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Seagrasses of Moreton Bay *Quandamooka*: Diversity, ecology and resilience

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Abstract

Seagrasses are a dominant feature in the seascape of Moreton Bay. They host numerous animals and provide the region with a wide range of ecosystem services that we are only beginning to better understand. In the past 20 years, the focus of seagrass research in Moreton Bay has shifted towards predictive modelling based on comprehensive ecological understanding. There are seven species of seagrasses in Moreton Bay that persist across a wide range of environmental conditions from muddy sediments in the western Bay to the cleaner, sandier waters of the eastern Bay adjacent to Moreton (Moorgumpin) and Stradbroke (Minjerribah) Islands. There has been an encouraging recovery of meadows in some of the more degraded parts parts of the Bay, yet with an ever-increasing human population in South East Queensland, the threats to seagrasses still require continued research effort and careful management. This paper reviews the current understanding of Moreton Bay's seagrass meadows and provides recommendations for future research.

Keywords: climate change, estuary, eutrophic, sediment, nutrient, flood

Introduction – Seagrasses in the global context

Seagrasses are the dominant habitat-forming component of many shallow coastal zones globally. They provide critical services such as habitat (1), nutrient recycling (2), coastal stabilisation (3) and carbon sequestration (4). These services are estimated to be worth approximately \$27,000 ha^{-1}yr^{-1} (5), yet despite this value, humans have contributed to steady declines of seagrass extent globally. Loss of seagrass has accelerated from 0.7% pre-1945 to 9% annually post-1945 (6). A range of global threats have been documented: declining water quality from increased sedimentation causing light stress, physical removal through land reclamation, eutrophication causing algal overgrowth, increasing sea surface temperature, and increased frequency of storms (7).

The seagrasses of Moreton Bay are not immune to these threats, which have been increasing steadily since the 1990s (8). Sediment accretion in the central basin in Moreton Bay has increased by three to nine times over the past 100 years (9), suggesting large-scale changes to sediment erosion from catchments flowing into the Bay. Major floods have resulted in seagrass loss in the Bay with nearly 20 km^2 lost from southern Deception Bay during the 1996 flood (10). The predicted rise in the population of South East Queensland from approximately 3.5 million in 2016 to 5.35 million by 2040 (8) means that pressures on seagrass ecosystems are likely to increase for the foreseeable future. Despite the forecast, and in the period since the publication of the first Moreton Bay and Catchments book (10), nutrient concentrations in the western part of Moreton Bay have declined significantly (see Saeck *et al.* (11), this volume) due to the nearly \$1 billion spent on improvements to sewage treatment.

This paper outlines advances in our knowledge of seagrass responses to threats that have been collected since the previous Moreton Bay & Catchment book released in 1998. We discuss the current distribution and diversity of seagrass ecosystems in Moreton Bay and how patterns have changed over time, the role of ecological feedbacks in driving resilience of the Bay's seagrasses to floods, the projected effects of climate change and land-use change, and the diversity of fauna that rely on the Bay's seagrass meadows.

The diversity and distribution of seagrasses in Moreton Bay

There are seven species of seagrasses in Moreton Bay. Seagrass is distributed across Moreton Bay (Fig. 1), predominantly in intertidal and subtidal regions to 5 m depth (below lowest astronomical tides, LAT), but some meadows of *Halophila* spp. in the northern Bay grow below 10 m depth. Seagrasses range from colonising species (*Halophila ovalis*), to opportunistic species (*Zostera muelleri*) and persistent species (*Cymodocea serrulata*). Colonising and opportunistic species are faster growing and short-lived, and recover rapidly following disturbance (12) (Fig. 2). Moreton Bay is, however, devoid of the larger, highly persistent species that grow in northern Australia (e.g. *Enhalus* spp.) and southern and western Australia (e.g. *Posidonia* spp.).
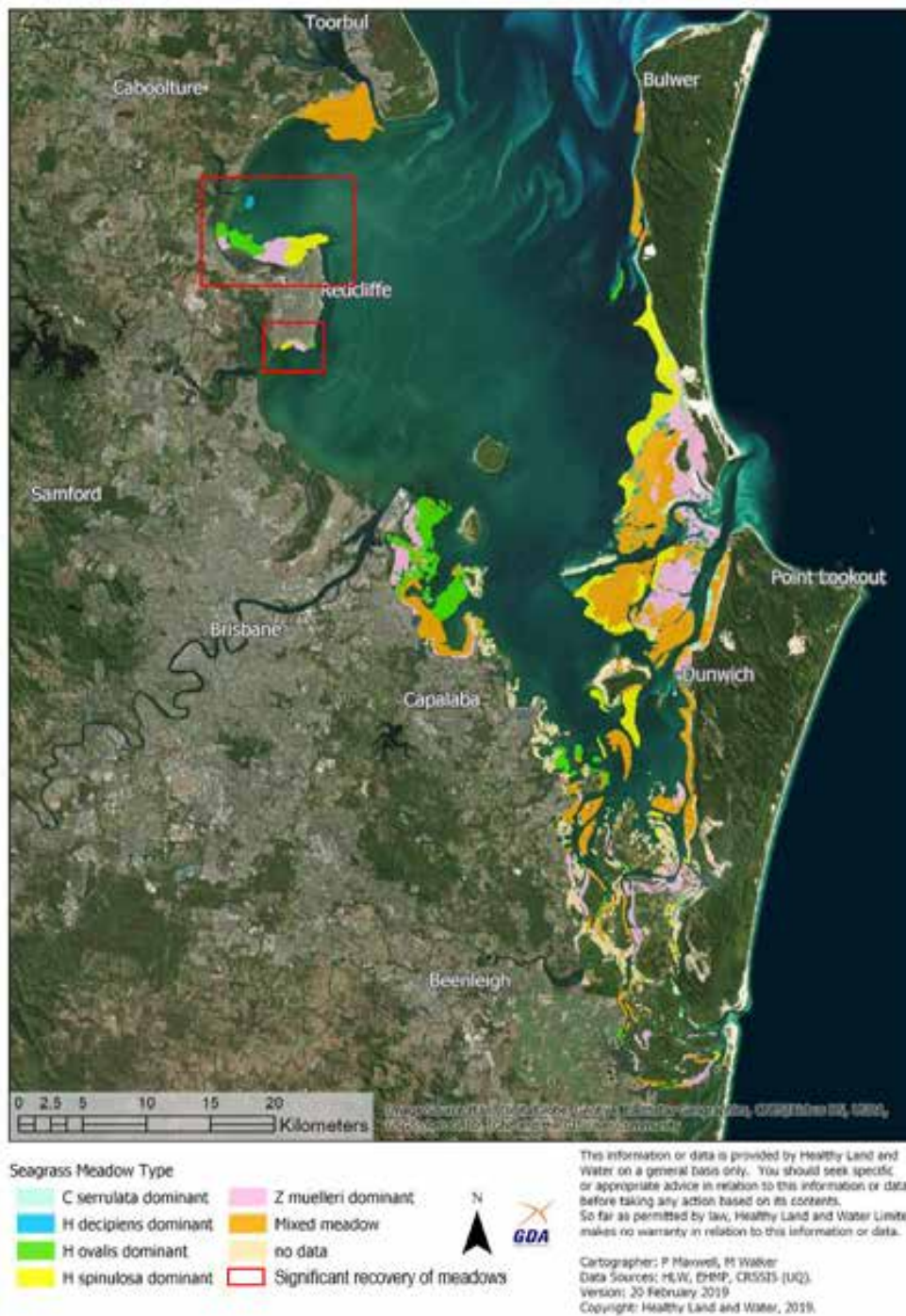
Figure 1. The distribution of seagrass species in Moreton Bay. Mapping conducted as part of the Ecosystem Health Monitoring Program (EHMP) in conjunction with research by the CRSSIS, University of Queensland (funded by Coastal Co-operative Research Centre). First published 2004, last updated 20 Feb 2019 by Healthy Land and Water.
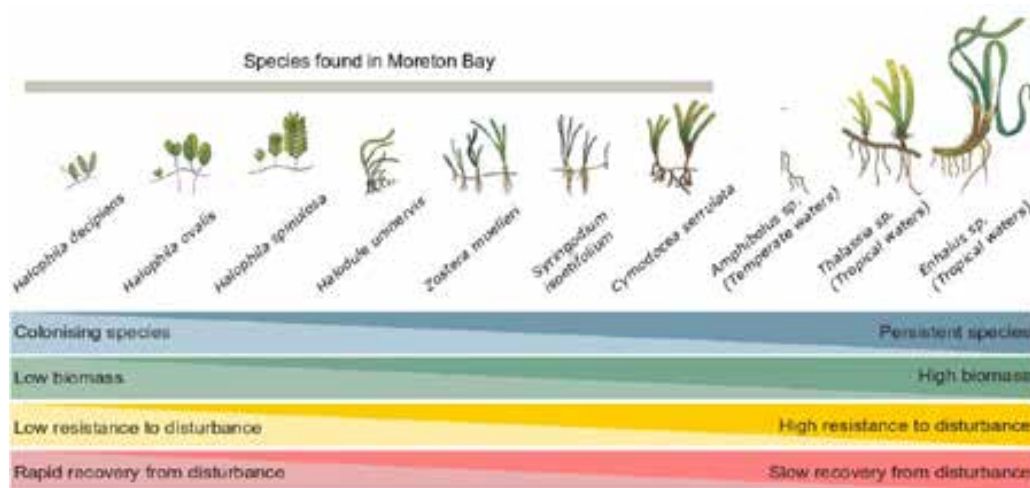
Figure 2. Characteristics of seagrass species found in Moreton Bay. Moreton Bay is dominated by colonising and opportunistic species that tend to be fast-growing and short-lived with a rapid recovery rate following disturbance, providing the conditions growth are suitable. (Adapted from (12)).

The largest expanse of seagrass in Moreton Bay is on the eastern side with mixed species meadows occupying the extensive intertidal and shallow subtidal Eastern Banks between Moreton and North Stradbroke islands. At least six of the seven species are found on and around these banks, with *Z. muelleri, H. univervis* and *H. ovalis* occupying the intertidal areas and *Syringodium isoetifolium* and *Cymodocea serrulata* dominating the shallow subtidal areas between –1 m and –2 m LAT. *Halophila spinulosa* dominates the deeper areas of the eastern Bay between –2 m LAT and –5 m LAT. In this area of the Bay, the species diversity and cover (%) vary through space and time (13), particularly on the Maroom and Amity banks, suggesting that changes in environmental conditions on the Eastern Banks (e.g. sediment movement, current) are a strong influence.

The diversity of species within meadows drops in the poorer water quality regions of the southern and western embayments of Moreton Bay (Fig. 1). These areas contain four species, the dominant being *Z. muelleri* which occupies both the intertidal flats and the subtidal zone down to depths of approximately –3 m LAT. *H. ovalis* typically occupies bare patches within *Z. muelleri* meadows in the intertidal zones and in sparse (~1% cover) ephemeral meadows in the deeper areas (~-5 m LAT) between Peel and Macleay islands and in Waterloo Bay between Manly and St. Helena Island. *H. spinulosa* typically occupies depths below the deep edge of *Z. muelleri* meadows.

The highest cover of seagrass in western Moreton Bay occurs in Waterloo Bay to the south of the Brisbane River. Waterloo Bay is dominated by *Z. muelleri* in the intertidal and shallow subtidal areas and by *H. spinulosa* and sparse *H. ovalis* in the deeper subtidal regions of the Bay (14). In the southern Bay channels, seagrass distribution, predominantly *Z. muelleri,* is limited to the thin strips of intertidal and shallow subtidal (0.5–1.0m below LAT) substrate on the edge of deeper channels (15).

A recent study into the relationship between genetic diversity and disturbance in *Z. muelleri*, one of the most widespread and abundant species in Moreton Bay, showed that seagrass meadows subject to long-term poor water quality have lower genotypic diversity (16). This suggests that in highly disturbed sites in the western and southern regions of the Bay, previous disturbances might have selected for a narrow range of genotypes to enable *Z. muelleri* to cope with poor conditions.

Since 1998 three maps of seagrass extent have been produced, however, each of these has used a slightly different technique to collect the information which has meant that finer scale comparisons (e.g. <5 km^2) of seagrass distribution cannot be made with confidence (17). At the larger 'bay scale', however, there has been significant variation in seagrass distribution particularly in Deception Bay and in the southern Bay. In southern Deception Bay, 20 km^2 was lost in 1996 following a significant flood in the Caboolture River catchment (10) (Fig. 1). Seagrass was absent from the area, replaced in part by substantial meadows of the algae *Caulerpa taxifolia*, until approximately 2009 when small patches of *Z. muelleri* appeared in the intertidal zone. Patches consolidated into sparse meadows in the intertidal and shallow subtidal areas surrounding Scarborough boat harbour. Since 2009, the seagrass extent in southern Deception Bay has steadily moved towards the west (Fig. 1) increasing in depth and therefore increasing in extent to nearly 4 km^2 by the first half of 2013 and to 6 km^2 in August 2016 (18).

The distribution of seagrass in other parts of the Bay has remained similar to that of 1996 (17). As pointed out by Roelfsema *et al.* (17), however, the different methods used to map seagrass distribution and the paucity of field-based data collected in 2011 have made it difficult to fully elucidate differences in distribution. There is still little seagrass cover in Bramble Bay; however, temporary populations of the opportunistic species *H. ovalis* have been recorded on some intertidal flats in this region of the Bay (19) since 2013 and more recently meadows of subtidal *Z. muelleri*, *H. ovalis* and *H. spinulosa* have been observed on the southern end of the Redcliffe Peninsula (15). Despite this encouraging news, modelling using water quality monitoring data, sediment erosion estimates, and seagrass distribution data has indicated that a non-linear decrease in habitat suitable for seagrass is expected with the increase in sediment loads predicted under future climate and management scenarios (20).

Impacts of disturbance on the seagrasses of Moreton Bay

The influence of riverine discharge and ongoing resuspension of fine sediments in the western and southern zones of Moreton Bay results in poor water quality. In contrast, the proximity to ocean water via the northern and two eastern passages into the Bay means water quality is typically good in the eastern zones of the Bay, resulting in an east–west decline in water quality across the Bay (11).

Seagrasses worldwide are used as an indicator of water quality impacts. In Moreton Bay, correlations between water quality and the maximum depth limit of seagrass growth have been used as a biological indicator of light availability in the Ecosystem Health

Monitoring Program since 1996 (21). The program was based on the observation that *Z. muelleri* grew to shallower depths as a result of poor light availability due to higher concentrations of phytoplankton and suspended sediments (22). Correspondingly, *Z. muelleri* meadows on the eastern side of the Bay grew deeper correlating well with the water quality gradient across the Bay.

After nearly 20 years of monitoring, this pattern broadly remains with the two deepest *Z. muelleri* sites in the well-flushed locations of northern Deception Bay (2.81 m below LAT) and at Crab Island (3.1 m below LAT) adjacent to Moreton Island (13) (Fig. 3). The sites with the poorest depth range are in the poorly flushed southern Deception Bay where seagrasses were lost following the 1996 Caboolture River flood, or in southern Moreton Bay close to the Logan River mouth (0.26 m deep at Behms Creek near Jacobs Well).
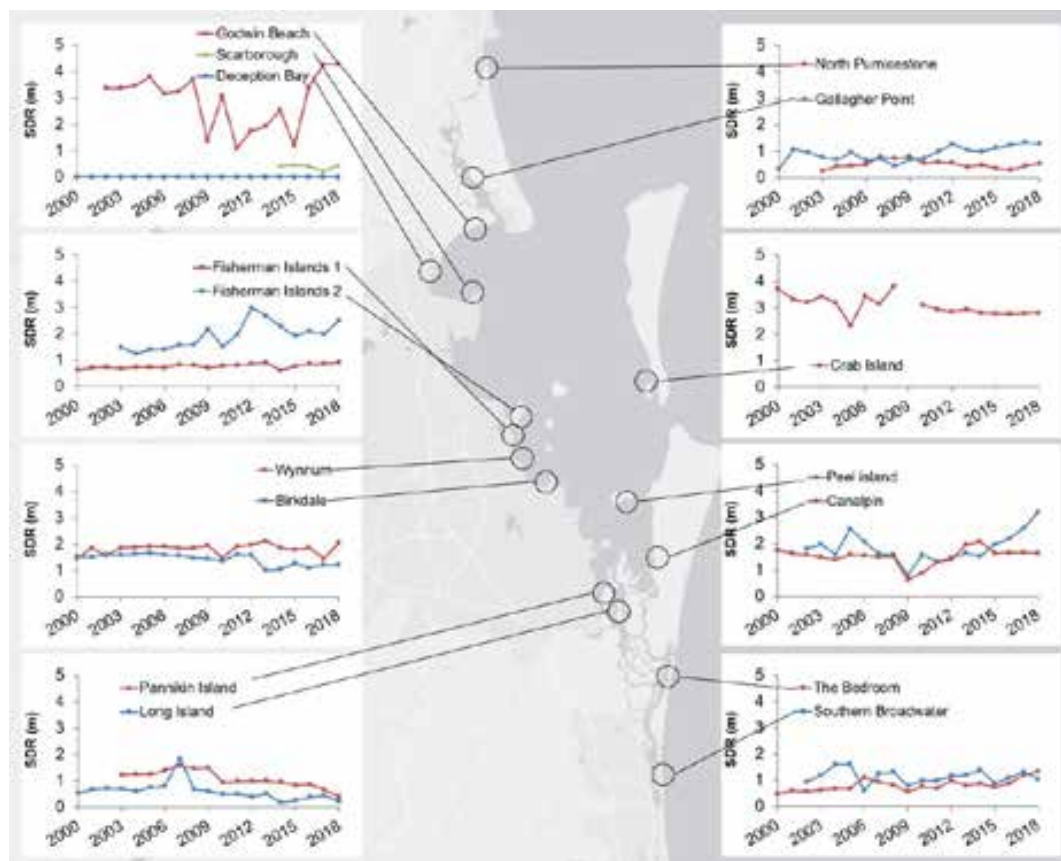
Figure 3. The depth range of *Zostera muelleri* meadows from across Moreton Bay. Typically the meadows in the poorer water quality areas of the western and southern Bays have smaller depth ranges; however, the relationship between water clarity and seagrass depth range is not linear.

At the remainder of the seagrass depth range sites (Fig. 3), the relationship between water quality and *Z. muelleri* depth range is much less distinct. After nearly 20 years of monitoring, the correlation between water quality and depth range is poor (r^2=0.4), with a large variation in mean water quality at the 18 depth range sites outside the extremes.

This suggests that additional factors, rather than just water clarity, are controlling the depth limit at those sites (see section on 'flood resilience' for possible alternatives).

The water quality gradient in Moreton Bay does not just influence seagrass distribution. Discharge from rivers on the western side of the Bay delivers organic matter and detritus that accumulates in seagrass meadows throughout the Bay (23). Carbon accumulation in Moreton Bay varies in both space and time (24). Vertical accretion rates and organic carbon burial rates have increased significantly since European colonisation in the catchment. Vertical accretion rates have increased to 0.66 cm^{-1}yr^{-1}, highlighting the impact of rapid catchment land-use changes. There is a similar pattern with carbon burial rates, with low rates of both organic carbon (OC) and inorganic carbon (IC) burial prior to colonisation (7$\pm$5 g OC^{-2}yr^{-1} and 10$\pm$14 g IC m^{-2}yr^{-1} respectively) being much lower than post colonisation (50$\pm$82 g OC^{-2}yr^{-1} and 73$\pm$115 g IC m^{-2}yr^{-1}, respectively) (24).

Despite the stark contrast between pre- and post-European carbon accretion and burial rates, the values from Moreton Bay are generally much lower than worldwide estimates. Pre-European vertical accretion rates in the Bay were recently estimated at 0.06 cm^{-1}yr^{-1}, less than half of the world average (25). Various factors may account for this. The rapid pace of land-use change (over approximately 150 years) in South East Queensland compared to the many hundreds of years of land-use change and therefore organic matter accumulation in other areas of the world is a likely factor, particularly in seagrass research hotpots in the Northern Hemisphere where many estimates have originated (26). The relatively low carbon content of South East Queensland soils (27) may play a part as well as the different morphologies and life histories of the smaller, less persistent seagrasses of *Zostera* sp. and *Halophila* sp. compared to the larger, matte-forming temperate seagrass, *Posidonia* (28).

In addition to chronic impacts of water quality, seagrass in Moreton Bay is under threat by large-scale blooms of *Lyngbya majuscula*. *Lyngbya* is a toxic, filamentous cyanobacteria that attaches to seagrasses and under the right conditions, blooms and smothers the underlying seagrass plants (21). The first well- documented bloom of *Lyngbya* occurred in 1996–97 and covered approximately 7 km^2 of the seagrass meadows off Godwins Beach in northern Deception Bay. Subsequent blooms and reports of the impacts to human health (29) and the crab and finfish harvests in Deception Bay (Greg Savige 2017 pers. comm. 02/04) led to a large-scale, multifaceted program in the mid 2000s to identify the factors that lead to bloom initiation (30–32).

Lyngbya attaches to seagrass and can rise to the water surface after gas bubbles accumulate (33), thereby removing seagrass leaves and causing substantial seagrass impact similar to that seen following light limitation (34). Blooms have been mapped throughout the Bay, varying from 8 to 80 km^2 (35), but have been recorded most regularly in northern Deception Bay and the shallow subtidal seagrass meadows on the Eastern Banks. Multiple interacting factors lead to *Lyngbya* bloom initiation, including the available nutrient pool, water temperature, current velocity and the light environment (32, 36).

Cyanobacteria and algal blooms have a marked effect on the organisms that use seagrass meadows in the Bay. Blooms of *Lyngbya* have a clear negative effect on the nematode, copepod and polychaete assemblages but particularly nematodes which, in meadows affected by blooms, are approximately half as abundant as those of non-bloom meadows (37). The mean density, live mass and number of species of small fish and prawns in seagrass meadows tend to decline during *Lyngbya* blooms, with fish that use both seagrasses and mangroves showing greater decline (38). Epibenthic species show greater decline than demersal species. The effect of blooms also extends to commercial fisheries with data from fishing logs showing how mean monthly fish catch is significantly reduced in bloom years. Despite this, seagrass meadows are not entirely devoid of life during *Lyngbya* blooms, with meadows continuing to function as nursery habitat for a diverse assemblage of fish and prawns (38).

The macroalga *C. taxifolia* has also increased in areal coverage over the past two decades (39–41). *C. taxifolia* is native to Moreton Bay, with museum records dating back to 1946 (42). However, there has been widespread concern over the increasing distribution of *C. taxifolia* given its long history of increasing colonisation in the Mediterranean Sea. Studies in New South Wales and Moreton Bay indicate that *C. taxifolia* is opportunistically colonising unvegetated areas that have already been denuded due to declining water quality, rather than being in direct competition with seagrasses (41, 43, 44). *C. taxifolia* provides some habitat value for fish and invertebrates (45), but selected taxa (most notably Syngnathids (e.g. seahorses and pipefish)) are absent from *C. taxifolia* (45, 46). Additionally, habitat preference studies indicate that fish spent significantly more time in seagrass than *C. taxifolia*, and this is likely due to a combination of structural, visual and chemosensory cues (45).

The rhizome system of seagrasses is easily damaged by bait digging and boat propellers, and even moreso by larger scale removal activities, and if the meadows do recover from such disruption it can take a year or more (47). Unfortunately even low-level trampling (by tourists and educational parties) can have a long-lasting detrimental effect (48).

Resilience to extreme events: the response to the floods of 2011

Extreme events such as floods and cyclones can have sudden, large and potentially destructive effects on the structure and function and ultimately the ecosystem services of marine ecosystems (49). Coastal habitats such as seagrass are especially vulnerable to extreme events, particularly with increases in the likelihood of higher frequency and more intense storms in coastal areas of Queensland.

In January 2011, a flood in the Brisbane River catchment, the largest in 37 years (50) discharged a significant tonnage of sediment into the Bay, reducing the Secchi disc depth (a measure of water clarity) to below 1 m in the western Bay from an average of 2 m (51). The flood caused significant decreases in water quality in the Bay with approximately one million tonnes of sediment estimated to have been deposited following the flood (52).

The most heavily affected meadows in the Bay were in Deception Bay to the north of the river mouth and Waterloo Bay, which is connected to the river via the narrow channel of Boat Passage (Fig. 1). The areas covered by *S. isoetifolium* meadows in northern Deception Bay reduced by approximately 50% following the flood (53). Other seagrass species in the region, predominantly *Z. muelleri* and *H. ovalis,* were largely unaffected by the flood which is likely a result of the salinity range that both species can tolerate (54) compared with *S. isoetifolium*, which in northern Deception Bay is likely at the lower end of its water quality tolerance. This is borne out by the loss of the macroalgae *C. taxifolia* and *Udotea* spp. (53) and the complete absence of epiphytic algae (55), all of which were likely impacted by the predominance of lower salinities following the flood. Loss of species diversity within near-shore meadows in Moreton Bay is highly likely to continue given the predicted increase in extreme storm events. This means that in areas of moderate water quality, diverse meadows could be replaced by mono-specific meadows dominated by *Z. muelleri*, the Bay's most phenotypically plastic species with a wide tolerance for changes in water quality (55).

This plasticity was demonstrated by responses of *Z. muelleri* to the 2011 flood. The meadows closest to the estuarine discharges in the Bay are subjected to chronically poor water quality with light quality that often fluctuates below the minimum light requirements of the species. As a result, *Z. muelleri* in these meadows has physiological and morphological adaptations that maximise photo-efficiency (e.g. increased chlorophyll content, wider and longer leaves, and a greater chl a:b ratio) and enhanced investment in below-ground carbohydrate storage (e.g. increase rhizome starch concentrations) (55).

Z. muelleri in the meadows in the comparatively well-flushed eastern Moreton Bay is characterised by physiological and morphological adaptations typical of plants inhabiting areas of stable water quality and abundant light. Leaves are smaller and thinner with lower chlorophyll content (56, 57), there is a greater energy investment in below-ground biomass and rhizomes are smaller with lower concentrations of carbohydrates. Following the flood, the plants in these meadows exhibited the same physiological response as *Z. muelleri* plants in the western Bay indicating similar levels of stress despite the flood impact being approximately 10% of that felt in the west (55).

The importance of feedback loops for maintaining seagrass meadows

Seagrasses globally are quintessential ecosystem engineers, exerting considerable influence on the environmental conditions that in many cases are essential to their persistence. As seagrass meadows support a diverse range of organisms disproportionate to their area (1), the loss of meadows results in an impact greater than the loss of meadows alone and can significantly reduce their ability to recover. The interactions between seagrass and local environmental conditions can result in non-linear responses to impacts which are controlled to a large degree by the presence of feedback loops (58–60). Feedbacks can result in seagrass persisting in areas that might otherwise be

characterised by undesirable environmental conditions, so once lost its absence can reduce the chances of recovery (61).

At least three of the common feedbacks found in seagrasses worldwide have been shown to be present in Moreton Bay. Firstly, high density seagrass reduces near-bed water currents, reducing the physical stress on seagrass plants (3, 62). The above-ground structure of seagrass plants slows water movement across seagrass meadows, allowing suspended sediment and organic matter to fall out of the water column, becoming bound and assimilated by below-ground structures. Roots and rhizomes bind sediments thereby limiting resuspension and both processes improve water clarity. This feedback improves conditions for seagrass growth and ultimately seagrass depth range, which may account for some of the lack of linear relationship between water clarity and seagrass depth range at the sites across the Bay, as noted above (63). Following the 2011 flood, light quantity was significantly higher at sites with seagrass present than at adjacent unvegetated sites (55).

Secondly, slowing water movement across the meadow also enables seagrass and its associated algal and microbial communities to sequester and incorporate dissolved inorganic nutrients (2, 64). In Moreton Bay, uptake rates of dissolved inorganic nitrogen in seagrass meadows following the 2011 flood were highest in meadows closer to the source of the flood (55). Nutrient uptake in unvegetated sites was lower than at all sites where seagrass was present (55). This suggests that the capacity for seagrasses in the Bay to assimilate nutrients from the water column, as elsewhere, is likely dependent on the above-ground meadow traits, (e.g. the length and density of shoots) and the extent of nutrient loading (2, 65).

The vulnerability of seagrasses in the Bay to competition from micro- and macroalgae is also reduced by herbivore grazing rates (66). The seagrass canopy provides significant predation protection for meso-grazers (e.g. gastropods, amphipods, isopods and herbivorous fish) that graze on algae (67). Grazing rates were tested in Moreton Bay following the 2011 flood. Rates were significantly higher at seagrass meadows impacted by the flood (25% wet weight algae lost over three days compared to 10% at sites with lower flood impact). Rates were also much higher in seagrass-dominated sites generally than in unvegetated sites (5% loss of algal wet weight after three days) (55).

When considered together, the strength of these three interacting feedbacks can be used to predict the likelihood of bistability (where ecosystems can theoretically exist in one of more states, such as bare or vegetated) in the Bay. A critical first step in integrating an understanding of non-linear dynamics into management plans for conserving and restoring the Bay's seagrass ecosystems (61). While large-scale restoration is not yet considered practical, recent research suggests that seagrass restoration may actually be cost-effective for increasing seagrass extent in Moreton Bay (20). Emerging techniques for seagrass restoration have been used successfully over relatively large scales in other regions (68). Using a Bayesian Network, regions of the Bay have been assigned a likelihood of bistability due to the strength of the interacting feedback loops controlling

seagrass presence, as described above. Large sections of the intertidal and shallow subtidal areas of the western Bay, including southern Deception Bay, northern Bramble Bay and the southern Bay, were predicted to be bistable. Some of these areas have experienced seagrass loss since 1987 (69) most notably in southern Deception Bay and the southern Bay channels. These are therefore areas in the Bay where any natural recovery after the loss of seagrass is likely to be delayed due to the breakdown of the feedbacks controlling the presence of seagrass.

Fish and invertebrate communities of seagrass meadows

Seagrasses provide a significant habitat for a wide range of fauna, and are recognised globally as critical nursery habitats for commercially important fish and invertebrate species (1, 70). They are also recognised as hotspots for biodiversity (71), the effect of which increases with the size and proximity of seagrass meadows to other habitats (72, 73). The fauna of seagrass meadows in Moreton Bay is dominated by invertebrates (74), fishes, turtles and dugongs, and these groups have been the focus of a substantial body of research, much of it published since the first synthesis on Moreton Bay. Although knowledge of where fauna assemblages in the Bay stand in relation to global seagrass assemblages is incomplete, and despite significant inroads into establishing an inventory of benthic invertebrates, changes to the faunal composition of the Bay's seagrass meadows over time and across the multiple stressor gradients remain unknown.

There are many factors that impact fauna assemblages in the seagrass meadows of Moreton Bay. For example, current speed, light penetration to the seabed, and even the potential success rates of various predators could all influence the relative importance of species present in the Bay's meadows. Surprisingly, the proportion of the total assemblage numbers in each functional group is effectively constant across at least small-scale space, e.g. over 0.4 ha of the Deanbilla Bay region of North Stradbroke Island (Fig. 4) (75).

The larger animals in the seagrass meadows (e.g. the highly visible sea pens, sea cucumbers, strawberry cockles, sentinel and hermit crabs, and mud whelks) are well known. However, more than 250 smaller species (defined as <4 mm in at least one dimension) have also been recorded from the seagrass meadows of North Stradbroke Island and they dominate the fauna both numerically and ecologically (74). This 'small animal' category includes the two overwhelmingly abundant and most widespread elements of the seagrass fauna, the < 2 mm long gastropod *Calopia imitata* and the < 5 mm crab *Enigmaplax littoralis*. Indeed, *C. imitata* is one of the most widely distributed and abundant snails in southern Moreton Bay, yet the biology and ecology of both species is still largely unknown (74, 76).

The denser seagrasses of the Bay support two to three times as many individual animals and species per unit area as adjacent bare sandflats (77). The contrast is still apparent even in relatively sparse *Halophila ovalis* meadows. This general disparity in richness between the two habitats leads to concerns that any ongoing loss of seagrass meadows

in the Bay will result in decreases of animal abundance and biodiversity. Species composition and overall abundance of fauna is incredibly patchy in space, varying markedly even over distances of centimetres (78) with 42% of species represented by only one or two individuals. Despite this, the total number of individuals and species per unit area is remarkably consistent even over kilometres in the absence of environmental gradients.
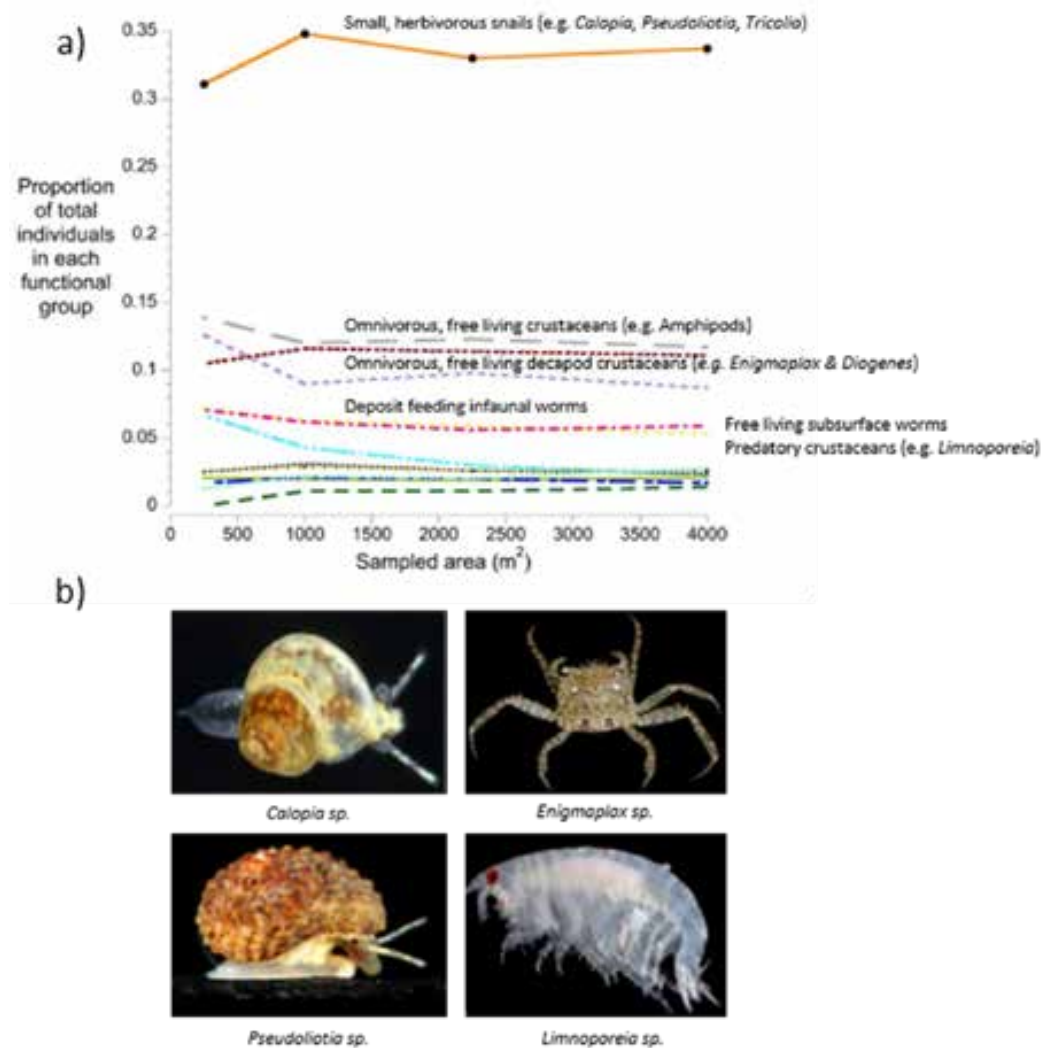
Figure 4. (a) Cumulative plots showing the effect of spatial extent on the proportion of the total individuals contained in each functional group across scales of 250 m^2 (4 stations), 1,000 m^2 (16 stations), 2,250 m^2 (36 stations) and 4,000 m^2 (64 stations) (Adapted from (75)). Note that the proportion of the total individuals contained within each group is effectively constant. (b) The four most abundant and widespread animals in the intertidal North Stradbroke Island seagrass meadows (Figure reproduced from (74)). [Images: *Calopia* from australianmuseum.net.au/blogpost/amri-news/amri-seagrass-grazers-coming-out-of-their-shells, © The Australian Museum; *Enigmaplax* and *Pseudolioti*a courtesy of and © Denis Riek (www.roboastra.com); *Limnoporeia*, reproduced here courtesy of Jim Lowry and Alan Myers through R Barnes)

Despite the contrast in animal diversity and abundance between seagrass beds and bare substrates, densities in Moreton Bay's seagrasses are relatively low, < 4,000 individuals m^{-2} (79) compared with estimates in other regions (e.g. in the NW Atlantic) which can exceed 80,000 individuals m^{-2} (80). This is likely due to 'top-down control' exerted by all juvenile prawns and small fish that use them as nursery grounds (66).

In Moreton Bay, the positioning of seagrass meadows throughout the seascape is a critical influence on the abundance and types of species that use them. Many of the commercially important fish species harvested in the Bay use seagrass meadows at some point throughout their life cycle, with key species like whiting initially settling in habitats adjacent to seagrasses before eventually moving into them (80). Larger numbers of fish and prawns use seagrass meadows that are nearer to mangroves than those further away (72, 82). This is likely due to the dietary benefit of organic matter derived from exported mangrove detritus for seagrass users. The effect is consistent despite variation in the density of the seagrass meadow suggesting that connectivity between habitat types is a greater influence than structural complexity of the meadow (83). This contrasts with findings in other regions that the density of seagrass residents is influenced by seagrass morphology, cover and size of the seagrass patch (84). In the Eastern Bay, fish species richness and assemblage composition are most influenced by the proximity of the meadow to the ocean exchange at the South Passage and to mangroves, with beta diversity (a measure of the number of distinct groups or communities) being most affected by the structure of the meadow (seagrass leaf length and shoot density) as well as the proximity to mangroves (83).

The positive effect that proximity to receiving waters has on seagrass fish assemblages is also replicated in the river estuaries that drain into Moreton Bay. The distance of habitats within estuaries to both mangroves and the mouth of the estuary is a significant driver of fish community composition; however, the proximity of those habitats to seagrass is a more dominant influence (85) with sites in estuaries closer to seagrass patches always supporting more species and containing more individuals than those further away from seagrass. This highlights the importance of retaining the linkages between seagrass meadows and adjacent fish habitats in and around the mouths of estuaries in order to support commercial and recreational fisheries and biodiversity of the Bay as a whole (86, 87).

Many seagrass inhabitants are either directly or indirectly consuming seagrass leaves or the epiphytic algae that grow on them. Grazing has been shown globally to be an important mediator of the structure and function of seagrass ecosystems (88). The feeding habits of the megaherbivores (e.g. green turtles and dugongs) in the Bay are relatively well known. Dugongs feed selectively to maximise their intake of the high nutrient, low fibre seagrass species such as *H. ovalis* (89) avoiding more extensive but more fibrous *Z. muelleri*. Dugongs have been shown to prevent the spread of *Z. muelleri* by intensively grazing areas such as the Eastern Banks and effectively cultivating areas for the preferred *H. ovalis* (89). Dugongs are found throughout the Bay (90, 91);

however, it is likely that the magnitude of their influence in shaping the structure and function of meadows in the western and southern Bay is reduced considering their numbers are generally low in those areas (2–5% of total population) (91). Consumption of seagrass by green turtle is likely to have a similar influence with simulated repeated grazing trials resulting in increased leaf regrowth of the preferred *H. ovalis* relative to ungrazed controls (92).

The influence of fish and invertebrate herbivores on the structure and function of Moreton Bay seagrasses is less well known but efforts to understand that influence have increased in recent years. Seagrass is consumed by herbivorous fish in the Bay, particularly rabbit fishes (Family Siganidae), the juveniles of which have a preference for the dominant *Z. muelleri* (93). Similarly, small gastropods like the abundant nerite *Smaragia souverbiana*, also have a preference for *Z. muelleri,* directly targeting seagrass leaves and avoiding those with an excess epiphytic algal load (94). The ecological function of these seagrass-consuming gastropods is not well known in Moreton Bay but there is some evidence that they target the more fibrous and less digestible *Z. muelleri* due to lower phenol content, a metabolite know to deter grazers (95). Lower phenol content could also account for small fish grazers preferring *Z. muelleri* (96). This could represent something of a trade-off between phenol content and digestibility, a local-scale process that could create more complicated seagrass–grazer interactions at a Bay-wide scale.

In contrast to direct seagrass consumption, other small fish and invertebrates inhabiting the Bay's seagrass meadows target the epiphytic growth (both algal and otherwise) on seagrass leaves, thereby improving the light environment available for photosynthesis (97). The contribution of fish and invertebrates to seagrass and algal epiphyte dynamics is extensive with the exclusion of small meso-grazers such as amphipods and juvenile shrimp shown to increase epiphytic algae by 2.5 times at one site in Waterloo Bay (66). Small fish like leatherjackets (Family Monacanthidae) and sabre-toothed blennies (Family Blennidae) that are ubiquitous in the Bay's meadows exert a similar, albeit lesser influence, on epiphytic algal biomass (35% and 15% reduction respectively in one 18-hour experiment) (97). The influence of these algal grazers in enhancing seagrass persistence is therefore likely to be substantial, particularly in the regions of Moreton Bay that have elevated nutrient loads (61).

Conclusions and recommendations

The understanding of the biology and ecology of seagrass meadows in Moreton Bay has come a long way since the previous Moreton Bay and Catchment book (10). In 1996, the focus of seagrass research in the Bay was on drawing attention to the declining extent and condition of the Bay's meadows and a focus on the threats and stressors that need to be addressed to protect and enhance this valuable habitat. Since those studies, the region has been galvanised into action, with significant work being done to reduce the point-source nutrient loads entering the Bay. In the past 20 years we have seen significant recovery of seagrass meadows in the heavily impacted western embayments

of southern Deception Bay and more recently parts of Bramble Bay. While this is a positive step, the Bay's seagrasses are still under considerable threat from urbanisation and land-use change in the catchment and the likely impacts of climate change. Our understanding of the organisms that inhabit the Bay's seagrasses has improved significantly since 1998. However, we are unable to say without qualification what the existing extents of seagrasses are, how much they vary over temporal scales, and therefore we cannot quantify the economic, social and ecological value of seagrasses for the human community in the region. We need to further investigate the importance of the linkages between estuarine seagrass habitats and the meadows in the Bay and the causes of change in seagrass extent and condition, including the complex relationships between the effects of multiple stressors, so that management activities can target pressures.

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