Wetland and benthic cover changes in Moreton Bay

Abstract

Wetlands are among the most productive ecosystems in the world, not only supporting a diversity of plants and animals, but improving water quality, and providing coastal protection against destructive impacts. Anthropogenic actions remain the greatest threat to these environments and in order to enable effective long term management of these areas, it is important to be aware of changes that have occurred to ecosystem distribution over time. This paper examines changes in the distribution of saltmarsh, mangrove, mudflat, seagrass and coral reef areas of the Moreton Bay wetlands, from historical records (circa 1950) to the most current mapping data available (circa 2015). Continued monitoring of the Bay's wetland communities through government organisations and community-science organisations such as MangroveWatch, Seagrass-Watch, CoralWatch and Reef Check Australia is vital in ensuring the management of these ecologically, socially and economically important wetlands remains effective into the future.

Keywords: wetlands, mangroves, saltmarsh, coral reefs, seagrass

Introduction

The wetlands of Moreton Bay comprise a diverse range of habitat types that include rocky shores, sand banks, mudflats, mangroves, saltmarshes, intertidal and subtidal seagrass meadows, and coral reefs (1). These distinct ecosystems include habitat and foraging grounds for a wide variety of organisms, some of which are International Union for the Conservation of Nature (IUCN) status "threatened" such as the green sea turtle, dugong and migratory wading birds (1). Additionally they deliver a number of critical services including coastal protection, water supply and purification (2). The significance of Moreton Bay's wetlands has led to their protection under the internationally binding Ramsar Convention (Ramsar Wetlands of International Importance (Ramsar Sites (3)).

Knowledge of how wetland areas respond to stressors is particularly important when considering climate change and its additive effect on wetland environments. To comprehend the degree and means by which stressors influence wetland communities, it is important to monitor their extent and composition over time. Specific chapters within this book detail the habitats within the wetland community. This chapter, however, will summarise the change in extent of Moreton Bay's wetland and benthic ecosystems including the intertidal flats, mangroves, saltmarshes, seagrass meadows, and coral reefs (Fig. 1).

The Intertidal Zone

Moreton Bay's intertidal zone is comprised of numerous habitat types, including tidal flats (mud and sand), mangroves, seagrass and saltmarsh environments (4). The community structure, complexity and diversity of organisms within the intertidal zone reflect the range of environmental conditions within each sub-zone (supratidal, upper mid-littoral, lower mid-littoral and lower littoral) (5). As such, the organisms within each zone have specific behavioural, biological and physiological adaptations (osmoregulatory, metabolic) enabling them to withstand the diverse conditions that are unique to each zone (6).

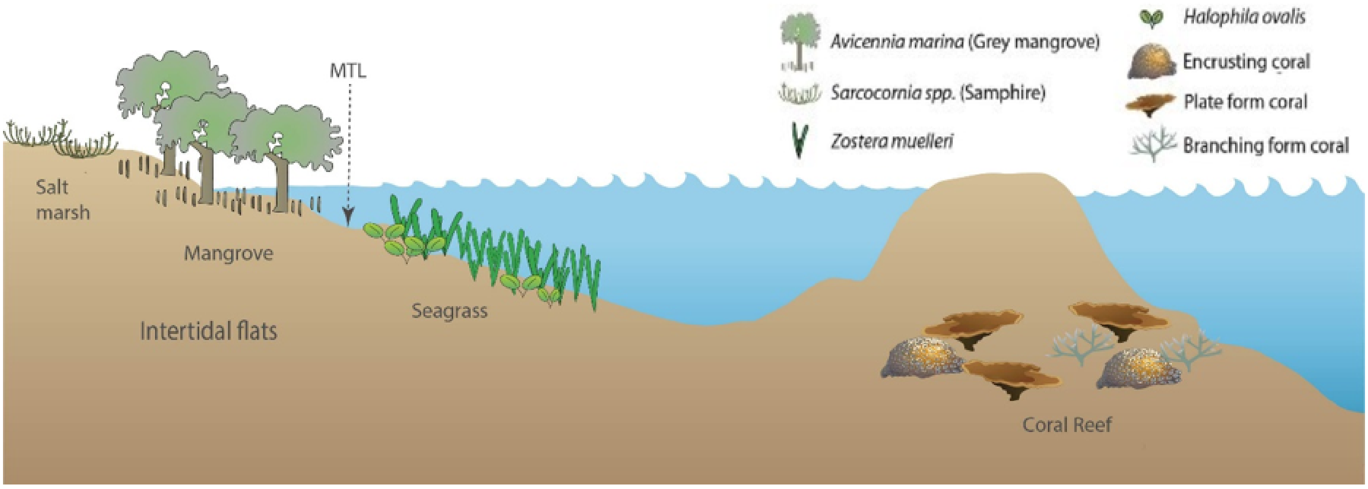

Figure 1. Moreton Bay wetland environments, a transition zone between the land and the ocean. These areas undergo periodic inundation and include all environments to a depth of 6 m. The intertidal zone is the most landward zone of the wetlands and is exposed to air at low tide, and submerged at high tide. The mid-intertidal zone indicated by the mean tide level (MTL) is regularly exposed and submerged. The intertidal zone encompasses saltmarsh, mangrove, seagrass and mudflat habitats. Wetland environments also include the inshore reefs found in shallow waters, atop a muddy substrate.

Saltmarshes

Within the intertidal zone, landward of the mangrove communities, lie saltmarsh wetlands (Fig. 1). They exist on a marine-derived soil substrate on low gradient marine and estuarine plains (7). These areas are highly dynamic and provide a habitat for a vast array of vertebrate and invertebrate species, including migratory birds, fish, crabs, and molluscs (8). For a detailed description of saltmarsh habitat and ecology, refer to Lovelock *et al*. this volume.

Documented records of saltmarsh extent in Moreton Bay are limited. An initial study (9) reported that between 1955 and 2012, approximately 43% of saltmarsh communities in Moreton Bay were lost through invasion of mangroves (Table 1), a major threat for saltmarsh communities (10). An additional, 46% of saltmarsh communities were lost to anthropogenic activities, including grazing and urban development (Table 1) (9). Any saltmarsh gains arose from mangrove dieback or saltmarsh invasion of *Melaleuca* or *Eucalypt* spp. patches where the frequency of inundation had been altered. Collectively, this equated to a net loss of 5,700 hectares (ha) (with only 2,400 ha stable), or a net loss of 64% of the 1955 saltmarsh extent (9) (Table 2; Fig. 2), and the loss occurred across all major saltmarsh community types.

Table 1. Saltmarsh community expansion (+) and loss (-) in Moreton Bay – the difference in aerial extent between 1955 and 1997, and 1997 and 2012 (9). Expansion/contraction rates are expressed in hectares per year in parentheses.

Saltmarsh Invasion into Mangrove and *Casuarina glauca* communities (ha)	
1955-1997	**1997-2012**
661 (+ 15.74 ha/yr)	180 (+ 12.00 ha/yr)

Saltmarsh Loss (ha)			
1955-1997		**1997-2012**	
Mangrove	**Anthropogenic**	**Mangrove**	**Anthropogenic**
3,077	2,170	670	618
(- 73.26 ha/yr)	(- 51.67 ha/yr)	(- 44.67 ha/yr)	(- 41.20 ha/yr)

Table 2. The total Moreton Bay saltmarsh area (ha) as recorded in the three mapping years (1955, 1997 and 2012) and the net change per study period (adapted from (9)).

1955	1997	2012	Decline 1955-2012	Decline 1997-2012

Total Saltmarsh Community (ha)	8,901	4,135	3,171	**-64 %**	**-23 %**

In 2011, a program was developed by the Queensland Herbarium to monitor wetland communities within Moreton Bay (11), and in 2013, the saltmarsh community of Moreton Bay was listed as a vulnerable ecological community under the Commonwealth Environment Protection and Biodiversity Conservation Act (10) with greater than 50% loss estimated for the saltmarsh communities of Moreton Bay.

In 2015, utilising existing maps of saltmarsh distribution (11), a non-governmental organisation (12) undertook the South East Queensland Coastal Saltmarsh Value and Protection Mapping Project, the “Saltmarsh For Life” initiative. The study was designed to identify key locations of associated saltmarsh areas and assign coastal values to these areas to facilitate regional conservation outcomes for the saltmarsh areas of South East Queensland (13). Saltmarsh clusters were identified and prioritised based on a number of criteria including patch size, habitat, environmental significance and Ramsar designation. Areas with the highest score were labelled as priority areas and recommended for protection (Fig. 3a). Additionally, a study was initiated which collated data collected by citizen scientists to map saltmarsh areas of interest and areas suited to saltmarsh restoration, as well as potential threats to saltmarsh habitats (12, 14) (Fig. 3b). Further, potential saltmarsh areas were identified from a desktop study that overlaid the Queensland Government Regional Ecosystems map, aerial imagery and a Preclearing Ecosystems map (12, 14). Similarly, potential saltmarsh recovery areas were marked through identification of areas that were not developed or disturbed and historically had contained a coastal vegetation community (Fig. 3b). This mapping is ongoing but serves as a reservoir for detailed information about the current state of saltmarsh communities, how they are being used by the community, and provide a means by which to prioritise conservation actions (12, 14).

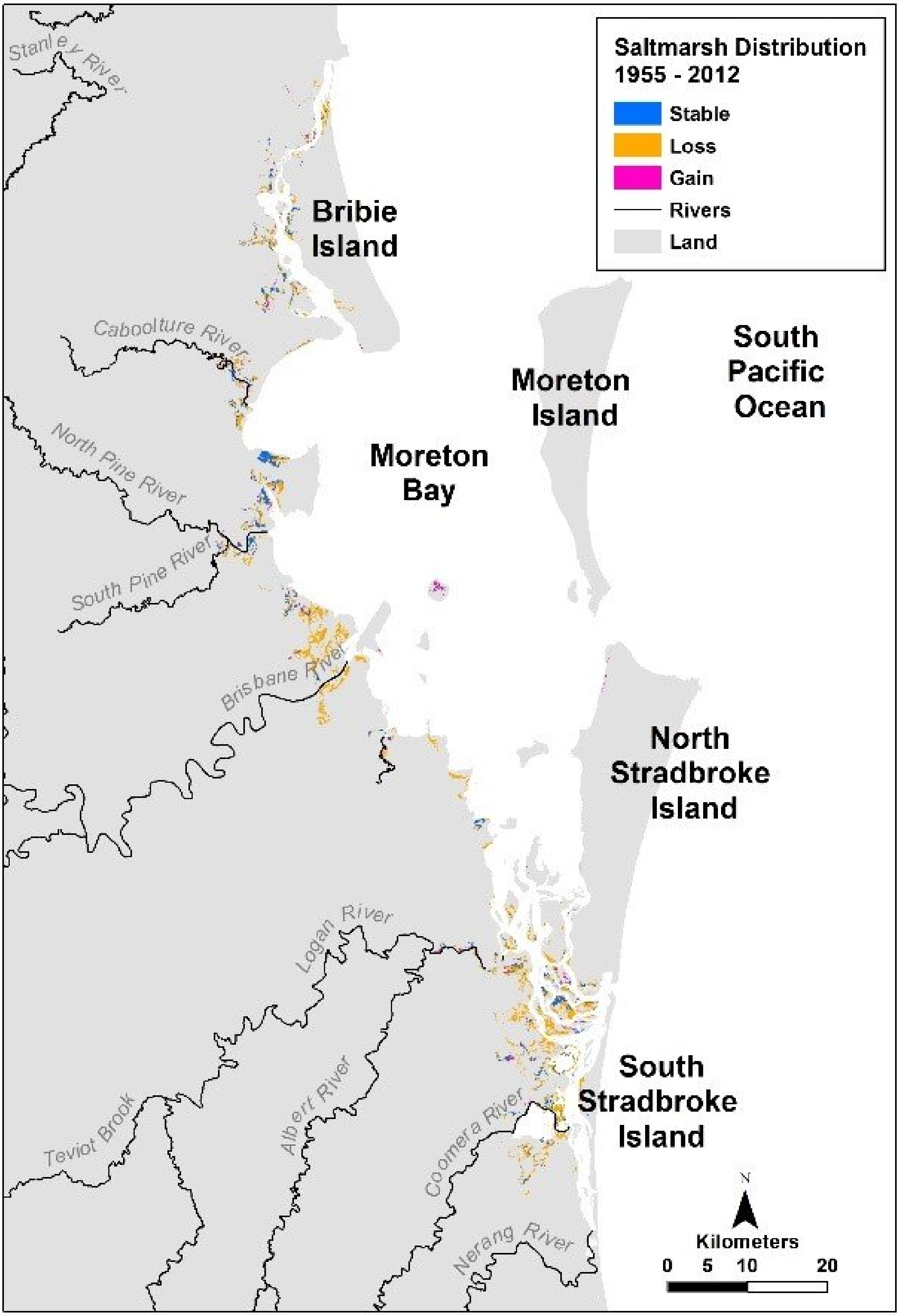
Saltmarsh Distribution
1955 - 2012
Stable
Loss
Gain
Rivers
Land
Stanley River
Bribie Island
Caboolture River
North Pine River
South Pine River
Moreton Bay
Moreton Island
South Pacific Ocean
Brisbane River
North Stradbroke Island
Logan River
Albert River
Teviot Brook
Coomera River
South Stradbroke Island
Nerang River
N
Kilometers
0 5 10 20

Figure 2. Loss and gain of saltmarsh communities in the Moreton Bay region. An assessment of saltmarsh areas from 1955 to 2012 (9, 11).

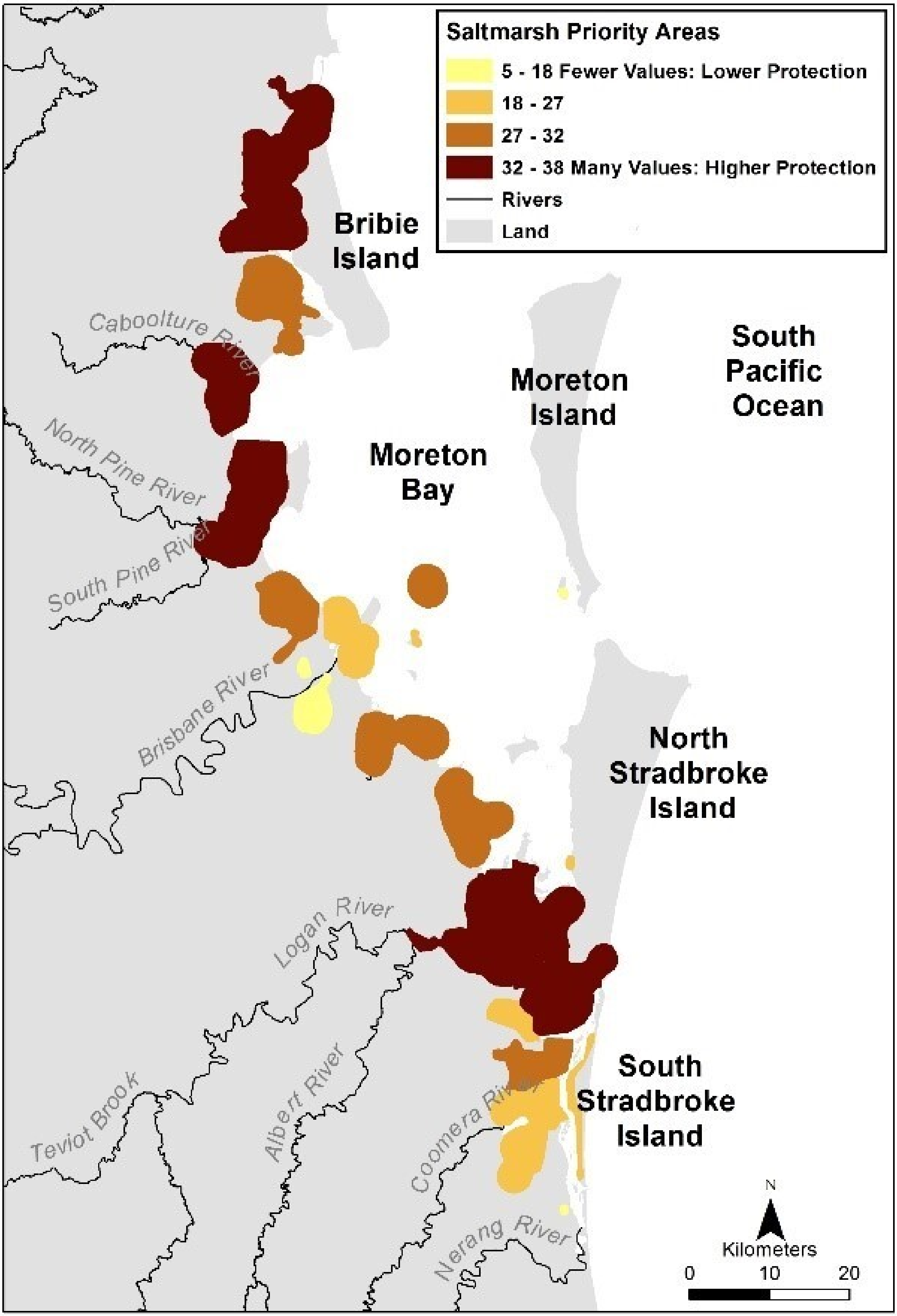
Saltmarsh Priority Areas
5 - 18 Fewer Values: Lower Protection
18 - 27
27 - 32
32 - 38 Many Values: Higher Protection
Rivers
Land
Bribie Island
Caboolture River
North Pine River
South Pine River
Brisbane River
Logan River
Albert River
Teviot Brook
Coomera River
Nerang River
Moreton Bay
Moreton Island
South Pacific Ocean
North Stradbroke Island
South Stradbroke Island
N
Kilometers
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Figure 3a. The saltmarsh communities of Moreton Bay. (a) Saltmarsh priority areas as mapped by (12, 13).

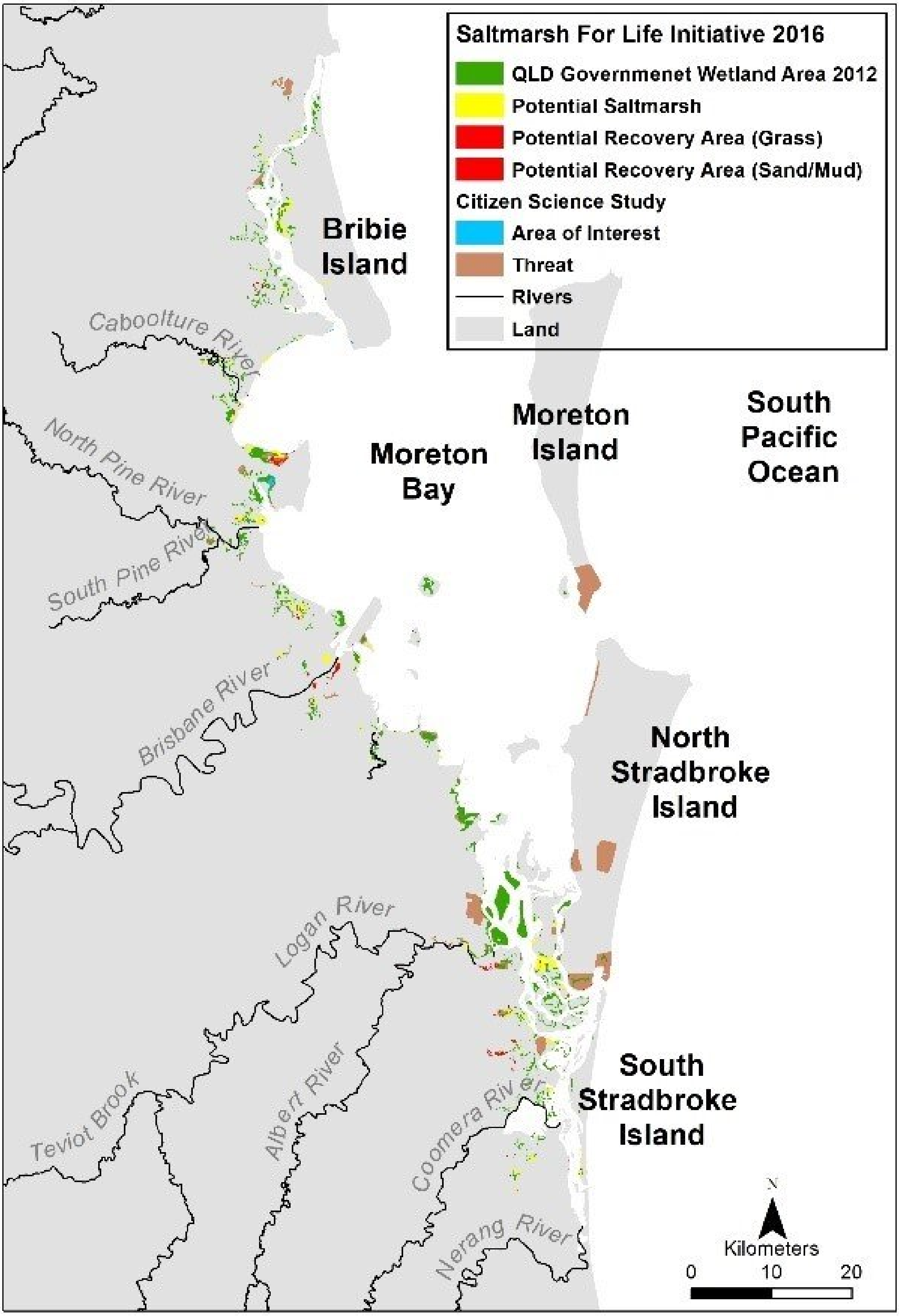
Saltmarsh For Life Initiative 2016
QLD Governmenet Wetland Area 2012
Potential Saltmarsh
Potential Recovery Area (Grass)
Potential Recovery Area (Sand/Mud)
Citizen Science Study
Area of Interest
Threat
Rivers
Land
Bribie Island
Caboolture River
North Pine River
South Pine River
Moreton Bay
Moreton Island
South Pacific Ocean
Brisbane River
North Stradbroke Island
Logan River
Albert River
Teviot Brook
Coomera River
South Stradbroke Island
Nerang River
N
Kilometers
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Figure 3b. Potential saltmarsh recovery areas determined via a desktop study, and citizen science recorded threats to saltmarsh areas, and restoration opportunities (12, 14).

Mangroves

Mangroves are salt-tolerant vascular plants, constrained by mean sea and maximum tide levels, limiting them to the coastal intertidal zone, estuaries and riverine systems (Fig. 1) (15). Mangroves are important habitats for many organisms, as well as acting as barriers that filter pollutants, nutrients and sediment, and providing protection for the mainland against extreme weather events (1, 16, 17). For detailed information regarding mangrove communities in the Moreton Bay catchment refer to Lovelock *et al.* this volume.

Monitoring of the mangrove communities of the Bay has occurred at irregular intervals since it was first comprehensively mapped in 1955 (9). There have been recent site-specific mangrove community studies in the Bay (18), but the most comprehensive analysis of the Bay's mangrove environments was performed by the Queensland Herbarium in 2016. It compared mangrove distribution in 1955, 1997 and 2012, using historical aerial photographs and supporting maps (9). It was found that there was a net gain in mangrove communities of 958 ha between 1955 and 2012 (Table 3; Fig. 4).

Table 3. The total Moreton Bay mangrove community (ha) as recorded in the three mapping years (1955, 1997 and 2012) and the net change per study period (adapted from (9)).

	1955	**1997**	**2012**	**Increase 1955-2012**	**Increase 1997-2012**
Total Mangrove Community (ha)	14,273	14,896	15,231	**+4.4%**	**+2.2%**

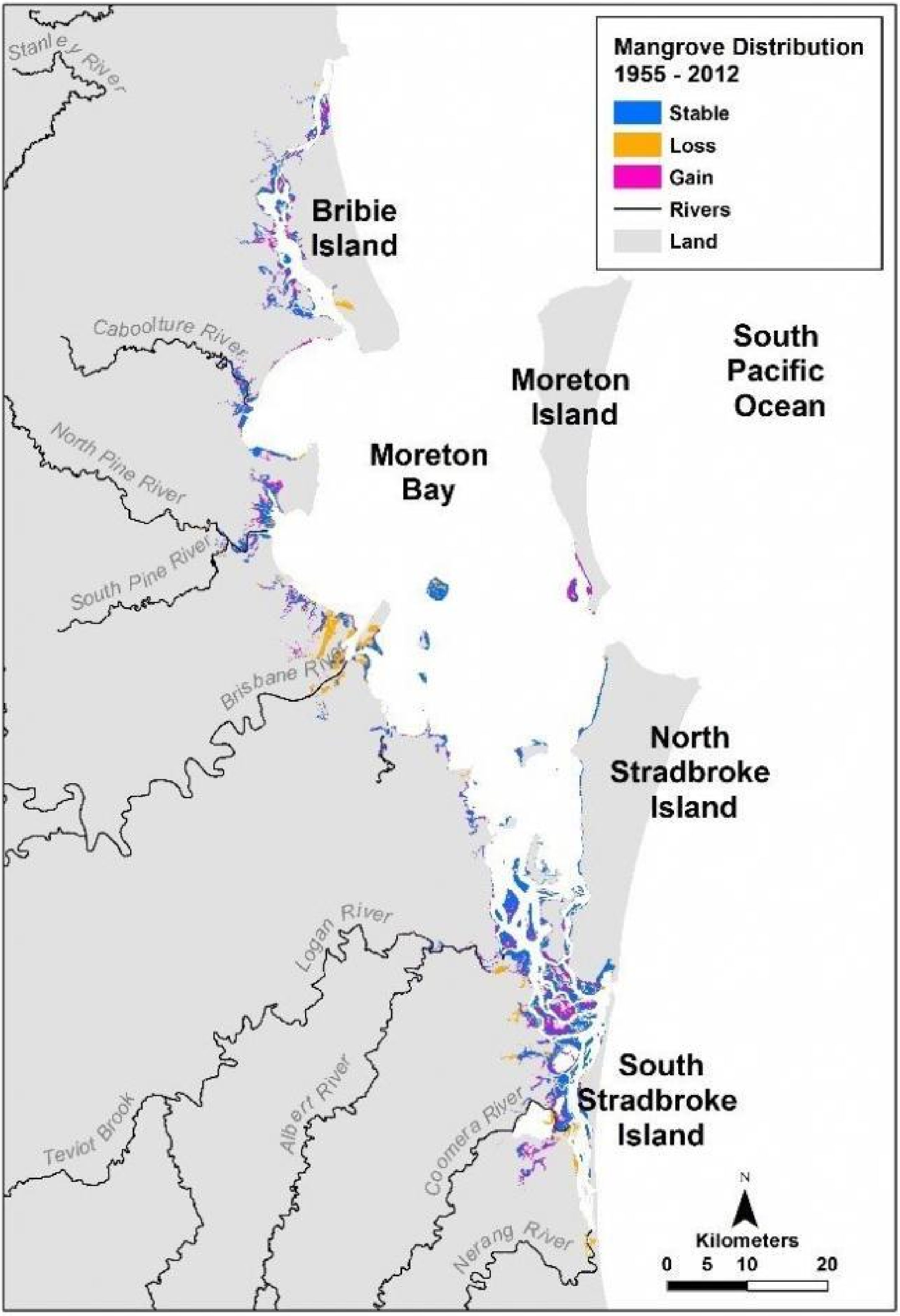


Figure 4. Loss and gain of mangrove communities in the Moreton Bay region. An assessment of mangrove areas from 1955 to 2012 (9, 11).

Of the original 1955 mangrove distribution 77% remained stable (9). The overall net expansion of mangrove areas was primarily attributed to mangrove encroachment into saltmarsh and *Casuarina glauca* communities (3,425 ha), as well as range expansion along the coastline and recruitment on newly formed islands (9). Interestingly, the net rate of mangrove community encroachment into saltmarsh and *Casuarina glauca* environments was greater for 1955-1997 than for 1997-2012 (Table 4) (9).

Encouragingly, the rate of mangrove die-back attributed to anthropogenic causes decreased by 84% (Table 4). This marked decrease strongly correlates to the instigation of more rigorous environmental management practices with declaration of the Moreton Bay Marine Park as a Ramsar wetland in 1993 (19).

As well as changes in extent, marked changes were observed with respect to community structure and floristic composition, however, this was not specific to any one mangrove species. Of note, the area covered by *Avicennia marina* subsp. *australasica* increased during the entire period (1955 – 2012) for both of its 1B(i) and 1B(ii)b community types (1,524 ha and 636 ha respectively), whilst all other mangrove community types decreased (9).

Table 4. Mangrove community expansion (+) and loss (-) in Moreton Bay – the difference in aerial extent between 1955 and 1997, and 1997 and 2012 (adapted from (9)). Expansion/contraction rates are expressed in hectares per year in parentheses.

Mangrove Expansion into Saltmarsh and *Casuarina glauca* communities (ha)	
1955 – 1997	**1997 – 2012**

Saltmarsh	***Casuarina glauca***	**Saltmarsh**	***Casuarina glauca***
2,656	209	535	25
(+ 63.24 ha/yr)	(+ 4.98 ha/yr)	(+ 35.67 ha/yr)	(+ 1.67 ha/yr)

Mangrove Loss(ha)					
1955 – 1997			**1997 – 2012**		
Saltmarsh	***C. glauca***	**Anthropogenic**	**Saltmarsh**	***C. glauca***	**Anthropogenic**
426	132	1,839	133	17	103
(- 10.14 ha/yr)	(- 3.14 ha/yr)	(- 43.79 ha/yr)	(- 8.87 ha/yr)	(- 1.13 ha/yr)	(- 6.87 ha/yr)

Intertidal Flats

Intertidal sand and mud flats dominate the lower intertidal zones of the Bay, lying between the mean high and low tide levels (20). They provide important ecosystem services and have high conservation values. Predominantly devoid of vegetation, these flats support abundant micro-organisms, but also diverse crustaceans, worms and molluscs, important in the diet of wading birds (21). Additionally, they protect the coastline from erosion and the impact of storms, are important nursery habitats and fish feeding grounds, and act as connecting pathways between other environments (21, 22). This is particularly significant when considering the life cycle of numerous marine species, as spawning and juvenile nursery habitats often occur within estuaries and mangroves (4). Additionally, intertidal flats act as broader migratory pathways for ecologically important species such as dugongs, dolphins and turtles and are feeding grounds for migratory wading birds (4).

Environmental conditions within these regions fluctuate, affected by climatic events and anthropogenic factors (23, 24, 25). In fact, tidal currents, duration of aerial exposure, estuarine deposits, wave action and bedform migration result in increased exposure of intertidal flats to radiation, variable temperatures and desiccation, and are major drivers of spatial and temporal changes in the distribution and abundance of intertidal assemblages (20, 23, 26, 27). As such, the benthic assemblages within these environments are often complex communities dominated by deposit, suspension and detritus feeders and predators, with species diversity higher in low energy environments that have shorter periods of subaerial exposure (20, 21).

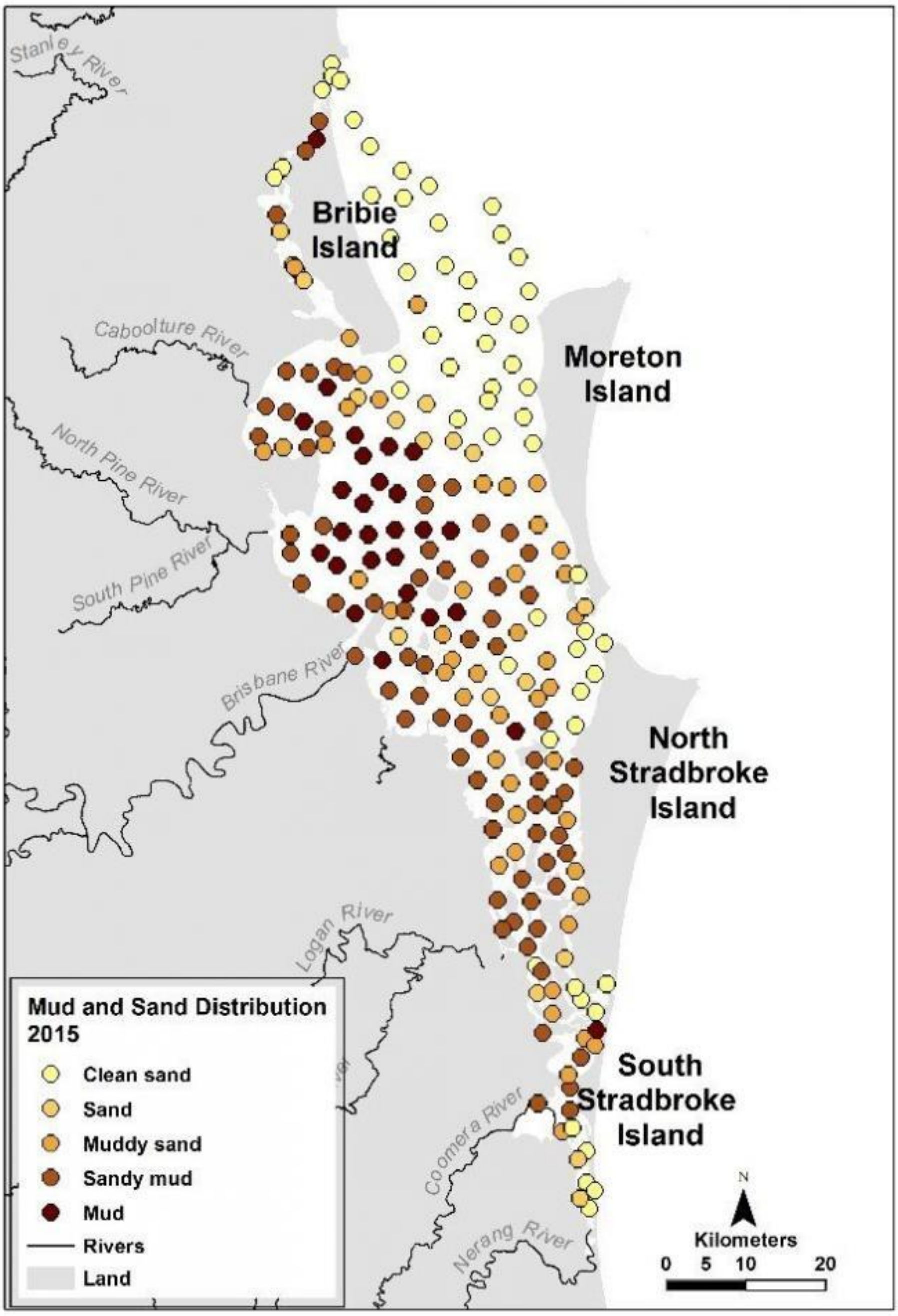


Figure 5. Sand and mud distribution throughout Moreton Bay. An intensive sediment sampling program (April to May 2015) examined the mud and sand distribution of Moreton Bay (25).

A 2017 study mapped the distribution of tidal flats within the Bay (25), and found sandflats and mudflats comprised of a variety of sediment classes with varying total areas: clean sand (569 km^2), sand (160 km^2), muddy sand (424 km^2), sandy mud (684 km^2) and mud (167 km^2) (Fig. 5). Sandflats within the Bay were largely concentrated to the east while mudflats were primarily concentrated to the west (25, 28). This distribution pattern was attributed to the land masses feeding terrigenous sediment into the Bay – those areas near the mainland were dominated by mud, whilst near barrier islands they were dominated by sand. Additionally, intertidal flat composition is influenced by the Bay's tidal currents, which are stronger on the eastern side, flushing out deposited sediment and creating tidal deltas at the Bay's ocean entrances (28).

Historically, the distribution of mudflats within the Bay has been more restricted (28), however, the 2017 study contrasted the distribution of tidal flats within the Bay between 1970 and 2015, to determine the impact of extreme weather events on mud deposition and fine particle suspension (25). The study revealed an increase in mudflat extent of more than 50% in the past 30 years, with mudflats now covering 860 km^2 of the Bay (25, 28). This dramatic change in distribution can be largely attributed to major weather events, including the 1974, 2011 and 2013 floods (29, 30) increasing mud deposition and fine particle suspension. In addition to increased fluvial mud inputs, wind-driven wave formation is responsible for sediment suspension and distribution in shallow waters during such events (31). Thus, extreme weather events, in conjunction with historical and ongoing anthropogenic degradation of the quality of Moreton Bay's catchment, coastal and stream networks (32), have collectively increased sediment loading within the Bay.

Seagrass

Seagrasses are marine angiosperms that form meadows in inter- and sub-tidal areas of Moreton Bay. These meadows are important for biodiversity, fish and crustacean habitats, coastal protection, and carbon stocks (33). As is the case for mangroves and saltmarshes, these habitats are impacted by both anthropogenic activities and natural processes (34). For a detailed discussion on the seagrasses of Moreton Bay refer to Maxwell *et al.* this volume.

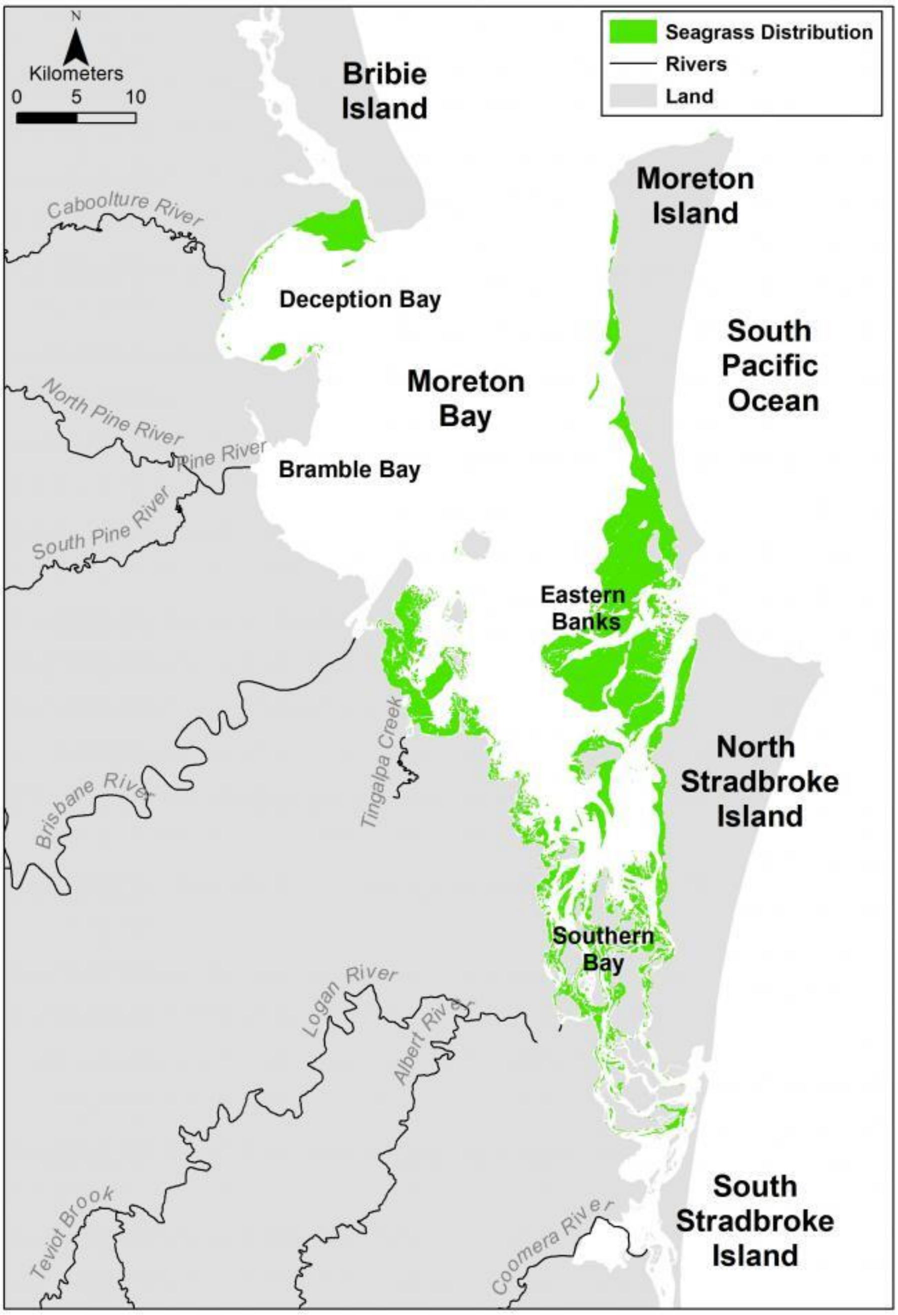


Figure 6. Moreton Bay's seagrass meadows (adapted from (35)).

The extent of seagrass in Moreton Bay has been monitored via many ad-hoc surveying exercises since the mid-1970s, but it was not until the advent of remote sensing methods that the broad scale extent and composition of seagrass communities was studied in a systematic and repeatable manner (35).

The Eastern Banks is the largest continuous seagrass community in the Bay, and sits nestled between Moreton and North Stradbroke Islands (Fig. 6). Here the seagrass meadows consist of six species: *Halophila ovalis, Halodule uninervis, Halophila* *spinulosa, Syringodium isoetifolium, Zostera muelleri* (dominant), and *Cymodocea rotundata* (36). Although these seagrass beds are dynamic, showing large changes in extent on both a monthly and annual time scale, from 1988 to 2010, the overall extent of the Eastern Banks seagrass meadows was shown to have been relatively stable (37). From a time-series of seagrass cover maps, it was shown that although the total area of seagrass meadows on the Eastern Banks remained mostly unchanged (not shown), seagrass cover trended towards lower cover levels (Fig. 7)(37).

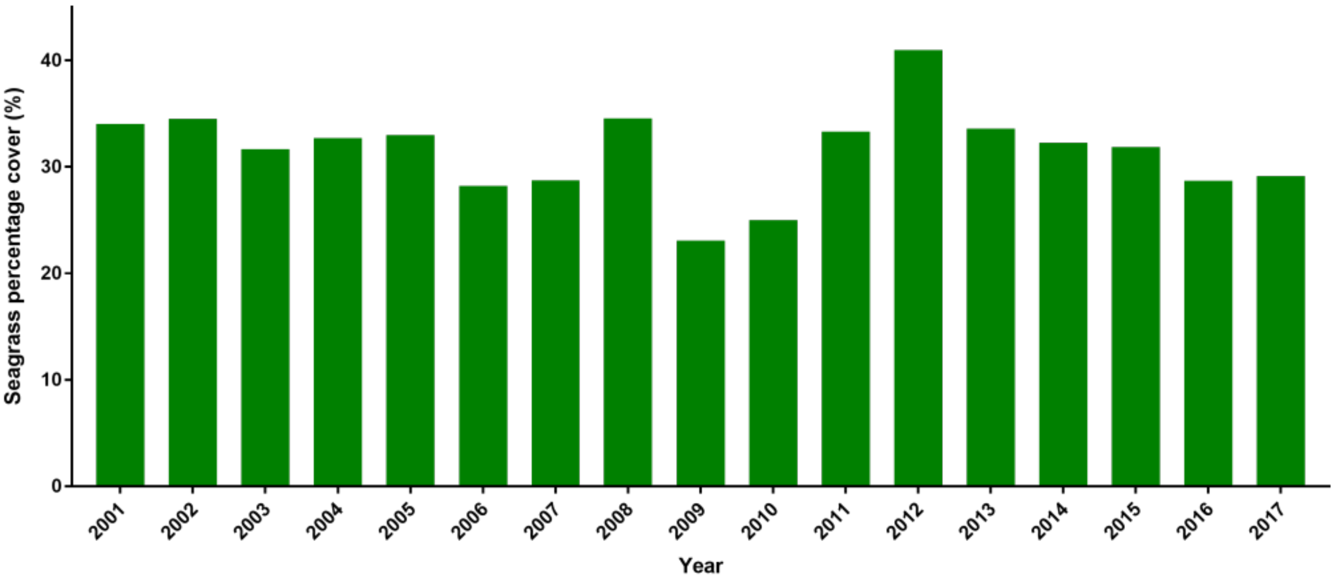


Figure 7. Change in area (ha)l of seagrass across the Eastern Banks. A generally decreasing trend is observed for mid to high level seagrass cover (bright green and dark green respectively), whilst the extent of low or no cover remains relatively stable (light green and grey respectively)(reproduced from (37)).

The non-contiguous seagrass meadows of western Morton Bay are monitored at 28 sites by Wildlife Queensland Coastal Citizen Science (WQCCS). Here seagrass communities are less diverse than in the east, consisting of *Zostera muelleri* subsp. *capricorni* (dominant)(38, 39), *Halophila ovalis* and *Halophila spinulosa.*

Seagrass is absent to sparse in several western embayments, a result of seagrass loss that occurred in historical times. The undocumented total loss of seagrass in Bramble Bay (Fig. 6) is believed to have occurred prior to the 1980s (38), whilst a 2,000 ha loss was calculated from 1987 to 1998 for southern Deception Bay following a flood event (Fig. 6), and seagrass loss in the southern Bay islands has been estimated to be 800 ha (40, 41). Since then, however, there have been no recorded losses of large areas of seagrass in the western Bay, even following two major flood events (2011 and 2013). Baltais (39) has reported the overall cover of western Bay intertidal seagrass has been stable since 2001 (Fig. 8), which in Pumicestone Passage has been reported since the early 1970s (42). Seagrasses are impacted by many factors including changes in salinity (43), epiphyte cover (44), disease (45), pollution (46), and poor water clarity (40). However, in areas where water clarity has improved, such as Deception Bay (12), seagrass is recovering (39, 47).

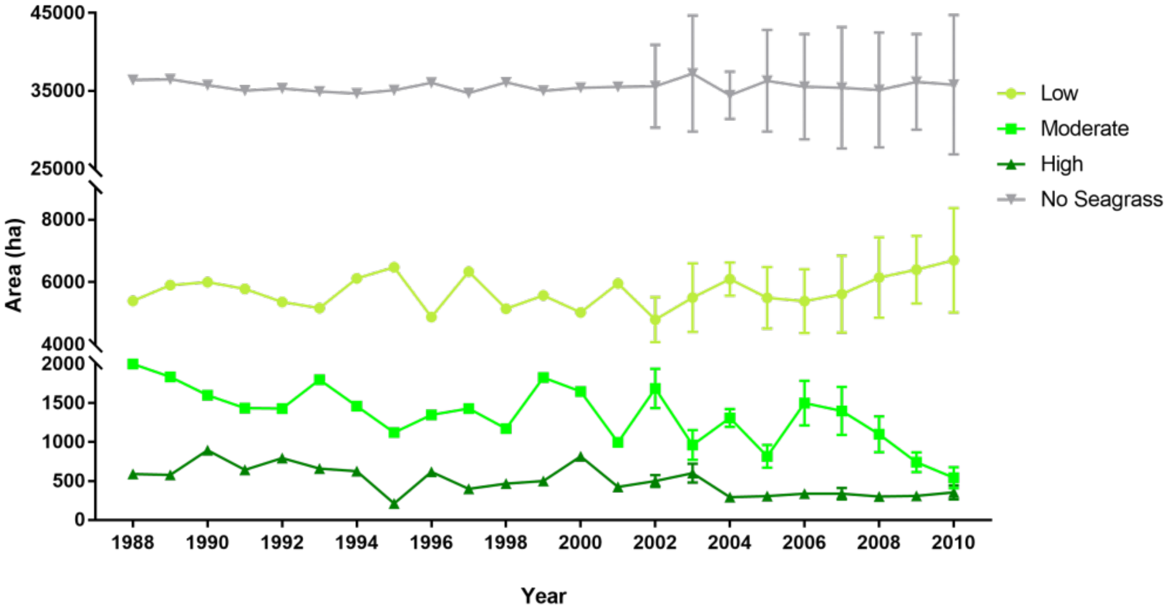


Figure 8. Total average intertidal seagrass percentage cover in the western region of Moreton Bay derived from data acquired at established survey sites. Seagrass recovery data at Deception Bay were not included as those were determined through remote sensing studies (39).

Port development and bait worming are human impacts that cause either localised seagrass loss or a reduction in seagrass cover (48). The Seagrass Monitoring Program (SMP) concluded that there has been a trend of slight expansion of seagrass at the Fisherman Islands port development in Moreton Bay, driven by seagrass expansion into deeper waters (49). However, in contrast, WQCCS has reported a 45-54% decrease in seagrass cover in areas subject to bait worming (Table 5), an activity that has increased by 30.5 ha from 2009 to 2013.

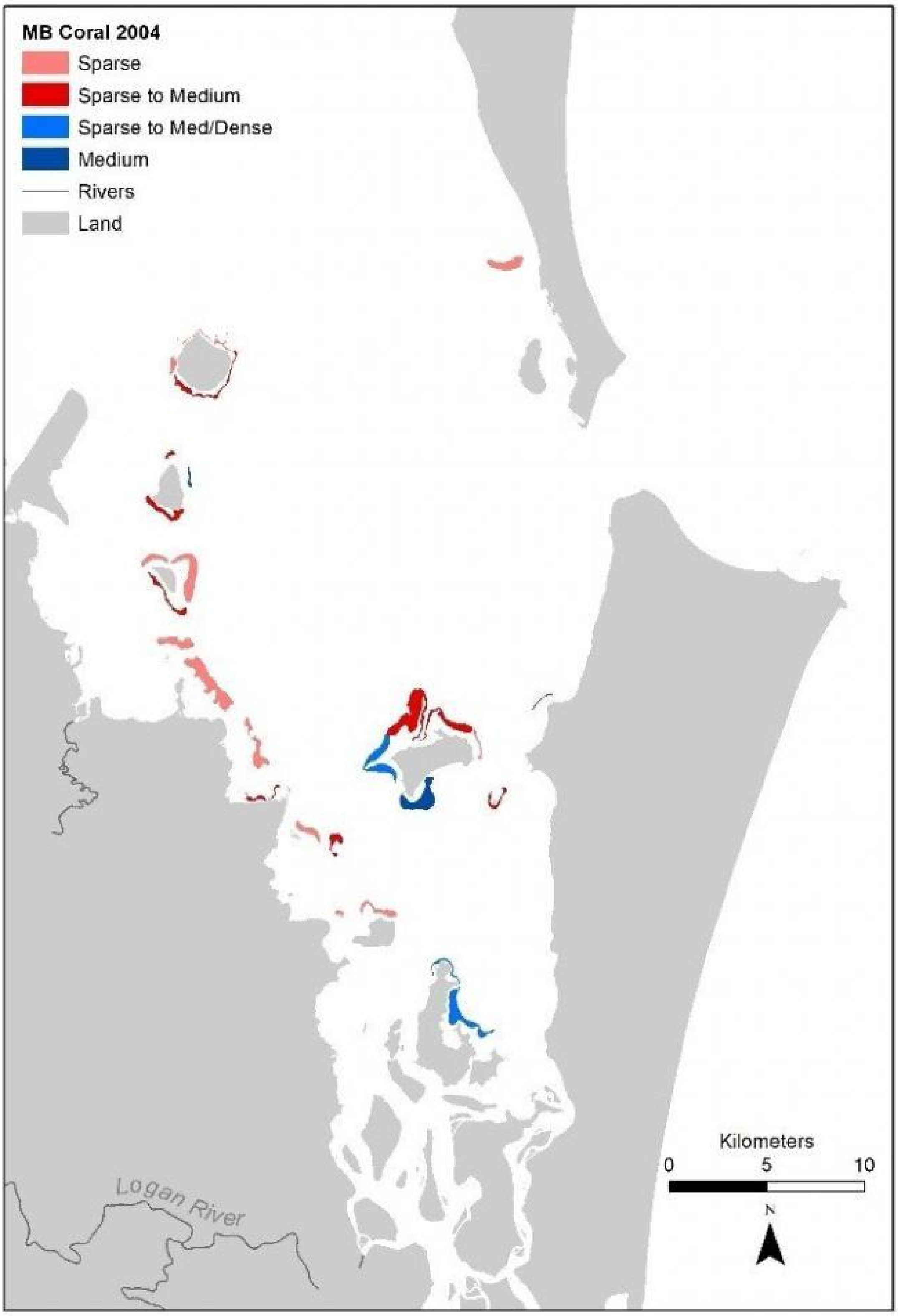
Table 5. Bait worming activity in western Moreton Bay from 2009 to 2013 (39). Site increases and the overall increase are indicated (ha).

Bait Worming Activity (ha)			
Site	**2009/2010**	**2013**	**Increase**
Manly	0	0.9628	**100%**
Snipe Island	0	2.056	**100%**
Lota/Thornside	7.065	34.474	**488%**
Total	**7.065**	**37.492**	**30.427 ha**

Coral Reefs

The coral reefs of Moreton Bay encompass areas of inshore reefs in central Moreton Bay in shallow water with a muddy substrate (around Mud, St. Helena, Green, King, Goat, Macleay, Russell and Peel Islands as well as some fringing areas) (50). For a detailed review of the corals of Moreton Bay refer to Pandolfi *et al.* this volume; for a review of the importance of Citizen Science for monitoring of Moreton Bay reefs refer to Roelfsema *et al.* this volume.

Due to the sensitivity of coral to environmental parameters and its ecological importance, the extent and condition of hard coral is identified as one of the regional metrics for south east Queensland (SEQ) Natural Resource Management targets (51). Moreton Bay coral extent maps tend to be updated irregularly, therefore comparisons between data sets are seldom possible. The Queensland Government created a baseline map of coral in Moreton Bay for 2004, from Comboyuro Point to Jacobs Well, as part of the Ecosystem Health Monitoring Program (Fig. 9a; (52)). The next map published was produced in 2016 following implementation of a collaborative citizen science project to re-map key coral habitat areas in central Moreton Bay (Fig. 9b)(53).


MB Coral 2004
Sparse
Sparse to Medium
Sparse to Med/Dense
Medium
Rivers
Land
Logan River
Kilometers
0
5
10
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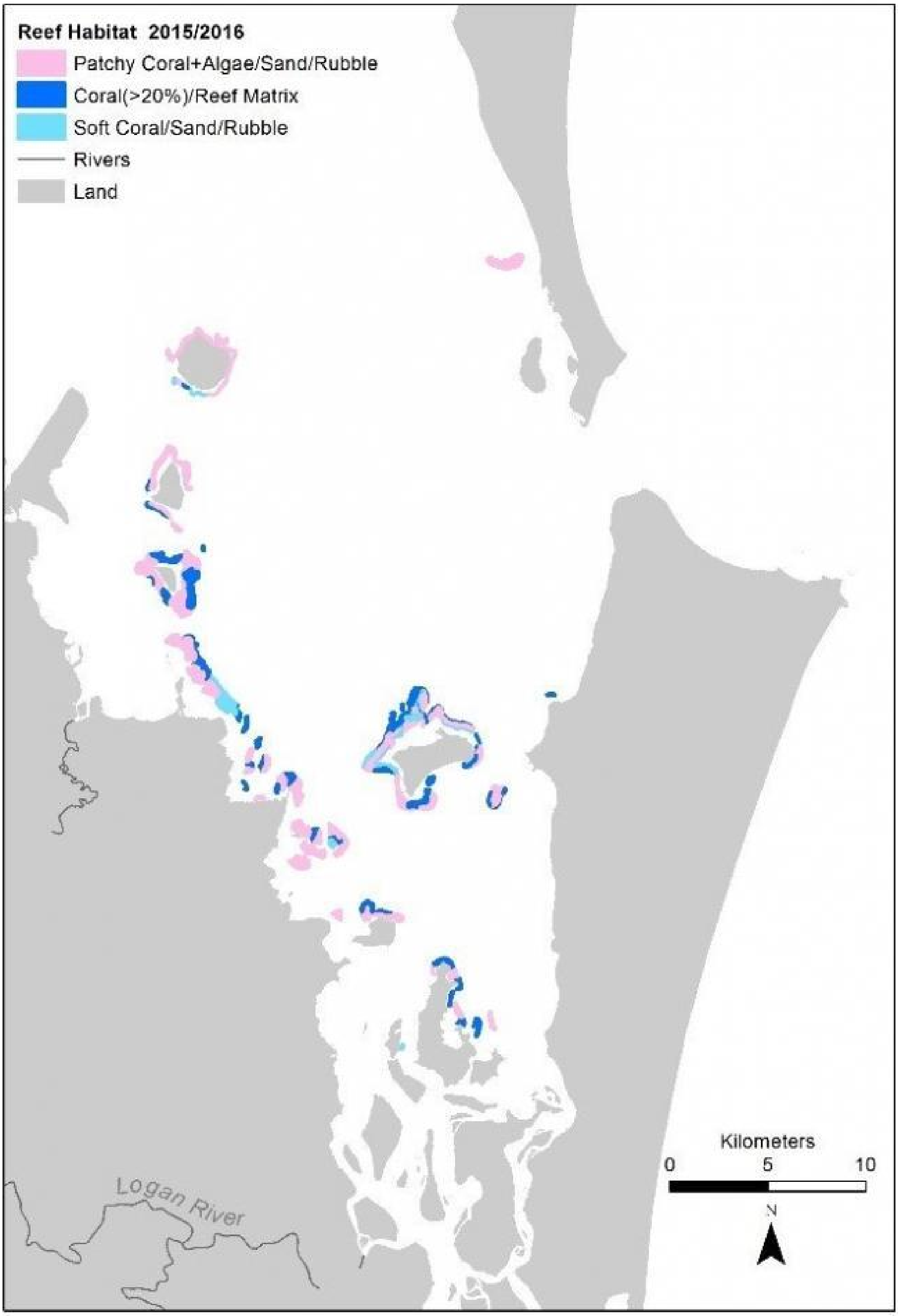

Figure 9. Coral habitat in Moreton Bay. (a) Location of coral in Moreton Bay mapped as

part of the Ecosystem Health Monitoring Program, State of Queensland, 2004 (52). (b) Inshore Moreton Bay reef habitat areas, derived through manual digitisation guided by 2014 ZY-3 satellite imagery (5 m x 5 m pixel), overlaid with spot-check field data collected in 2015 and 2016 (53).

The largest reef area was identified around Peel Island in both studies, with smaller fringing reefs occurring around the islands of inshore Moreton Bay, and the coastline between Wellington Point and Coochiemudlo Island. Unfortunately, as the refined habitat assessment of 2016 utilised high resolution satellite imagery, more advanced mapping software and increased field knowledge, no direct comparison of specific habitats can be made with the 2004 baseline map. However, an estimate of the extent of areas containing coral can be made from each of the maps (Table 6). In 2004, 1,724.7 ha of coral were mapped, whilst in 2015/2016, a total of 1,627.5 ha of areas containing hard coral and an additional 192.5 ha of areas containing soft coral were mapped (1,820 ha combined total).

The 2016 study does not necessarily reflect an increase in coral cover in Moreton Bay as the higher resolution of the mapping product has provided more accurate identification of reef areas and as such should be viewed as a more accurate baseline quantification of the extent of coral cover.

Table 6: Extent of coral habitats mapped in 2004 (52) and in 2016 (53). For the 2004 study, coral was recorded as the density observed at each field site (52). Due to the availability of higher resolution satellite imagery for the 2016 study, more complex categories were used to record benthic cover at each field site. Each of these categories contained at least some coral (53).

Year	Coral Habitat	Area (ha)
2004	Sparse	742.4
	Sparse to Medium	555.5
	Medium	150.3
	Sparse to Med/Dense	276.4
2015/2016	Soft Coral/Sand/Rubble	192.5
	Patchy Coral + Algae/Sand/Rubble	1091.0
	Coral(>20%)/Reef Matrix	536.5

Conclusion

This analysis of the historical and current range of wetland communities highlights the threats that climate change, sea-level rise and anthropogenic stressors pose to wetland communities. Sadly, many of the wetland areas of Moreton Bay are in decline. Human activity has resulted in marked decreases in the areal extent of all wetland communities, reiterating the threat that these changes have and will continue to have, particularly on the more vulnerable wetland communities such as saltmarsh.

For instance, increasing sediment loading decreases ecosystem health by increasing siltation which decreases water clarity, restricting penetration of sunlight, and decreasing photosynthesis (54). This increased siltation smothers the benthos and creates a shift from benthic to pelagic productivity (55, 56, 57). Additionally, sediment loading is accompanied by phosphorus and nitrogen, which can lead to increased risk of cyanobacteria and algal blooms within the Bay (58, 59), thus exacerbating the decrease in water quality.

As the Bay's wetland areas are important socially, culturally, ecologically and economically, it is vital that we maintain a comprehensive understanding of the health of these systems, their ability to respond to disturbances, how their extent changes with time, and develop models to predict how they are likely to fare in the future under various management scenarios.