to 2021

Temporal changes in assemblages of sponges and ascidians in Wallis and Smiths Lakes were investigated from 2002 to 2022 by comparison to the results of previous studies by Barnes (unpublished data), Barnes (2009 & 2010) and Barnes et al. (2017). While there was some variation in the numbers and arrangement of sites sampled among times between 2002 and 2022, the sampling methods including the counting of sponges, ascidians and aquatic vegetation, size of transects, numbers of transects and numbers of timed searches per site remained consistent across all times. Sites sampled in Wallis Lake in 2007 and 2009 are illustrated in Supplemental Figures 2 and 3 respectively.

Temporal changes in species present were examined at the level of an entire lake with sites pooled. Changes in the abundances of species of interest were examined at comparably located sites within each lake. For example, in Wallis Lake, multiple sites were always sampled in the southern portion of the lake near Pacific Palms on all 14 surveys (**Figure 1**). This area which typically contained extensive meadows of the stonewort (Charophyta), *Lamprothamnion* sp. in previous surveys (Barnes 2009) was also identified as a hotspot for sponge diversity and abundance. Abundances of the sponges *Suberites* cf. *diversicolor, Dysidea, Mycale, Haliclona* sp. 2 and a species of calcareous sponge, along with the ascidian *Styela plicata* were compared through time at multiple sites in the southern basin of Wallis Lake near Pacific Palms. Since 2017, these species were also examined at additional locations to the north; Booti Booti and Tiona (**Figure 1**). At least two sites were sampled in these areas on each occasion. Similarly, percentage covers of *Lamprothamnion* were compared through time at sites near Pacific Palms to investigate possible relationships with sponge and ascidian abundance.

The studies by Barnes in Smiths Lake from 2002 to 2005 used a hierarchical sampling design with sites nested within locations. Between two and four locations sampled at each time and kilometres apart were used in the comparisons through time for Smith's Lake (**Figure 2**).

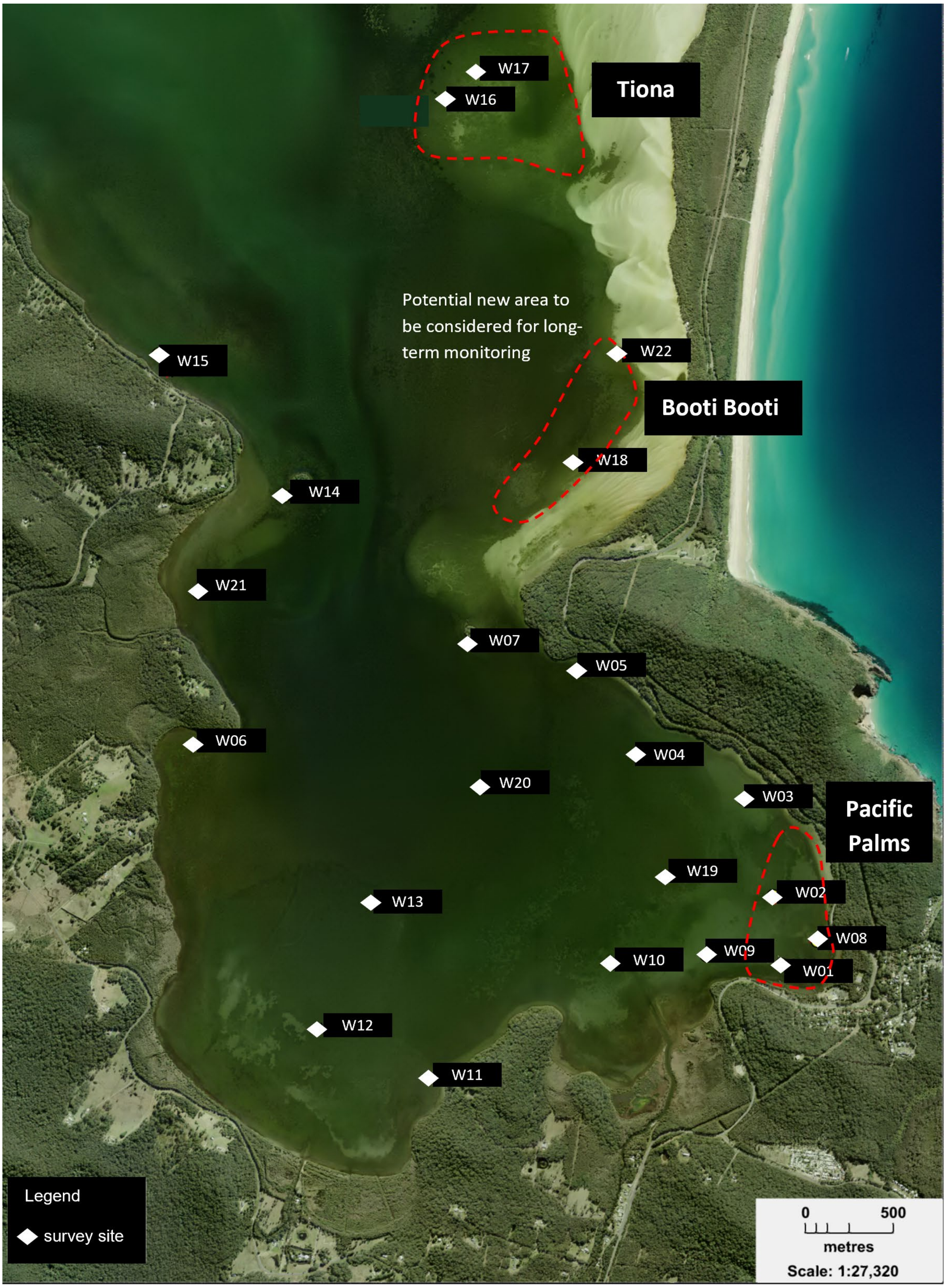

Figure 1. Of the twenty two sites established in Wallis Lake, between thirteen and seventeen were sampled in the period 2019 to 2022. Three locations (denoted by a dashed red line ---) were targeted for longer term quantitative comparisons of abundances of sponges and ascidians. The southern Pacific Palms location was surveyed from 2002 to 2021. While the northern (Booti Booti) location and Tiona location further to the north have been the focus of sampling from 2017-2021.

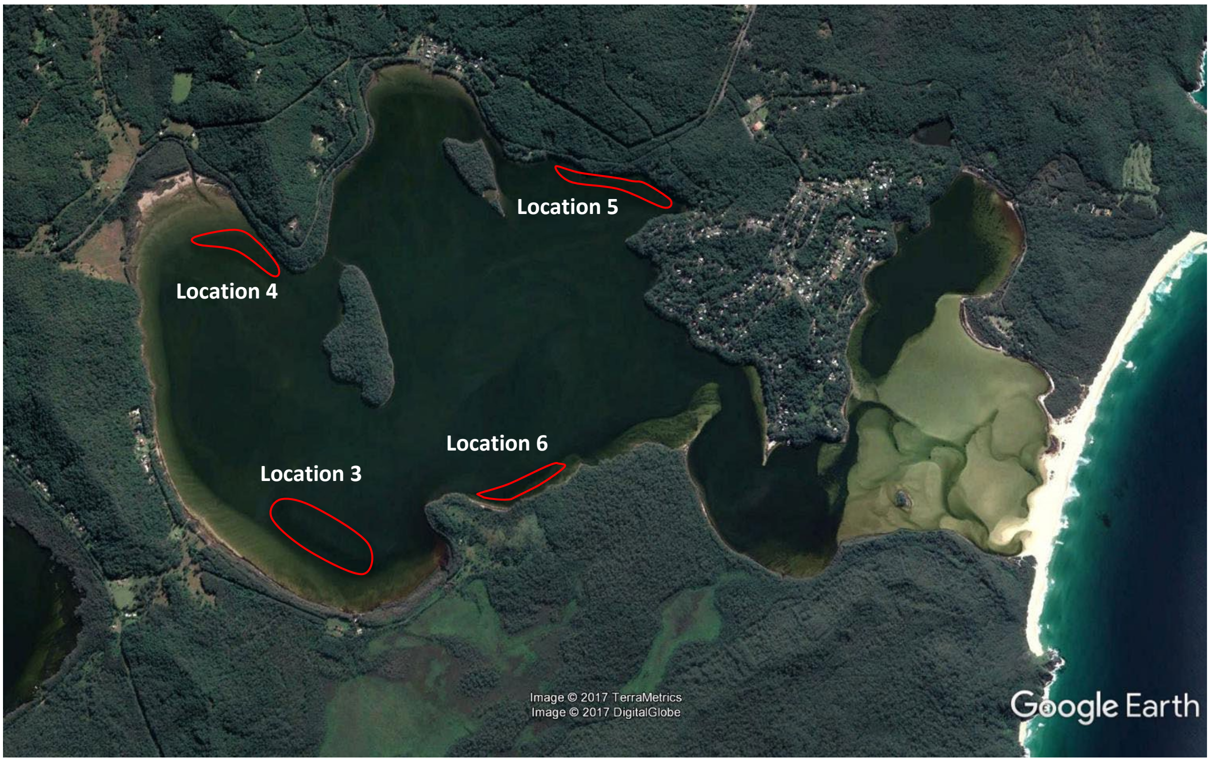

Figure 2. Locations sampled in Smiths Lake from 2002 to 2022. Two sites were sampled in each location at each time. Numbering of locations is consistent with Barnes (2009) and Barnes *et al.* (2013).

3 | RESULTS

3.1 | Smiths Lake

The diversity of sponges and ascidians has remained small in Smiths Lake with a maximum of two species of sponge and two species of ascidian recorded for the majority of the sampling period until 2017. The last five years has seen increases in diversity to four sponge species (2021), while the intensity of sampling has decreased from a maximum of sixteen sites surveyed to eight in recent years. In contrast, ascidian diversity has reduced to a single taxon, *Styela plicata*, and in several years (early 2017, 2020 & 2022) no ascidian species were detected at all (**Table 1**).

The patterns of occurrence of sponges, however, have differed greatly among species. *Suberites* cf. *diversicolor* (**Figure 3**) has shown more stable and widespread patterns of distribution in Smiths Lake compared to *Dysidea* sp. and *Tetilla* sp. which fluctuated dramatically over time (**Figure 3**). *Aplysilla* sp. was detected for the first time in late 2019 and has persisted through all of the recent surveys (**Table 1**). Abundances of *Suberites* and *Dysidea* were among the largest ever observed in April 2022, despite a very wet summer associated with a strong la niña event and potential lower salinities which may negatively affect sponges (Roberts et al. 2006; Barnes 2009) (**Figure 3**).

Table 1: Sponges and ascidians found in Smiths Lake from 2002 to 2022. Number of individuals per site (pooled across all transects for sites).

	2002	2003				2004				2005	2017		2019	2020	2021	2022
	January	March	August	September	December	Feb-March	August	October	December	February	January	April-May	December	December	April	April
Number of sites sampled	12	12	14	8	8	16	16	8	16	16	8	8	6	8	8	8
Sponges																
Aplysila sp.													<5	<25	<1	<1
Dysidea sp.						<1						<5	<25		<25	<50
Suberites cf. *diversicolor*	<25	<10	<10	<10	<25	<10	<5	<5	<5	<10	<50	<150	<5		<5	<100
Tetilla sp.	<1										<350	<150			<10	
Total number of sponge taxa	2	1	1	1	1	2	1	1	1	1	2	3	3	1	4	3
Ascidians																
Microcosmus squamiger			<1		<1					<1						
Styela plicata	<1	<10	<5	<5	<5	<5	<5	<10	<1	<1		<1	<5		<10	
Total number of ascidian taxa	1	1	2	1	2	1	1	1	1	2	0	1	1	0	1	0

<1 <5 <10 <25 <50 <100 <150 <350

Suberites cf. *diversicolor* has been recorded on all occasions since 2002 (with the exception of December 2020) with relatively stable abundances among times within locations and was typically widespread, occurring in many locations in Smiths Lake (**Figure 3, Figure 4**). In contrast, the sponges *Tetilla* sp. and *Dysidea* sp. have varied dramatically through time typified by large peaks in abundances at some locations, particularly in 2017 (**Figure 3**). Prior to 2017, a total of three individual *Tetilla* sp. were recorded from a single transect in April 2002 and two *Dysidea* sp. were observed at a single site in April 2004 in Smiths Lake (**Figure 5, Figure 6**). Clearly, sightings of these two species were rare, despite 10 periods of quantitative sampling and many hundreds of additional hours of observation from 2002 to 2005. It should also be noted that this included actively searching for *Dysidea* sp. in the deeper waters of Smiths Lake based on information from local commercial fishers (Barnes pers. obs). Notably, *Dysidea* sp. reached its highest observed abundance in the most recent sampling (April 2022).

The explosion in the abundance of *Tetilla* sp. was particularly striking. From a maximum of three individuals observed across all sites in 2002 abundances rose to a maximum of 588 individuals in a single transect in location 3 in 2017 (**Figure 3, Figure 5**). Tetillid sponges (Order Spirophorida) are known to lack free swimming larvae (Hooper & Van Soest 2002). Under favourable environmental conditions the direct development of individuals very short distances from adults may see populations build very rapidly. Fertilised eggs can be extruded, fix to the substratum and develop directly. Alternately, young sponges develop directly and are released by localised breakdown of tissue (this mode of development may go some way to explaining the explosive appearance of this species). There also appeared to be a marked die-off in *Tetilla* sp. in the three months between sampling in February and May 2017 and the virtual disappearance of this species since 2019. The majority of *Tetilla* sp. observed in February 2017 appeared superficially healthy with no signs of disease or necrosis. In contrast, abundances in May had reduced on average from 348 individuals to 31 individuals per transect at Location 3 and almost all *Tetilla* sp. observed showed signs of necrosis. A small percentage (less than 2%) of *Suberites* cf. *diversicolor* also showed signs of necrosis in May 2017. Very large jumps in sponge necrosis were observed in 2021, coinciding with heavy rainfall. Almost 60% of the modest number of *Suberites* encountered (n=7) were necrotic, while 42% of *Dysidea* sp. (n=36) and 54% of *Tetilla* sp. (n=13) were also necrotic. By 2022, levels of necrosis had returned to levels seen prior to 2021. In 2022 only a small fraction (<2%) of *Suberites* (n=75) exhibited necrosis, while no necrosis was observed on *Dysidea* sp. (n=37). *Tetilla* sp. was not observed on transects in 2022.

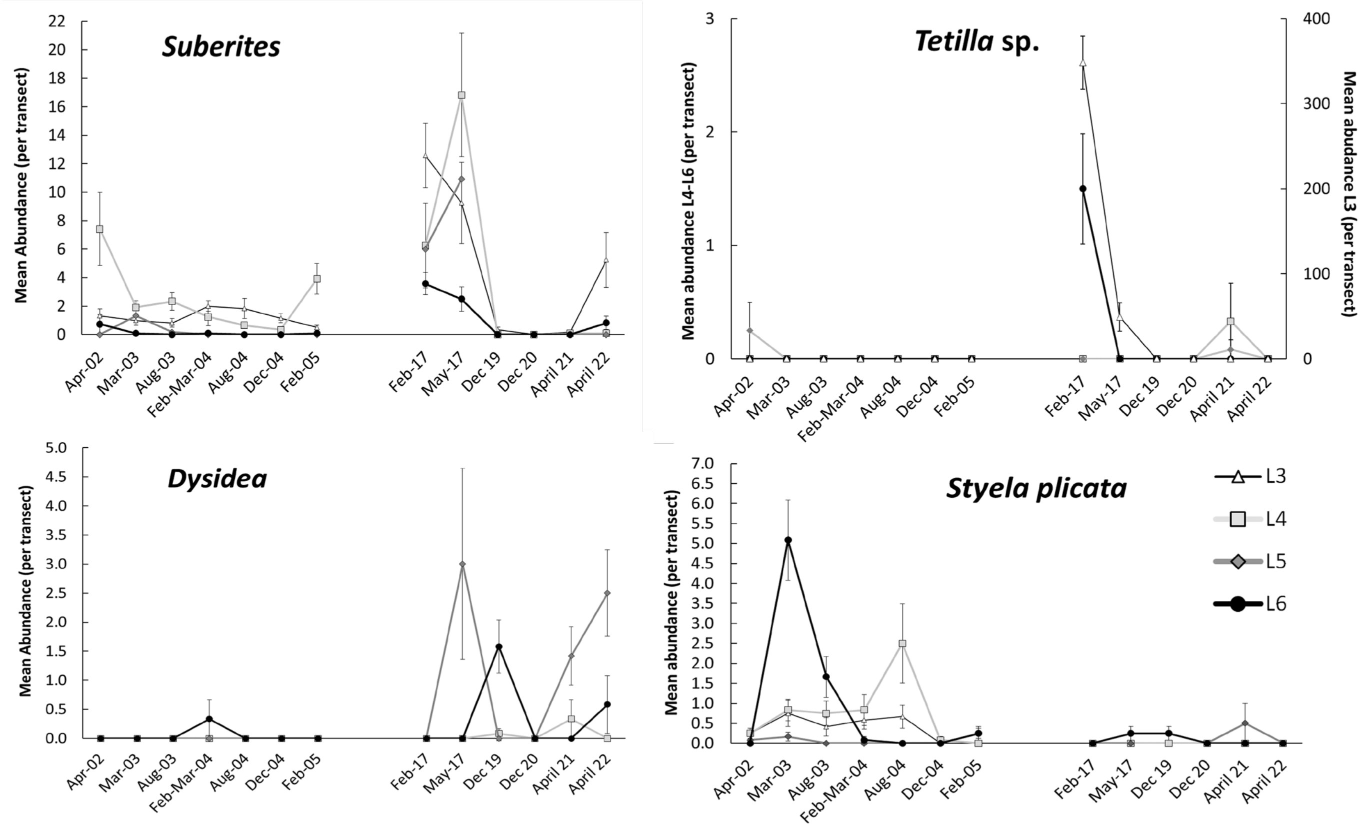

Figure 3. Mean (±SE) abundances per transect of the sponges *Suberites* cf *diversicolor*, *Tetilla* sp. and *Dysidea* sp., and the ascidian *Styela plicata* in Locations 3, 4, 5 and 6 in Smiths Lake from 2002 to 2022. * Note: *Tetilla* sp. abundances for location 3 are indicated on a secondary axis due to the high abundances recorded in 2017 at this location.

Peaks in abundance of *Dysidea* sp. were less marked than *Tetilla* sp., but noticeably more *Dysidea* sp. were observed in 2017 than in all previous years and these high abundances continued at some locations in 2019, 2020 and 2021 (**Figure 3**). Prior to 2017, only two *Dysidea* sp. had ever been observed and these were in a single site in February 2004. In contrast, *Dysidea* sp. were recorded in timed searches at three locations in February 2017 and averaged three individuals per transect in Location 5 in May 2017. It was then not recorded at this location in 2019 or 2020, but numbers rebounded here in 2021 and 2022 with an average of 2.5 individuals in the final year of sampling.. Dysidea was recorded on transects from 2 of the 4 locations within Smiths Lake in 2021 and 2022.

Aplysilla sp. was first detected in Smiths Lake in December 2019 and its abundance peaked in December 2020. It has persisted through 2022, but with low abundance.

The ascidian *Styela plicata* (considered an introduced species) was observed in Smiths Lake on all sampling occasions with the exception of February 2017, December 2020 and April 2022 (**Figure 3**). In general, the abundance and distribution of *S. plicata* has reduced from the peaks observed in 2002 when this ascidian was recorded in most locations. In 2017 *S. plicata* were not observed in February and only observed in small numbers (three individuals) at location 6 in May. The small ‘native’ solitary ascidian *Microcosmus squamiger* has been uncommon and only recorded on three sampling times and in small numbers since 2002. It has not been observed since 2005.

Figure 4. *Suberites* cf. *diversicolor*: large example of the sponge *Suberites* cf. *diversicolor* in *Zostera* meadows of Smiths Lake (Left). *Suberites* cf. *diversicolor* in New South Wales estuaries typically have a digitate morphology (i.e. 'fingerlike'), with prominent oscula (exhalant openings) and are bright blue to green in colour due to the presence of photosynthetic cyanobacteria in their tissues (Barnes 2009). Smaller individuals have commonly been found on bivalve shells or small stones (right). Small encrusting specimens, orange in colour and presumably lacking photosynthetic cyanobacteria have been found on surfaces not exposed to sunlight such as the underside of stones in Smith Lake.

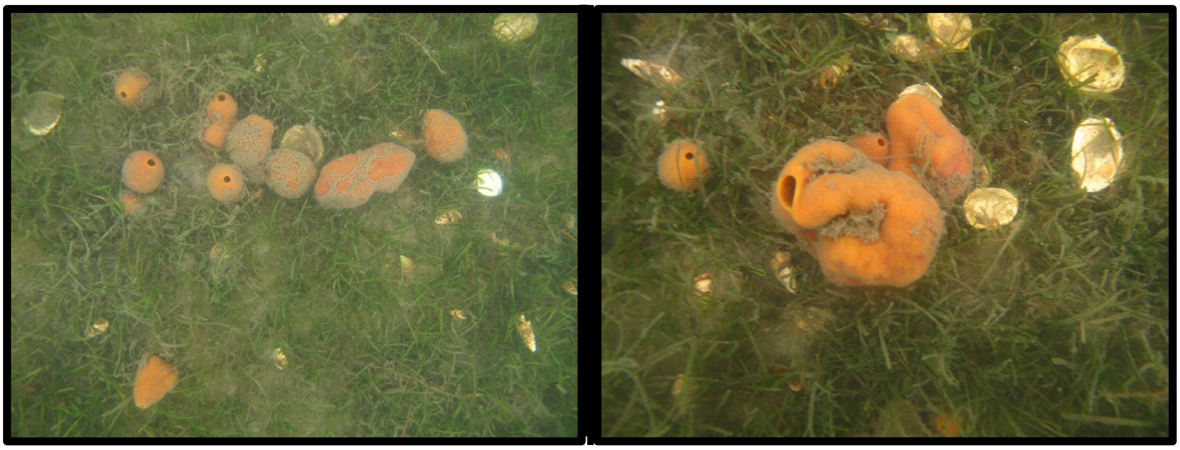

Figure 5. *Tetilla* sp.: The sponge *Tetilla* sp. in *Zostera* meadows of Smiths Lake. The majority of *Tetilla* sp. observed in Smiths and Wallis Lakes have been relatively small (approximately thumb sized or smaller) with a simple vase shaped morphology, single prominent osculum and apricot in colour (left). Larger individuals with more irregular morphology and sometimes with multiple oscula (exhalant openings) were also observed (right) but were much less common than the simple vase shaped individuals in Smiths Lake in 2017.

Figure 6. *Dysidea* sp.: The sponge *Dysidea* sp. in *Zostera* and *Halophila* meadows of Smiths Lake. *Dysidea* sp. are typically mauve in colour, irregularly shaped with varying numbers of oscula and a coarse, hard and bumpy surface texture.

3.2 | Wallis Lake

3.2.1 | Species composition in Wallis Lake.

The species composition of sponges in the southern and central basins of Wallis Lake has varied over short time periods (ranging from 2 to 10 species) but in the longer-term from 2002 to 2021 has shown some evidence of decline (**Table 2**). Three of the ten species found in 2002 were also observed in 2021, along with the recent appearance (2017) and persistence of *Pseudospongosorites* sp. The consistency in species present is more obvious when considered in the context of differences in the sampling designs of the studies included in this report. The first suite of studies from 2002 to 2005 targeted habitats identified as commonly containing sponges and ascidians. These were the seagrass and algal meadows around the fringe of the Lake, typically between approximately 0.5 to 1.5 metres deep (Barnes *et al.* 2006; Barnes 2009). These studies were in part designed to examine changes over time periods ranging from months to seasons to years; as such the numbers of sites sampled during this period also varied over time.

The more recent sampling, commencing in 2007 (Barnes 2010) and including sampling in 2009, 2017 along with the most recent tranche of sampling (2019-2021) had a broader spatial scope with four key differences:

- sites in the central and typically deeper areas of the southern basin of Wallis Lake were added
- rocky habitats near Earps and Booti Booti Islands were added
- sites in Pipers Bay from the suite of studies from 2002 to 2005 were not included
- multiple sites were no longer nested in locations as occurred from 2002 to 2005

Despite these changes, only three new sponge taxa (a small calcareous species, *Chondrilla* cf. *australiensis* and *Pseudospongosorites* sp. - first observed in 2017) have been recorded since the first survey in 2002. The addition of *Chondrilla* cf. *australiensis* in 2007 was likely due to the inclusion of rocky habitat near Earps and Booti Booti Islands which were not surveyed in the initial study from 2002 to 2005. *Chondrilla* is typically associated with hard substrata and rocky reef and therefore would be unlikely to be found on seagrasses and soft sediments of previous sampling. It has been observed on artificial hard surfaces including jetties and aluminium cans (Barnes, pers. obs). In addition, as expected several species were only recorded in time searches, rather than transects. Consequently, taking these changes in the sites sampled into account and the recent reduction in the number of sites sampled in each time period, the sponge diversity within Wallis Lake has changed little in the longer-term.

Fewer species at sometimes may have in part been due to fewer sites sampled. However, there were also fewer species in 2007 and early 2021 when similar numbers of sites covering similar regions of the lake were sampled to 2002 and November 2021. The sole presence of *Suberites* cf. *diversicolor* within transects in March/April 2021 was a little unusual, but several taxa, including *Aplysilla* cf. *sulfurea, Mycale* sp. and *Pseudospongosorites* sp. were detected in November 2021.

Species were typically very patchy in their spatial distribution among sites kilometres apart with most species recorded in only a small number of sites (**Table 3**). Many species including *Mycale* sp., *Dysidea* sp., *Haliclona* sp. 2, *Aplysilla* cf. *sulfurea* and the small calcareous sponge varied greatly in abundance among times with large abundances at sometimes interspersed with very low abundances or absence from transects at other times. In contrast, *Suberites* cf. *diversicolor* was the only sponge found on all occasions and was more stable in abundance than these other species.

Table 2: Species of sponges and ascidians recorded in Wallis Lake from 2002 to 2021. The size of the circles represents the relative abundance of that species at each time pooled across all sites sampled. (green dot) indicates that taxon was found in timed searches only.

	2002	2003				2004				2005	2007	2009	2017		2019	2020	2021	
	January	March	August	September	December	Feb-March	August	October	December	February	November	December	January	April-May	December	Nov - Dec	March / April	November
Number of sites sampled	12	12	16	16	16	16	16	16	16	16	11	25	22	22	16	17	12	13
Sponges																		
Aplysilla cf. *sulphurea*	<1 (timed)			<1	<5		<5	<5	<1	<1 (timed)	<10	<1	<1 (timed)		<1	<100		<350
Chondrilla cf. *australiensis*											<1 (timed)	<1 (timed)	<1	<1	<100			
Dysidea sp.	<1	<10	<1	<1		<1		<1					<1 (timed)	<1 (timed)				
Halichondria sp. 1	<1		<1 (timed)			<1				<1 (timed)								
Halichondria sp. 3	<1					<1												
Haliclona (*Haliclona*) sp. 1	<1		<1									<1 (timed)						
Haliclona (*Haliclona*) sp. 2	<1	<1	<1			<1	<1			<1 (timed)			<5	<5	<5			
Mycale sp.	<5	<1	<1	<1		<1	<1				<5	<1	<1	<5	<100			<50
Pseudospongosorites sp.													<1	<10	<10	<5	<1 (timed)	<5
Raspailia sp.	<1	<1										<1						
Suberites cf. *diversicolor*	<1	<5	<5	<5	<5	<10	<10	<5	<5	<5	<5	<1	<5	<1	<100	<100	<100	<10
Tetilla sp.	<1 (timed)															<1 (timed)		
Calcareous spp.			<1	<25			<25					<1 (timed)						
Total no. of sponge taxa	10	5	7	5	2	4	5	3	2	4	4	7	7	6	6	4	2	4
Ascidians																		
Eudistoma laysani				<25	<1			<1 (timed)			<1 (timed)							
Microcosmus squamiger	<1		<1	<1			<5	<5		<1 (timed)								
Pyura stolonifera	<1	<1 (timed)				<1												
Styela plicata	<150	<25	<10	<5	<1	<5	<1	<1	<1	<1	<5	<1	<5	<5	<100	<100	<5	
Total no. of ascidian taxa	3	2	2	3	2	2	3	3	1	2	2	1	1	1	1	1	1	0

<1 <5 <10 <25 <50 <100 <150 <350

Table 3: Presence of sponges and ascidians in each site sampled in Wallis Lake on the six sampling occasions from April 2017 to Nov 2021*. Data are from transects as well as timed searches. All 22 sites were sampled in 2017, but sites W10, W14, W15, W19 and W20 (highlighted in red type face) were not sampled in subsequent years. Records of necrotic individuals at sites appear in green type face. Single observations of two unidentified species have not been included in this table.

	Sponges							Ascidians
Site	***Aplysilla cf. sulphurea***	***Dysidea* sp.**	***Chondrilla* cf. *australiensis***	***Haliclona* sp. 2**	***Mycale* sp.**	***Pseudospongo-sorites* sp.**	***Suberites* cf. *diversicolor***	***Styela plicata***
W1				17^{J} 17^{A}			17^{J} 19 20 21^{A} 21^{N}	19
W2				17^{J} 17^{A} 19	17^{A}	19	17^{A} 19 21^{A}	17^{A} 19
W3	22				19		21^{A}	17^{A} 19
W4							20	19
W5	20						20	17^{J} 17^{A}
W6					17^{J} 17^{A} 19		17^{J} 17^{A} 19	17^{A} 19 20
W7	19 20 21^{N}		17^{J} 17^{A} 19	17^{A} 19	17^{J} 17^{A} 19	21^{N}	19 20	17^{J} 17^{A} 19 20 21^{A}
W8				17^{J} 17^{A}	19	17^{J}	19 20	
W9		17^{A}	17^{J}		17^{A} 19 21^{N}	17^{A} 19 21^{N}	17^{J} 17^{A} 19 21^{A} 21^{N}	
W10		17^{A}			17^{J}			17^{A}
W11	21^{N}			19	17^{A} 19		17^{A} 19 20 21^{A} 21^{N}	17^{A} 19
W12							19 21^{N}	17^{A} 19
W13					17^{A} 19			17^{A} 19
W14								17^{J} 17^{A}
W15								17^{J} 17^{A}
W16				19	17^{A} 19	17^{A} 19	21^{A}	17^{J} 17^{A} 19 20
W17					17^{A}	17^{J} 17^{A} 19 20	21^{A}	17^{J} 17^{A} 19 20
W18	20				17^{A}		17^{J} 17^{A} 19 20	17^{A} 19 20
W19								
W20								17^{J} 17^{A}
W21					17^{J} 17^{A} 19 21^{N}		19 21^{A}	17^{J} 17^{A} 19 20
W22							17^{J} 17^{A} 19 20 21^{A}	

* January 2017 (17^{J}), April 2017 (17^{A}), December 2019 (19), December 2020 (20), March April 2021 (21^{A}), November 2021 (21^{N})

3.2.2 | *Suberites* cf. *diversicolor* in Wallis Lake

The genus *Suberites* (Suberitidae), a member of the order Hadromerida, is cosmopolitan and is most commonly encountered in cold temperate waters (Hooper & Van Soest, 2002). Although the species with local lakes, *Suberites* cf. *diversicolor,* has been reported from Indonesian Lakes and Lagoons, along with Vietnam (see below). In the most recent tranche of *sampling* (2019-2021), *Suberites* cf. *diversicolor* (hereafter *Suberites,* **Figure 7**) were found in almost every site surveyed. This contrasted with the previous sampling in 2017 where *Suberites* were patchily distributed across Wallis Lake and were recorded in approximately 25% of the 22 sites. This patchiness among sites was typical of previous years (**Table 2**, **Table 3**). *Suberites* has been the most consistently encountered (recorded on all times) and had the most stable abundances of any sponge or ascidian from 2002 to 2021 (**Table 2**). The southern basin of the Lake adjacent to Pacific Palms has been consistently surveyed for *Suberites* since 2002 allowing for longer term comparisons. In this area, *Suberites* were relatively common from 2002 to 2007, but in 2009, 2017 and 2020 *Suberites* were uncommon, with abundances close to zero and only one or two specimens found on timed searches at some sites (**Figure 8**). The most recent tranche of sampling saw the abundance of *Suberites* bounce back to abundances seen almost two decades ago in the Pacific Palms region. The addition of sites at Booti Booti (2017-2021) saw some of the highest abundances ever seen for this species (sites W18 & W22), with an average of more than 3 individuals per transect in 2020; the very year they were only rarely detected in the Pacific Palms region. *Suberites* were only rarely observed in the more northern Tiona sites (W16 & W17), first added in 2017, and only in March, April 2021. Following intense la niña driven rainfall *Suberites* was represented by a single necrotic individual across all three locations in November 2021.

Figure 7. *Suberites* cf. *diversicolor* in *Zostera* meadows in Site 18 north of Booti Booti in Wallis Lake (Left). Individuals may sometimes be obscured by fine sediments which accumulate on the surface of the sponge as part of the natural filtering process of the sponge (Right). Sediment may need to be wafted by hand from the surface to confirm the identity of the sponge.

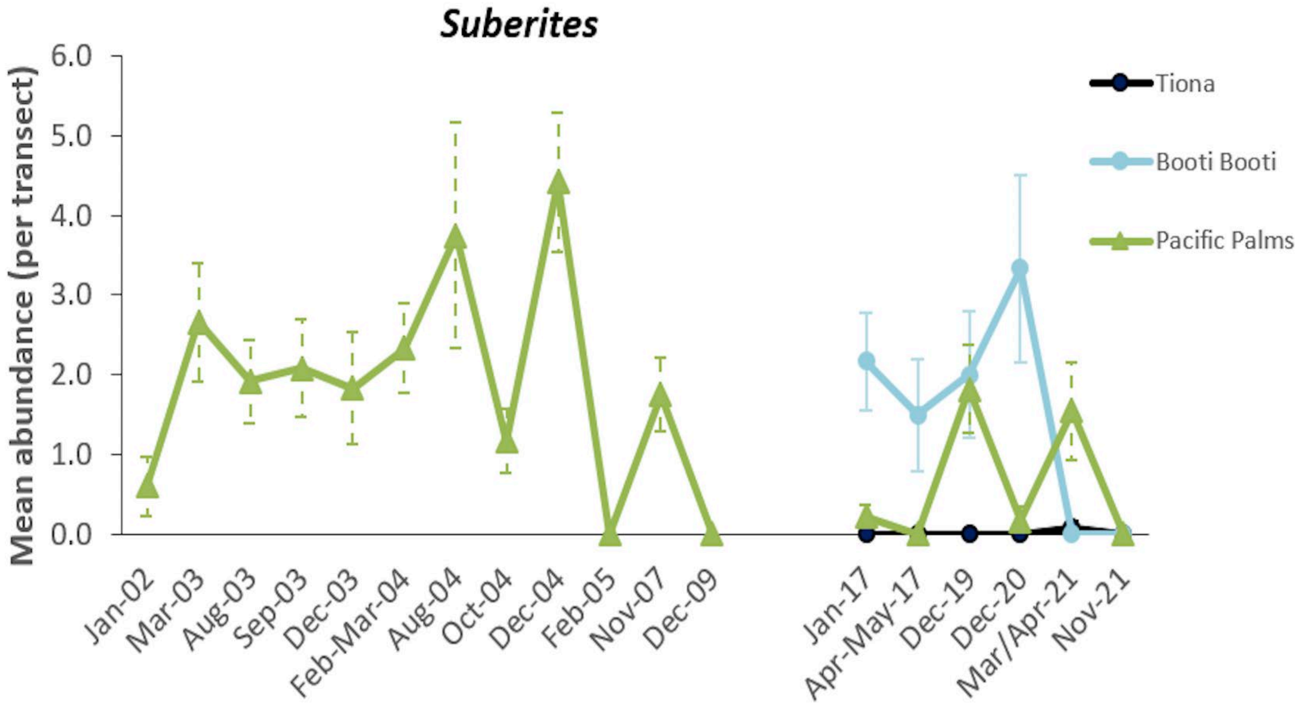

Figure 8. Mean (±SE) abundance of *Suberites* cf. *diversicolor* in sites near Pacific Palms from 2002 to 2021. Two additional locations, Booti Booti (sites W18 & W22) and Tiona (sites W16 & W17), were added in 2017. *Suberites* cf. *diversicolor* were observed on one timed search at Pacific Palms in April and May 2017 but were not observed on transects at that time. A single necrotic individual was observed in transects near Pacific Palms in November 2021, but not at either of the other locations.

3.2.3 | *Pseudospongosorites* sp. in Wallis Lake.

The genus *Pseudospongosorites* (Suberitidae), another member of the order Hadromerida, is normally restricted to central west Atlantic, including North Carolina (USA) and Venezuela (Hooper & Van Soest, 2002). In Wallis Lake, *Pseudospongosorites* sp. was recorded for the first time as part of long-term monitoring in January 2017. Individuals appeared to be diverse in form (**Figure 9**). *Pseudospongosorites* sp. were uncommon and patchily distributed among sites in January 2017 with only single specimens found at each of two sites. In April 2017, *Pseudospongosorites* sp. were still very patchily distributed, but considered very abundant at site 9 near Pacific Palms where there was an average of 18 sponges per transect. The vegetation at Site 9 was dominated by almost 100% cover of the charophyte, *Lamprothamnion* sp. In the most recent tranche of sampling (2019-2021) *Pseudospongosorites* sp. continues to be commonly encountered at Site 9, but was also quite widely distributed, appearing at Tiona and near Pacific Palms (**Figure 10**).

Figure 9. Examples of the sponge *Pseudospongosorites* sp. from Wallis Lake in 2017 showing a range of growth forms.

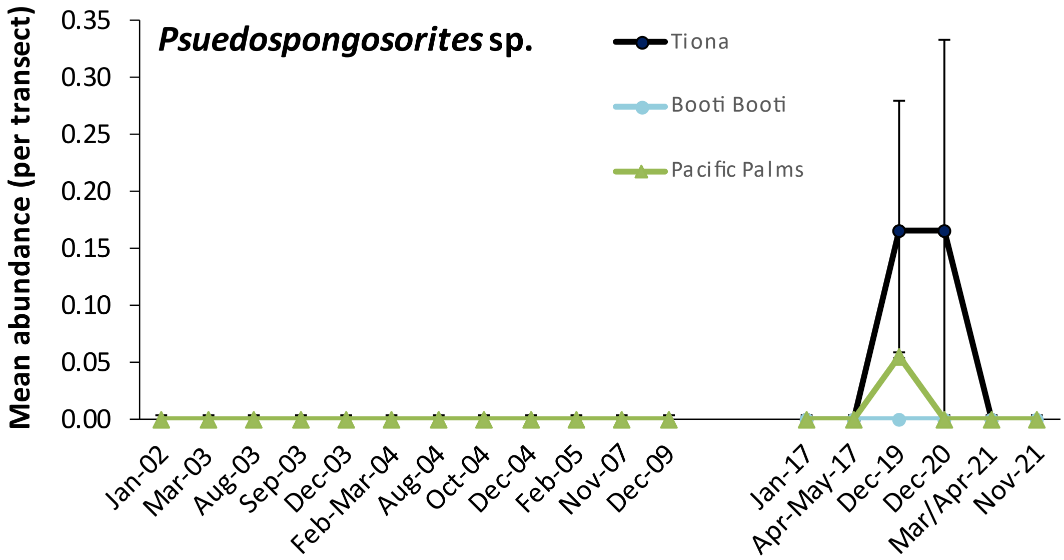

Figure 10. Mean (±SE) abundance of Pseudospongosorites sp. in sites near Pacific Palms from 2002 to 2021. Two additional locations, Booti Booti (sites W18 & W22) and Tiona (sites W16 & W17), were added in 2017 and this sponge first appeared within samples in January of that year.

3.2.4 | *Mycale* sp. in Wallis Lake.

Mycale sp. (**Figure 11**) was one of the most widespread sponges in Wallis Lake in 2017 and achieved its highest recorded lake-wide abundance in December 2019. In April 2017, *Mycale* sp. were recorded at ten sites (of 22) and in Dec 2019 it appeared in nine of sixteen sites sampled (**Table 3**). It then disappeared; there were no records of *Mycale* sp. for 2020 or early 2021, but it was again recorded in transects in November 2021. In this last sampling period, it appeared at just two sites (Sites 9 and 21) but notably with a single transect yielding 27 individuals at the later site. In the sites near Pacific Palms where it was possible to make long-term quantitative comparisons from 2002 to 2021, abundances of *Mycale* sp. peaked in January 2002, were again elevated in the summer of 2004 and the summer of 2019. On these three occasions abundances of more than 0.5 individuals per transect were observed (**Figure 12**). In April-May 2017 sites at Tiona saw abundances rivalling those observed at Pacific Palms over the twenty years of sampling, underscoring the patchy nature of the abundance of many of these sponges.

Figure 11. The sponge *Mycale* sp. growing on seagrass blades in Wallis Lake. *Mycale* sp. in Wallis Lake has typically been observed growing on *Lamprothamnion*, *Zostera* and *Posidonia* fronds. Typically blue to light blue in colour with orange to red spots. In other lakes such as Lake Conjola, this species is orange in colour with blue or reddish spots (Barnes 2009).

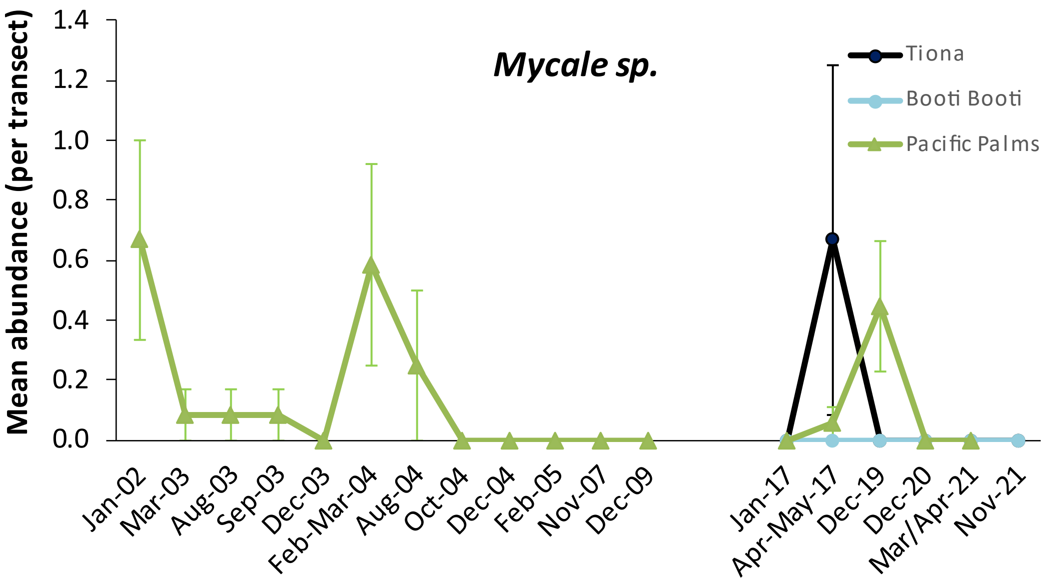

Figure 12. Mean (±SE) abundance of the sponge *Mycale* sp. in sites near Pacific Palms from 2002 to 2021. Two additional locations, Booti Booti (sites W18 & W22) and Tiona (sites W16 & W17), were added in 2017.

3.2.5 | *Dysidea* sp. in Wallis Lake

The sponge *Dysidea* sp. (**Figure 6**) has been sporadic in appearance with small population sizes in Wallis Lake over the entire monitoring period. It has not been recorded in transects since 2004 and was only recorded on timed searches at two sites in April – May 2017 (**Table 2, Table 3**). *Dysidea* sp. was not recorded at all in the most recent tranche of sampling (2019-2021). In sites near Pacific Palms, where it was possible to make long-term quantitative comparisons from 2002 to 2021, abundances of *Dysidea* sp. peaked at an average of over 9 individuals per transect in March 2003 (**Figure 13**). Since 2003, *Dysidea* sp. has not been found near Pacific Palms, nor the other locations added in 2017.

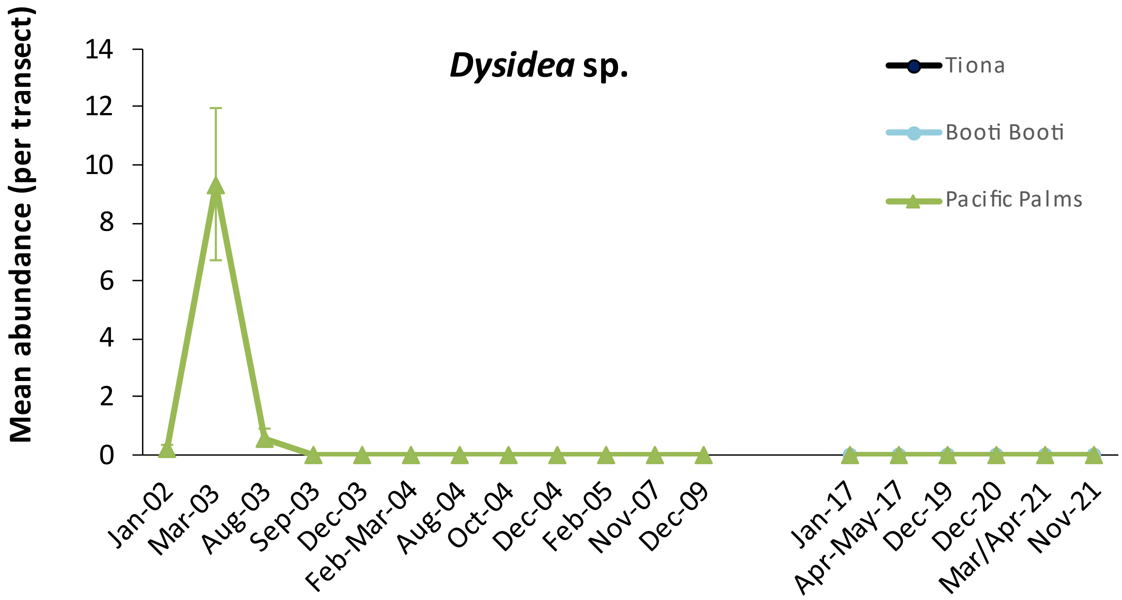

Figure 13. Mean (±SE) abundance of the sponge *Dysidea* sp. in Sites near Pacific Palms from 2002 to 2021. Two additional locations, Booti Booti (sites W18 & W22) and Tiona (sites W16 & W17), were added in 2017.

3.2.6 | *Styela plicata* in Wallis Lake

The introduced solitary ascidian *Styela plicata* has consistently been one of the most widespread and commonly encountered sessile invertebrates in Wallis Lake since 2002 (**Table 2**). The largest populations since their peak in 2002 were detected in December 2019 and December 2020. *Styela plicata* was found in more that 75% of sites in 2019, but this dropped to 35% of sites in 2020 (**Table 3**), but by November 2021 this ascidian was not detected at all. In sites near Pacific Palms, abundances of *S. plicata* peaked at an average of over 140 individuals per transect in January 2002 (**Figure 14**). Since 2002, there have been typically many fewer *S. plicata* with on average less than one per transect. Sites at Tiona saw a resurgence in the abundance of this ascidian in 2019 and 2020. with abundances of more than 5 individuals per transect, the highest densities observed on transects for almost two decades.

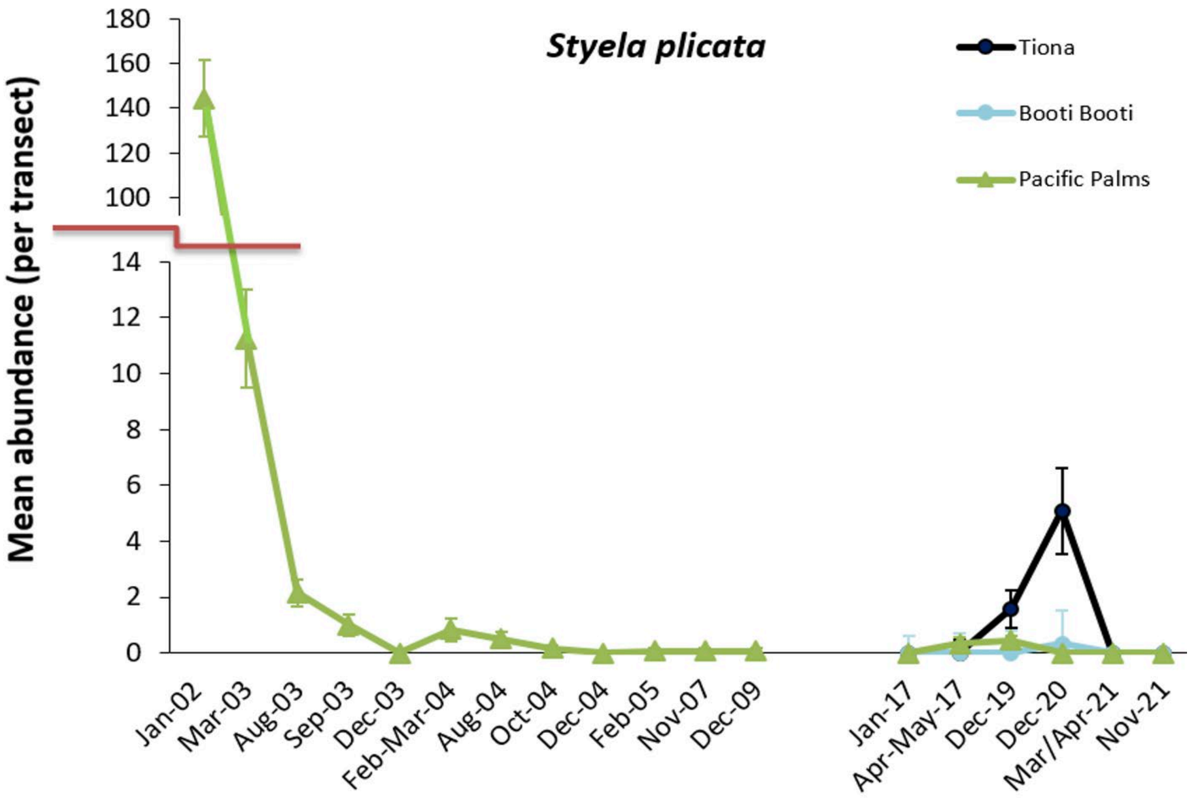

Figure 14. Mean (±SE) abundance of the ascidian *Styela plicata* in sites near Pacific Palms from 2002 to 2021. Two additional locations, Booti Booti (sites W18 & W22) and Tiona (sites W16 & W17), were added in 2017. Note the scale break on the vertical axis due to very large abundances in January 2002.

3.2.7 | *Haliclona* sp. 2 in Wallis Lake

Haliclona sp. 2 (**Figure 15**), although recorded on most sample dates, has never been particularly abundant in Wallis Lake (**Table 2**). This species has been recorded in up to 25% of sites sampled, most notably in 2019. A dramatic increase in abundance of this species was observed in 2017 near Pacific Palms; at sites 1 and 8 in this year, abundances approached or exceeded three individuals per transect (**Figure 16**). These sites were dominated by filamentous green algae. In the most recent tranche of sampling, *Haliclona* sp. 2 was not recorded at any sample sites in 2020 and 2021 (**Table 3**).

Figure 15. The sponge *Haliclona* sp. 2 in Wallis Lake is typically pink to mauve in colour sometimes bottle-shaped and with fistulae (tubular projections). Note: 'sp. 2' is in reference to the naming used in Barnes *et al.* 2005 & 2013 for this species in Wallis Lake.

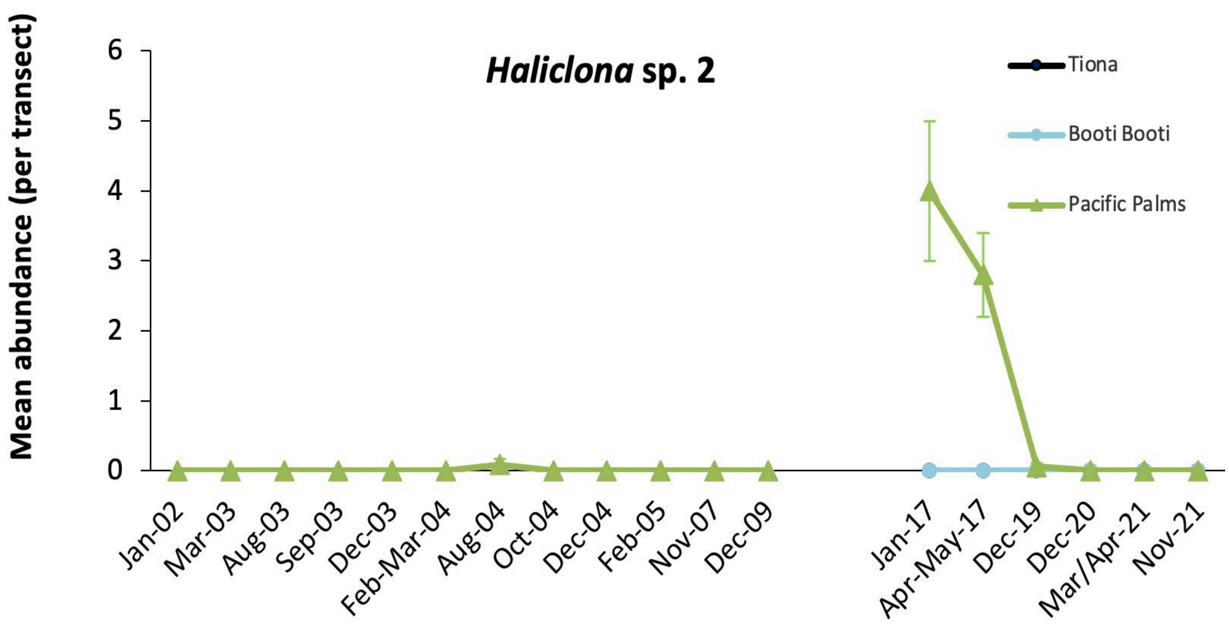

Figure 16. Mean (SE) abundance of the sponge *Haliclona* sp. 2 in sites near Pacific Palms from 2002 to 2021. Two additional locations, Booti Booti (sites W18 & W22) and Tiona (sites W16 & W17), were added in 2017. Note: 'sp. 2' is in reference to the naming used in Barnes *et al.* 2005 & 2013 for this species in Wallis Lake.

3.2.8 | *Lamprothamnion* sp. in Wallis Lake

The charopyte *Lamprothamnion* sp. was consistently the dominant aquatic vegetation type in sites near Pacific Palms from 2002 to 2007 forming dense meadows with almost complete cover of the muddy lake floor interspersed with small patches of *Zostera,* macroalgae and bare sediment. The sharp decline in the cover of *Lamprothamnion* sp. first observed in December 2009 and coincided with a similar steep decline in abundances of *Suberites* (**Figure 8**). In the more recent tranche of sampling *Lamprothamnion* sp. has continued to decline, while the abundance of Suberites did not continue on a downward trajectory. By March-April 2021 *Lamprothamnion* sp. had fallen to almost 15% cover and in the most recent sampling (Nov. 2021), cover was below 4% (**Figure 17**).

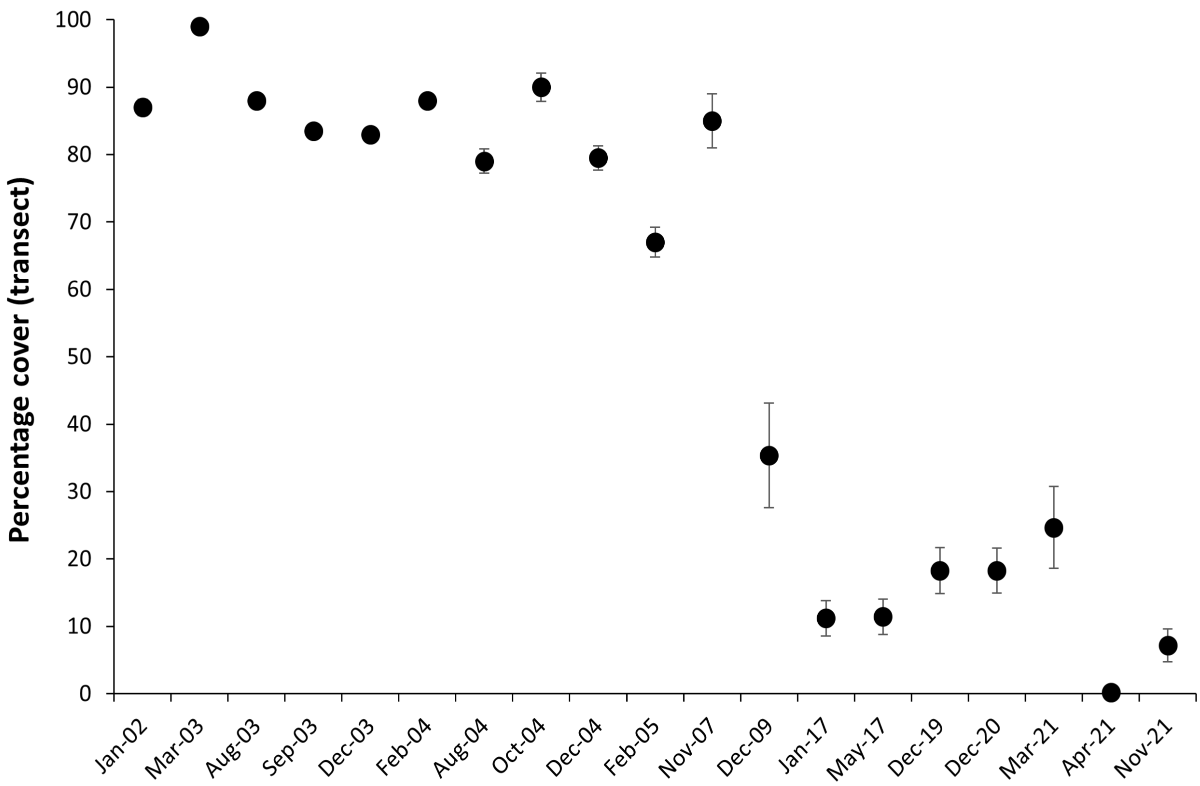

Figure 17. Mean (±SE) percentage cover of the charophyte *Lamprothamnion* sp. in sites near Pacific Palms

4 | DISCUSSION

Patterns of distribution of sponges and ascidians in Wallis Lake have generally been complex among times, patchy among places and patchy among habitats (e.g. species of seagrass, macroalgae, rocky shores). With the exception of the sponge *Suberites* cf. *diversicolor*, many of the species have bloomed in large abundances at times, often interspersed with long periods of very low numbers or were apparently absent. Worldwide, information on sponge and ascidian assemblages over a 20 year timeframe are extremely rare and we view this dataset as particularly valuable given the complex patterns it has identified. The majority of the taxa recorded also remain largely understudied particularly in estuarine systems of Australia. An understanding of potential mechanisms responsible for these patterns whether natural or anthropogenic will help support effective management and conservation.

4.1 | Diversity of sponges and ascidians

The species composition of sponges in Wallis Lake has remained remarkably similar in the longer-term (2002 to 2021), despite large fluctuations in abundances through time, short-term changes in the presence of species between seasons or months and the restriction of most species to a subset of sites. Six of the ten species recorded in 2002 were also recorded in the most recent tranche of sampling (2019-2021). Only three additional species have been recorded since that time: *Chondrilla* cf. *australiensis* which is common on rocky reefs on the open coast (Wright et al. 1997) was first recorded in 2007 when sites containing rocky reefs were sampled for the first time in Wallis Lake; a species of small calcareous sponge was first recorded in 2003 and has periodically bloomed and declined; finally, the discovery of a species of *Pseudospongosorites* (**Figure 9**) in 2017 has perhaps been the most interesting new species. Given its relatively conspicuous appearance, distinct morphology from other sponges identified in Wallis Lake, and capacity to bloom in large numbers at some sites in a range of habitats it is unlikely to have been observed and not recorded in Wallis Lake previously.

Ascidian diversity appears to have declined over the timeframe of sampling. Diversity peaked at four species, but in the most recent tranche of sampling just a single taxon was represented – the introduced solitary ascidian *Styela plicata*. When first sampled in 2002 the abundance of *S. plicata* was very high and has subsequently declined, although we note it has been recorded on every occasion the Lake has been sampled, with the exception of the most recent sampling in November 2021. Until then, *S. plicata* was one of the most persistent species.

The long-term persistence of this suite of species is perhaps surprising given that enclosed water bodies can experience conditions unfavourable to fauna. This may include large fluctuations in water quality, including temperature and salinity, compared to the open coast. Temperatures in Wallis Lake are known to fluctuate from as low as 11 degrees during winter to 29 degrees in summer (Barnes et al. 2013). The relative roles of abiotic conditions and biotic drivers of diversity and abundance can only be speculated over at this stage, but would be worthy of additional study. We do know that the most commonly encountered sponge *Suberites* cf. *diversicolor* (*Suberites* hereafter) has maintained the most stable and persistent populations; it was always found in both Wallis and Smiths Lake (with the exception of one sampling period) and is a particularly hardy species. It has also been recorded in Lake Macquarie and the Tuggerah Lakes (Barnes *et al.* 2013), and there is an unconfirmed report from shallow water in Port Hacking, just south of Sydney (Allison Broad, pers. obs.) and perhaps – 'Peel Harvey estuary in Western Australia (Barnes – unpublished data). More is also known about the biology and ecology of this sponge in New South Wales Lakes than any of the other species. Under experimental conditions in Smiths Lake, *Suberites* survived in salinities as low as 13 parts per thousand, under increased sediment loads and after being caught as by-catch in trawls (Barnes unpublished data). *Suberites* in Smiths Lake have been observed to reproduce by fragmentation after partial necrosis and spawn at night (Barnes unpublished data). Preliminary genetic analyses confirmed that the population also reproduced sexually (Barnes 2009).

While *Suberites* appears a hardy species, far less is known of the biology and ecology of the other species in these coastal lakes and their mechanisms for persisting. Although rare for marine sponges, some species produce gemmules which are small resistant structures that ensure sponges survive unfavourable conditions such as low temperatures or lack of oxygen which may kill adults (Simpson & Fell 1974). Adult sponges may also be going undetected but surviving in very small numbers in isolated pockets of the Lake and then increasing in numbers when environmental conditions are more favourable. For example, the presence of many species is correlated with habitat type, in particular biogenic habitat, including the presence of seagrass or algal meadows. *Suberites* is often associated with patchy or very short meadows of *Zostera* and absent from dense meadows with tall fronds where they can be eaten by Monocanthid fishes (leatherjackets) (Barnes 2009).

4.2 | Boom or bust for most species

The periodic but pronounced blooms of sponges in both Wallis and Smiths Lakes suggests the importance of fluctuating abiotic and biotic conditions for sponges. The increase in abundance of *Tetilla* sp. to hundreds of animals per transect where previously it was only infrequently observed underscores how dramatic these changes can be. Changes in environmental quality, most notably sedimentation/turbidity and food or habitat availability have been highlighted as important drivers of sponge abundance, at least in tropical environments (Knapp et al. 2012, Pawlik et al. 2015). In contrast to these 'bottom-up' effects, the 'top-down' impacts of predators – such as monocanthid fishes – cannot be discounted (Wulf 1995, 2008); this includes impacts on *Suberites* in Smiths Lake (Barnes 2009).

Rapid dramatic changes in abundance of two sponge species at the Booti Booti Island site (W07) were particularly noteworthy. *Chondrilla* cf. *australiensis* was observed at low abundance at this site in 2017, often associated with reef. In December 2019, this species reached an average abundance of almost 17 on transects (sem±3.7), with up to 50 individuals on a single transect at this site. It was then not detected there over the next three sample occasions (December 2020, April and November 2021). A second species, *Aplysilla* cf. *sulphurea* was represented by a single individual across all transects in December 2019. By December 2020 average abundance stood at 9.3 individuals (sem±3), but it was then not recorded in April 2021. Just seven months later, it was again strikingly abundant, reaching an average abundance of 54 individuals (sem±14), with up to 97 individuals on a single transect.

The striking abundance of the invasive sea squirt, *Styela plicata*, when sampling was initiated in 2002, followed by its near disappearance is a further example of boom bust cycles in these systems. Interestingly, another invertebrate (the jellyfish *Catostylus mosaicus*) is known to periodically bloom in Smiths Lake (Pitt et al. 2008; West et al. 2009). Jellyfish blooms in the lake are reportedly typically short-lived, lasting for weeks or months. West et al. (2009) suggested that subsequent decomposition of large volumes of dead jellyfish on the lake floor can dramatically change water chemistry. It could, in turn, be a significant source of nutrients with major implications for primary production and may also lead to hypoxia in bottom waters of the Lake. *Catostylus* can also be very common in Wallis Lake (Pitt & Kingsford 2000) with presumably similar potential for influencing physico-chemical processes as suggested for Smiths Lake.

Some species appear particularly prone to boom and bust population dynamics. In marine environments for example, members of the green algal genus *Caulerpa* are particularly prone to dramatic increases in abundance followed by their virtual disappearance (Davis et al. 1997). Such dramatic increases in abundance have only rarely been observed for sponges. There is an unpublished account of a close relative of *Tetilla* sp., perhaps even the same genus, undergoing very rapid increases in population abundance (Prof. Janie Wulff, pers. comm). The drivers of these patterns remain unexplored, but the reproductive mode of Tetillids is reliant on direct development as they lack free-swimming larvae (Hooper and Van Soest 2002). So should environmental conditions be favourable (e.g. release from predation pressure, availability of food, availability of suitable substrata for settlement, appropriate water quality and temperature, to list a few), then a method of reproduction which produces many recruits within a short distance from adults might explain this pattern. It may be the case that the coincidence of favourable conditions with high reproductive output is relatively rare in any coastal Lakes at the same time. These conditions may contribute to the explosive increases in abundance observed for this group, although this remains speculation.

Whether the fauna we have observed in the Lake is restricted to these environments remains unclear. *Aplysilla sulfurea* is a cosmopolitan species recorded from several locations from around Australia and the world. There has also been a recent opportunistic collection of *Suberites* from the Peel Harvey Estuary in Western Australia in March 2017 (P. Barnes pers. obs) and is most likely the same species found in Wallis and Smiths Lakes (Lisa Goudie, pers. comm.). This species has also been reported from an artificial lagoon near Darwin and natural lagoons in Indonesia (Becking *et al.* 2013).

4.3 | Uniqueness of Wallis Lake

In terms of the diversity of ascidians, Wallis Lake cannot be considered unique. A total of four taxa have been recorded since 2002 and all are widely distributed. For example, *Styela plicata* is considered an introduced species in Australian waters and is cosmopolitan. *Eudistoma laysani* and *Microcosmus squamiger* occur throughout the Indo west Pacific (Kott 1985, 1990). While *Pyura stolonifera* is commonly encountered on rocky shores of Australia's east coast (Ruis & Teske 2013).

The uniqueness of Wallis Lake in terms of diversity of invertebrates lies with its sponge fauna. In a survey of 10 coastal lakes in 2002 (Barnes 2009), the ten taxa encountered within Wallis Lake were almost twice that of any other coastal lake. Sponges and ascidians are absent from the majority of lakes and lagoons in New South Wales. Most species appear restricted in distribution to only one or a few lakes. For example, *Dysidea* sp., *Raspaillia* sp., a species of *Haliclona* and a species of *Halichondria* and the recently encountered *Pseudospongorites* sp. have only been recorded from Wallis Lake and Smiths Lake (Barnes 2009 and current study). Of the thirteen species so far reported from the southern basin of Wallis Lake only, *Chondrilla* cf. *australiensis* (typically a species associated with rocky reefs on the open coast), *Aplysilla* cf. *sulphurea* and *Suberites* cf. *diversicolor* could be tentatively identified to species. The remainder are likely to be undescribed and new to science. The broader distribution of many of these species outside Wallis Lake is difficult to determine because of the paucity of studies and uncertain taxonomy. This is highlighted with a recent opportunistic collection of a *Suberites* cf. *diversolcolor* from the Peel Harvey Estuary in Western Australia in March 2017 (P. Barnes pers. obs). This was likely to be the same species found in Wallis and Smiths Lakes (Lisa Goudie pers. comm.).

4.4 | Contributions of sponges to the ecology of Wallis Lake

Evidence continues to grow of the strong linkages between diversity, natural ecological processes and the ecosystem services (ie benefits) that natural systems provide to humans (Solan et al. 2004, Mooney 2010). Diverse marine systems also tend to be more resistant to invasive species (Stachowicz et al. 2002). The sponge and ascidian diversity of Wallis and Smiths Lakes, although modest, likely plays an important role in the ecology of these Lakes. These animals constitute important biogenic habitat and sponges often provide refuge for a large number of associated taxa (e.g. Chin et al. 2020). Many organisms also consume them; Barnes (2009) chronicled the likely consumption of *Suberites* by monacanthid fishes (leatherjackets), while members of the sponge-feeding molluscan family Triphoridae have been observed associated with *Suberites* (Authors' personal observation). Sponges are also an important food resource for many nudibranchs (see for example https://nudibranchdomain.org/spongivores-the-sponge-eaters/, accessed 30 June, 2022).

There is growing recognition of the importance of facilitation or positive interactions in natural systems (Bruno and Bertness 2001) and recent research explores how sponges may affect facilitation. On tropical reefs, sponges incorporate dissolved organic matter and then shed organic material (cells) to the benefit of other members of the assemblage (de Goeij et al. 2013). This so called 'sponge loop' has solved a conundrum that puzzled Charles Darwin – how the marine deserts of tropical reefs can support such a diversity and abundance of life. In a recent study of more relevance to Wallis Lake, the sponge *Ircinia felix* was transplanted into tropical seagrass beds in the Bahamas (Archer et al. 2021). Living sponge transplants averaged 2.5 litres in volume. Within two years, seagrass nutrient content and growth increased, along with elevated macroalgal abundance, in the sponge transplant plots. These impacts were not seen in unmanipulated controls or procedural controls (the addition of a polypropylene sponge mimic). On a cautionary note, it should be emphasised that effects were over relatively small scales (0.25 metres) and the seagrass system examined was oligotrophic, unlike the lakes in NSW; nevertheless an intriguing outcome.

4.5 | Potential threats to sponges in Wallis Lake

In coastal environments, the distribution of sponges and ascidians may be affected by a variety of human impacts (Carballo *et al.* 1996; Carballo & Naranjo 2002) including sewage and silt deposition

(Roberts *et al.* 1998; Roberts *et al.* 2006). Potential impacts to sponges and ascidians in Wallis Lake remain similar to those proposed by Barnes (2010) as below.

Increased sediment loads

While little is known of the tolerances of the species in Wallis Lake to impacts such as silt deposition, it is likely that increased sediment loads could adversely affect the physiology and interfere with the feeding efficiency of filter feeders such as sponges (e.g. Roberts et al. 2006). Further, many sponge taxa, including *Suberites,* contain photosynthetic symbionts. Symbioses between sponges, cyanobacteria and other algae are common in shallow well-lit waters and the photosynthesising symbionts often provide a large proportion of energy to the sponge. It is reasonable to hypothesise that long-term and dramatic reductions in light availability caused by increased sediment loads may adversely affect species with symbionts such as *Suberites*. This must, however, be balanced by the results of a study in nearby, Smiths Lake, that found no negative effects on *Suberites* after 1 month of shading (Barnes 2009). In addition, impacts from increased sediment loads to important habitat may indirectly affect sponges and ascidians.

Loss of habitat (algal and seagrass meadows)

Many species of sponges in Wallis Lake and other New South Wales coastal lakes show strong associations with the types and structure of seagrass and algal meadows (Barnes 2009). For example, the *Lamprothamnion* meadows in the southern portion of the lake typically support the most diverse and abundant populations of sponges; some species of the sponge *Halichondria* in Wallis Lake have only been recorded on the brown alga, *Cystoseira trinodus* (Barnes 2009). *Mycale* sp. typically grows on the fronds of seagrasses or commonly on macroalgae (particularly the charophyte *Lamprothamnion*). One of the few other lakes where *Mycale* sp. could be considered abundant is Lake Conjola on the New South Wales south coast. However, in Lake Conjola, *Mycale* sp. grows predominantly on the invasive alga *Caulerpa taxifolia* which is considered an introduced pest and has been the target of an intensive eradication programme. Substantial losses or changes in the distribution of seagrasses and macroalgae due to human impacts are common in Australia and around the world (Waycott et al. 2009). Two of the key causes of seagrass loss have been increased nutrient loads from urban, industrial and agricultural run-off (e.g. use of fertilisers) causing algal blooms and increased sediment loads. Both processes act to reduce light reaching the seagrasses.

The potential effects on sponges from loss or changes in aquatic vegetation were apparent in this study. We observed a reduction in the *Lamprothamnion* meadows near Pacific Palms (**Figure 17**) and this corresponded with declines in the abundance of *Suberites* (**Figure 8**). Between 2002 and 2007 the substratum in this area was dominated by thick *Lamprothamnion* meadows with close to 100% cover. Since 2009, the coverage of this charophyte on the seafloor have become patchier, exposing more bare sediment. In the corresponding time frame, this area has changed from being the most common area for *Suberites* in Wallis Lake to *Suberites* becoming highly variable in its abundance. It is difficult to determine whether the factors contributing to the loss of *Lamprothamnion* are also directly affecting *Suberites* (e.g. changes in water quality may affect both species) or perhaps *Suberites* can tolerate these factors but are affected by the loss of *Lamprothamnion* in other more complex ways (e.g. increases in sediment loads as a result of more exposed fine sediments, changes in nutrient concentrations, changes in distribution of sponge predators, reduction in physical structure for attachment and growth). The more recent (2019 and 2020) very high abundances of *Suberites* at the Booti Booti location (Sites W18 and W22) corresponded with sparse meadows of the seagrass *Zostera*. It seems likely that if large areas of seagrass or meadows of *Lamprothamnion* are further reduced in Wallis Lake, there will be a concurrent loss of sponge species.

5 | RECOMMENDATIONS

The small population sizes of many ascidian and sponge taxa within these Lakes may render them susceptible to extinction from unforeseen or planned human disturbances (e.g. increased nutrient loads leading to loss of aquatic vegetation; large inputs of sediment from construction, roadworks, land clearing, etc.). It is, therefore, recommended that for precautionary reasons to protect the most diverse sponge fauna in New South Wales coastal lakes, which includes several species yet to be named, that every effort be made to prevent the deterioration of water quality in the lake and prevent the loss of valuable seagrass and macroalgal habitats, in particular the large beds of *Lamprothamnion* in the southern portion of the lake.

6 | ONGOING MONITORING AND COMMUNITY INVOLVEMENT

We suggest ongoing monitoring would provide ecologically reliable and valuable information to support management by Midcoast Council. The distinct morphologies and colouration of most of the important sponge and ascidians along with the potential to target accessible and shallow sites in Wallis and Smiths Lakes provides a potentially practical and cost-effective opportunity for Council staff and community volunteers to be heavily involved with in-field monitoring with appropriate technical and research support.

With the studies in 2007, 2009, 2017 and now 2022 building on the initial intensive sampling from 2002 to 2005 a comprehensive long-term dataset has now been assembled. These data highlight that although patterns are often complex through time, most of these species appear to be persistent in the longer term. For example, *Suberites* has always been found in Wallis and Smiths Lakes. Ongoing monitoring is deemed important as NSW enters its third successive La niña weather pattern.

The success of any volunteer or citizen science project will be reliant on having clear goals, is practical, has adequate technical and research support including training and resource materials, and delivers reliable and useful information.

In Wallis Lake we recommend on-going monitoring of multiple sites in the shallower waters near Pacific Palms and multiple sites in the patchy *Zostera* meadows north of Booti Booti Point, including Tiona (see areas circled in **Figure 1**). Pacific Palms and Booti Booti appear both ecologically important to target and have practical advantages for sampling. Ecologically, the *Lamprothamnion* meadows near Pacific Palms have been the hotspot for sponge diversity not only in Wallis Lake, but in all coastal lakes sampled in New South Wales. This area is further ecologically important to understand because of changes in species composition and declines in abundance as *Suberites* which has been previously very stable including in neighbouring Smiths Lake. There is a shorter time series of information for the areas north of Booti Booti, but results from the most recent sampling saw the highest abundances of *Suberites*. Given the patchy and complex changes in distribution it is important to monitor multiple areas to better understand natural changes which will provide opportunity to identify potential anthropogenic impacts.

Pacific Palms, Booti Booti and Tiona also have practical advantages for sampling; they are relatively shallow, generally less than 1.5m deep, which will be easier for snorkellers because the sampling will not require as much 'duck diving' as deeper sites. The sites are also relatively close to shore which provides the option of sampling from shore rather than using a boat. Barnes et al (2006), concluded from cost benefit analyses using Wallis Lake, that a total of 12 sites per lake was not only adequate to sample sponges, but had the additional advantage of being able to be sampled within a day. Therefore, eight sites should be able to be done within one day and also allow time for training of new staff and volunteers.

We also recommend a similar arrangement of sites in Smiths Lake are monitored at similar times to provide comparison with changes in Wallis Lake.

Given the potential dramatic changes in abundance typified by the bloom and subsequent die-off of *Tetilla* sp. in Smiths Lake in 2017, ideally monitoring would be done at a minimum of twice per year. The largest temporal changes within each year appear to often occur between the summer and autumn periods and timing of monitoring could be designed around this. The difficulties of working in colder waters of autumn are also recognised and monitoring could also be effective between December and February. If sampling was not practical on a yearly basis, we recommend periodic monitoring on a two or three yearly basis. We also recommend monitoring of near shore areas in Wallis Lake is complemented by less regular, but broader monitoring which includes deeper and less accessible sites and with researchers present to support local staff and volunteers.

This project offers an opportunity for council to engage with enthusiastic members of the community to collectively generate high quality information which improves our understanding of the ecology of these Lakes as well as contributing to the conservation and management of this fauna. The relatively low diversity and morphologically distinct species encountered ensures that volunteers will not be overwhelmed, and relatively shallow waters contributes to accessibility of sites. The inclusion of photographs of the sponge fauna in this report will assist with the training of volunteers. There are tangible benefits in engaging the community and exposing them to the unique nature of these Lakes and their fauna. This will ensure the building of understanding, stewardship, and advocacy.

Acknowledgements

We thank the Midcoast Council for support and funding of this project; Isabelle Strachan, Suzanne Fiebig, Chloe Redman, Brian Hughes, April McKay, Peter Goonan, Erin Masters and Carol Cordonis de Silva for support with fieldwork from 2017 particularly persevering in the cold waters of autumn;

Isabelle Strachan, Suzanne Fiebig and Chloe Redman undertook data entry and checking. Lisa Goudie aided with sponge identification.

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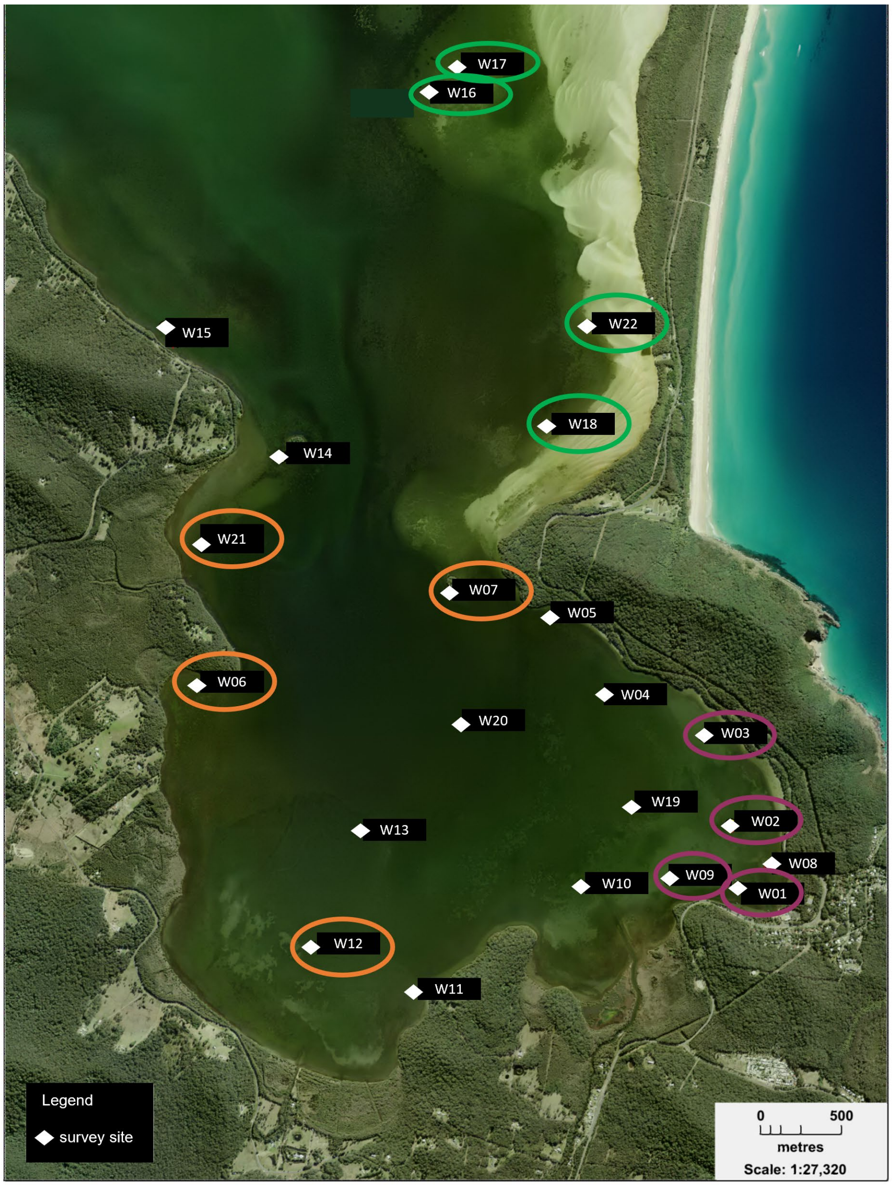
Appendices: Previous sample sites within Wallis Lake



Southern Basin—1 day

W09

W02

W01

W03

North of Booti—1 day

W17

W16

W22

W18

Other Sites if there is time

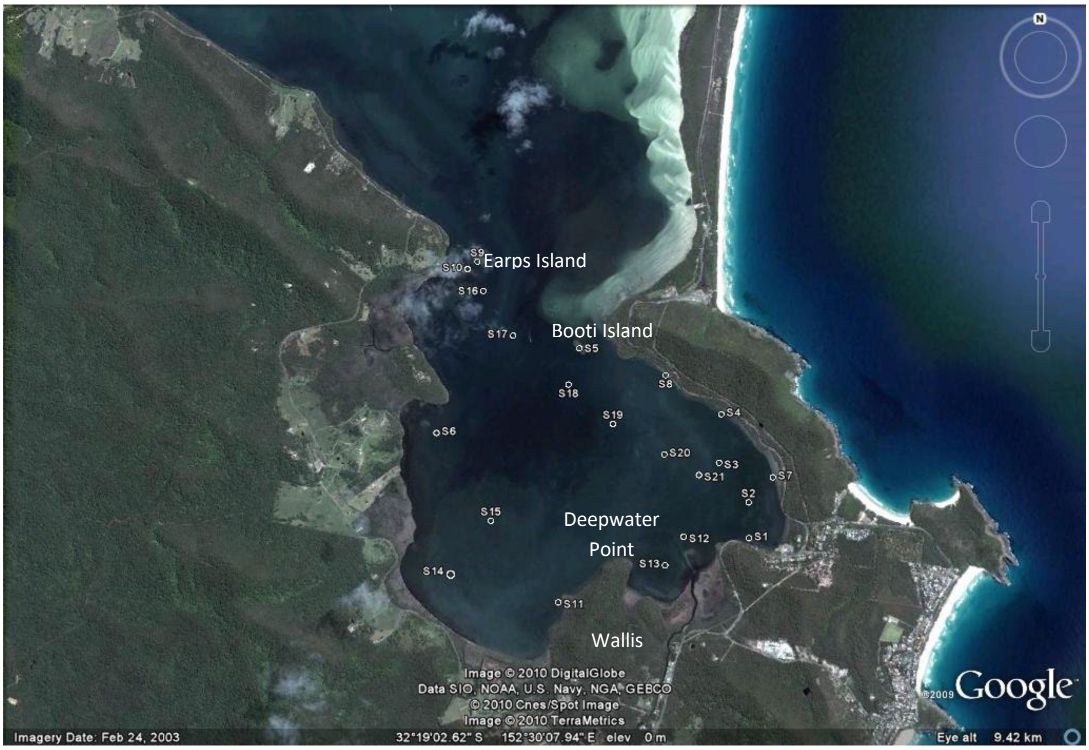
W7—Booti Island

W21—Brushy Point

W06—Brushy Point

W12—Charlotte Bay

Supplemental Figure 1: Sites targeted for monitoring in the most recent tranche of sampling – 2019 to 2021. All 22 sites are listed.



Supplemental Figure 2: The 21 Sites sampled in Wallis Lake in November 2007

Supplemental Figure 3: The 25 Sites sampled in Wallis Lake in December 2009