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Monitoring estuarine wetlands within the Reef 2050 Integrated Monitoring and Reporting Program:

Final Report of the Wetlands Expert Group

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The Great Barrier Reef Marine Park Authority acknowledges the continuing sea country management and custodianship of the Great Barrier Reef by Aboriginal and Torres Strait Islander Traditional Owners whose rich cultures, heritage values, enduring connections and shared efforts protect the Reef for future generations.

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Shortened Forms

ABS	Australian Bureau of Statistics
BIEEC	Boyne Island Environmental Education Centre
BM	Burnett-Mary
BOM	Bureau of Meteorology
CATI	computer-assisted telephone interviewing
CRC	Cairns Regional Council
CCRC	Cassowary Coast Regional Council
CPUE	Catch per unit effort
CQU	Central Queensland University
CQAMP	Central Queensland Ambient Monitoring Program
CY	Cape York
DAF	Queensland Government Department of Agriculture and Fisheries
DES	Queensland Government Department of Environment and Science
DSC	Douglas Shire Council
EB	Eco Barge
EPBC Act	Australian Government Environment Protection Biodiversity Conservation Act
F	Fitzroy
FRDC	Fisheries Research Development Corporation
The Reef	The Great Barrier Reef
The Authority	The Authority
World Heritage Area	Great Barrier Reef World Heritage Area
GHHP	Gladstone Healthy Harbour Partnership
GPC	Gladstone Ports Corporation
HEV	high ecological value
JCU	James Cook University
MMP	Marine Monitoring Program
msPAF	multi-substance Potentially Affected Fraction
MW	Mackay Whitsunday
MWHR2RP	Mackay Whitsunday Healthy Rivers to Reef Partnership

N/A	not applicable
NRM	Natural Resource Management
NQBP	North Queensland Bulk Ports Corporation
OCR	Ocean and Coast Research
OGBR	Office of the Great Barrier Reef
PCIMP	Port Curtis Integrated Monitoring Program
PN	Ports North
PoT	Port of Townsville
PASS	potential acid sulfate soils
P2R	Paddock to Reef
OUV	Outstanding Universal Value
QPWS	Qld Parks and Wildlife Service
Reef 2050 Plan	Reef 2050 Long-Term Sustainability Plan
RIMReP	Reef 2050 Integrated Monitoring and Reporting Program
SCU	Southern Cross University
SLATS	State-wide Landcover and Trees Study
TBC	to be confirmed
TBD	to be determined
TBF	Tangaroa Blue Foundation
UNSW	University of New South Wales
WT	Wet Tropics
WTHWP	Wet Tropics Healthy Waterways Partnership

Executive Summary

The Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) has identified a number of outcomes, objectives and targets required to ensure the Great Barrier Reef (the Reef) continues to improve on its outstanding universal value every decade between now and 2050 to be a natural wonder for each successive generation to come. To know if their actions are working to achieve these ends, managers require quality information which must be based on effective monitoring of a variety of important ecosystems and species, including estuarine systems. While there are many monitoring programs operating in the Great Barrier Reef World Heritage Area (World Heritage Area), changes and improvements are required to address management needs. The challenge is to achieve the best result from these programs while maintaining the commitments required to keep them operating effectively and efficiently and yet be flexible enough to take advantage of improvements in our knowledge base and technological advancements.

One key reporting requirement for management of the World Heritage Area is the Outlook Report, produced every 5 years, which documents the status and trend of a number of key attributes that underpin the outstanding universal value of the World Heritage Area. These attributes include a number of important components of estuarine systems including mangrove, saltmarsh and seagrass communities, and iconic species that rely on these systems such as marine turtles, dugongs, saltwater crocodiles and inshore dolphins. Estuaries are also the primary habitat for a range of threatened and vulnerable species including three species of sawfish, two species of inshore dolphins and thread fin salmon as well as endangered terrestrial species like the false water rat and the yellow chat. The Outlook Report also documents status and trend of estuarine-dependent attributes that, while being important biological components of ecosystems, also underpin the community and economic benefits provided by the World Heritage Area. This includes a range of commercially and recreationally important fish, shark and crustacean species that contribute to the enormous economic value provided by the World Heritage Area to the Australian community. Though the Outlook Report reports on components of estuaries, confidence in the analysis has been generally low.

There are also significant gaps in the monitoring of high value estuarine wetlands. There are two internationally recognised, largely estuarine wetlands in and adjacent to the World Heritage Area. These are also two of the largest iconic wetlands systems in eastern Australia, namely the Bowling Green Bay Ramsar wetlands and the Shoalwater/Corio Bay Ramsar wetlands. Estuarine monitoring is almost completely absent from these wetlands though some water quality monitoring in the Catchments Loads Monitoring Program (CLMP) does happen upstream of the Bowling Green Bay site. As such there is no understanding of present land use discharge impacts on these high value systems.

Unfortunately, even where they exist, few of the programs monitoring estuaries have been in place and continuous for any length of time and those that have are generally limited in both their spatial and temporal coverage.

These are critical issues for monitoring programs in an area the size of the World Heritage Area. This is an area which experiences a broad range of climatic variation from wet tropical through dry tropical to sub-tropical weather patterns. These weather patterns are also in flux with many significant changes predicted including sea level rise, changes to major weather event frequency (i.e. cyclones) and significant temperature increases (both air and seawater) as a result of climate change.

Indicators need to link to management actions and tools to allow for assessment of management effectiveness at a range of scales. Estuaries are of considerable value in the context of both community benefits and economic benefits. Incorporating indicators that link to these themes is important to achieve a truly integrated Reef-wide monitoring program.

Estuarine systems are unique, placed as they are in the boundary between marine and terrestrial systems. They provide a buffering role between the ebb and flow of fresh water (from the land) and marine water from the sea (tides and storm surges). These daily, monthly, seasonal and annual cycles of water flow make estuaries the most dynamic environment in the World Heritage Area, posing some significant questions to our capacity to understand whether changes to the estuarine systems are being driven by human actions or climatic factors and how best to manage them. These patterns of water movement are critical to life in estuaries. They provide breeding, feeding and migration habitats for myriad species at a variety of times in their lifecycles. Changing even seemingly small elements can have significant implications for estuarine species.

Estuarine systems are also hugely important to people. They are arguably the locations where most users of the World Heritage Area spend the majority of their time on the coast. They are important for recreational and commercial activities and play an invaluable role in protecting human infrastructure from the vagaries of weather and the coast from damaging erosion forces. They are however susceptible to damage from cyclones and severe dry and hot conditions, both being predicted to be more severe and more frequent respectively as an outcome of present climate change trends. This buffering role of estuarine systems might also be affected as the rising sea level squeezes estuarine systems against the developed landscape behind them. Monitoring the changes in estuarine communities could provide an improved understanding of the implications of these ongoing climate-induced changes.

Historically there has been significant human development in and adjacent to estuarine areas, especially around major river mouths. All major population centres in the World Heritage Area catchment are based close to the coast around major rivers, as are a number of the major export and regional service ports. The modification of estuarine systems increases southwards from Port Douglas with modification to freshwater flows from bunds, roads, agriculture, aquaculture and urban expansion. Change to flows is also created by dams, weirs and poorly designed drainage systems. All these development actions can and have impacted on estuarine areas, increasing pollutant loads on the one side and restricting fish passage on the other. This has implications for the health of plants and animals that live in and breed, feed and migrate through estuaries.

While most of the significant impacts on estuarine extent are historic and there are now relatively strong protection mechanisms in place, the impacts of past actions continue to affect estuarine ecosystem health. Thus, estuarine monitoring programs must not only continue to monitor the extent of remaining ecosystems to ensure targets are being met, but they must also incorporate multiple indicators of ecosystem health with some level of independence between indicators. This is necessary to support reporting on the condition and trend in ecosystem health used in the Outlook Report. Ideally this could also include species populations reliant on healthy estuarine systems including vulnerable or threatened species where possible. The monitoring program also needs to include indicators which represent pressures on, or drivers of change to estuarine systems.

The recent development of annual Report Cards for the Wet Tropics and Mackay Whitsunday NRM Regions has led to the development of methods and associated indicators, with input from relevant experts, for addressing the impacts of structures that affect fish passage between marine and freshwater systems. These indicators should be supported for implementation across all the regions subject to similar pressures. This work seeks to capture the impacts on fish diversity in both estuarine and freshwater systems but also to understand improvements in diversity of fish populations as a consequence of barriers being removed over time to achieve the outcomes of the Reef 2050 Plan. This is also a potential community and economic benefit measure if these actions flow through to improved fishing outcomes.

Estuarine monitoring programs should cover the full extent of key components of estuarine systems, mangrove, seagrass and saltmarsh (including saltpan) communities, and align monitoring effort and location with other relevant programs such as catchment and marine water quality monitoring, and biodiversity/fishery/economic benefit monitoring programs. Monitoring integration across these programs can be achieved by locating monitoring efforts together and/or identifying complementary indicators across different monitoring programs.

Some existing programs, such as DES's estuarine ambient water quality monitoring program should be extended to cover all six NRM regions (four are covered at present) and expanded to include pesticides and certain soluble metal species. The expansion should include data collection specifically in the wet season and for event monitoring. Consideration should be given to using continuous monitoring equipment, especially in more remote parts to capture wet season rainfall events when access to sites is difficult. This would be the most cost-effective way to improve the applicability of the estuarine program to management needs.

Mangrove and saltmarsh monitoring is presently undertaken as part of the Queensland Herbarium vegetation mapping program which is updated every few years and reported, in part, under the wetlands reporting element in the Paddock to Reef program. This monitoring provides a measure of extent of estuarine systems and should be supported by a program such as that developed by James Cook University (JCU) which uses satellite imagery to assess health of mangrove species based on leaf reflectance. This mangrove health index assessment should be supported by other independent indicators of estuarine health such as bio-indicators including fish or crab populations estimated regularly through monitoring as part of the Queensland fishery monitoring programs or developed specifically to support the estuarine monitoring program. Mud crab monitoring took place in Queensland during the 2000s (halted in 2009) so some baseline exists that could be drawn on; modifying that previous program to incorporate a tag and release element would provide a measure of both population (and harvestable stock) and ecosystem health. Monitoring in this way supports several Reef 2050 Plan outcomes at the same time.

The recommendations for improved estuarine monitoring are summarised below:

1. The present ambient estuarine water quality monitoring program(s) should be expanded to include;
    a. A more comprehensive coverage of estuaries along the Reef coast including high value systems e.g. Shoalwater and Corio Bay Ramsar site;
    b. The program should include increased event sampling using continuous monitoring technologies; and
    c. The data collection should be expanded to include a number of other contaminants or water quality components including pesticides, heavy metals and pH.
2. Estuarine ecosystem extent and condition monitoring should be expanded to include:
    a. Regular reporting of mangrove and saltmarsh (including saltpan) extent should be continued as part of Queensland's vegetation management arrangements but enhanced through;
        i. The addition of mangrove health assessments (as developed through Gladstone Healthy Harbour Partnership (GHHP)) should be undertaken in all NRM regions and where possible to complement other monitoring efforts, especially water quality monitoring; and
        ii. Mud crab monitoring should be reinstated and enhanced with demographic assessment elements and mark, capture and release methodologies (as per published Fisheries Research Development Corporation (FRDC) research methodologies).

Consideration also needs to be given to improving our understanding of estuaries by focusing research efforts (in association with monitoring) on the key indicators of the health of elements of the estuarine ecosystem not yet covered. This includes better understanding of the role that saltmarshes and saltpans play in the productivity of estuarine systems and their role in carbon sequestration. There is also a need to expand the number of indicators of estuarine ecosystem health to ensure a more robust understanding of how pressures are affecting the systems. This could be achieved through support for a pilot of grapsid crab monitoring at a regional level. This would support development of multiple lines of evidence and an improved understanding of estuarine health indicators.

There are a number of additional indicators of estuarine health that are, or should be collected in estuarine areas as part of other RIMReP monitoring programs. For further information on these refer to Table 7.

Effective integration across these varied monitoring programs requires a number of actions. Firstly, some effort needs to be made to understand just where in the landscape/seascape monitoring is occurring. This information will present opportunities to identify and use complementary indicators across the relevant programs and the estuarine monitoring program. This will support improved integration and synthesis within and between the programs.

This rapid review of potential elements for an effective and efficient estuarine monitoring program has identified a number of programs that should be supported with the introduction of other elements to improve both spatial and temporal coverage. There is also the opportunity to include some emerging technologies to support these requirements. Some programs (e.g. mud crab monitoring program) could be reinstated and modified to provide a much more robust assessment of both ecosystem health and stock assessment for harvesting.

This desktop assessment of present estuarine monitoring programs has been undertaken in a very short time. It would benefit from some broader input from informed stakeholders. Thus, we recommend that a workshop of experts is convened to confirm which estuaries within each NRM region should be monitored, the priority ambient monitoring indicators based on an assessment of risk for each estuary and drawing on Tables 2 and 7 in this report, appropriate event based monitoring, and critical links with proposed RIMReP programs.

1. Background and design considerations

The following section summarises the information needs that should inform the design requirements for monitoring the estuarine wetlands of the Great Barrier Reef World Heritage Area (World Heritage Area). For the purpose of this report the term “estuarine wetlands” is used to encompass a range of estuarine habitats including saltmarshes, saltpans, mangroves, seagrass meadows as well as bed, bank and water column of the tidal reaches of coastal rivers and creeks.

1.1 Objectives of RIMReP

The Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan) provides an overarching strategy for managing the Great Barrier Reef (the Reef). It contains actions, targets, objectives and outcomes to address threats and protect and improve the Reef’s health and resilience, while allowing ecologically sustainable use. The Reef 2050 Plan has been developed in consultation with partners, including Traditional Owners and the resource sector including ports, fishing and agriculture, as well as local government, research and conservation sectors.

A key component of the Reef 2050 Plan is the establishment of the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP). The program will provide a comprehensive and up-to-date understanding of the Reef —the values and processes that support it and the threats that affect it. This knowledge is fundamental to informing actions required to protect and improve the Reef’s condition and to drive resilience-based management.

There are currently over 90 monitoring programs operating in the World Heritage Area and adjacent catchment. These programs have been designed for a variety of purposes and operate at a variety of spatial and temporal scales. The comprehensive strategic assessments of the World Heritage Area and adjacent coastal zone —both of which formed the basis for the Reef 2050 Plan —identified the need to ensure existing monitoring programs align with each other and with management objectives. RIMReP will fulfil this need.

RIMReP will provide information across the seven themes that make up the Reef 2050 Plan Outcomes Framework. The themes are ecosystem health; biodiversity; water quality; heritage; community benefits; economic benefits and governance.

The intent of RIMReP is not to duplicate existing arrangements but to coordinate and integrate existing monitoring, modelling and reporting programs across disciplines. For example, the Reef 2050 Water Quality Improvement Plan underpins the Reef 2050 Plan’s water quality theme and its Paddock to Reef 2050 Integrated Monitoring, Modelling and Reporting Program will form a key part of the new integrated program.

As the driver of resilience-based management under the Reef 2050 Plan, RIMReP’s primary purpose is to enable timely and suitable responses by Reef managers and partners to emerging issues and risks, and enable the evaluation of whether the Reef 2050 Plan is on track to meet its outcomes, objectives and targets.

The RIMReP’s vision is to develop a knowledge system that enables resilience-based management of the Reef and its catchment, and provide managers with a comprehensive understanding of how the Reef 2050 Plan is progressing.

Three goals for the knowledge system are that it is:

- ***Effective*** in enabling the early detection of trends and changes in the Reef’s environment, informing the assessment of threats and risks, and driving resilience-based management.
- ***Efficient*** in enabling management priorities and decisions to be cost effective, transparent, and based on cost-benefit and risk analyses.
- ***Evolving*** based on the findings of Great Barrier Reef Outlook Reports, new technologies, research and priority management and stakeholder needs.

RIMReP will be central to ensuring decisions regarding the protection and management of the Reef are based on the best available science, consistent with the principles of transparency and accountability, and underpinned by a partnership approach.

Figure 1. RIMReP Program Logic.

Each of the three goals has associated development and implementation objectives as well as foundational inputs.

1.2 Information needs for the Great Barrier Reef Outlook Report and other reporting requirements

The Outlook Report documents condition and trend across a broad range of ecosystems and populations and the factors influencing these trends including drivers of change and major issues such as climate change. Vulnerability and risk to these ecosystems and populations from present uses and drivers and the future long-term outlook, with regard to the present management arrangements and tools are also explored.

Estuaries are comprised of, or support, a number of the attributes that contribute to the outstanding universal value (OUV) of the World Heritage Area and these have previously been reported in the Great Barrier Reef Outlook Reports. This includes ecosystems such as mangroves and estuarine seagrass meadows, specific threatened or endangered species reliant on estuarine systems within populations of sharks and rays (three species of sawfish, speartooth shark), dolphins (two inshore species), bony fishes (e.g. thread fin salmon), marine turtles, dugongs and a number of shorebird species (largely migratory). Other components of estuaries (saltmarshes) are reported as part of terrestrial ecosystems that support the health of the Reef.

There has been limited species-specific reporting, including threatened estuarine species in the 2014 Outlook Report[26], is largely because of the lack of reliable or comprehensive information on the individual species' status and trends. Terrestrial species found almost exclusively in estuarine systems (e.g. false water rat) have not been reported in the Outlook Reports in the past. Recent publications, such as the *Great Barrier Reef Marine Park Authority's Biodiversity Conservation Strategy*[27], a number of associated Vulnerability Assessments for Reef ecosystems and species (2011-2017) and *Informing the Outlook for Great Barrier Reef Coastal Ecosystems*[4] have outlined more details on these attributes of estuarine systems and further identified the pressures, vulnerabilities, risks and actions needed to protect their present and future health.

Water quality is also an issue reported specifically in the Outlook Reports but this, in the past, has been based on the broadest context of increased loads generated by catchment agricultural land use activities discharging increasing loads of pollutants into inshore waters. Monitoring has generally been focused on catchment freshwater riverine areas and marine reefal areas with little or no monitoring in estuarine areas. This has changed relatively recently with the development of a number of regional report cards. There have been estuarine water quality monitoring programs in some parts of the World Heritage Area, with some running for many years, but reporting has been infrequent. The scope of these programs is reviewed below.

Management of fish populations and fishery take in estuarine system is important for maintaining healthy food webs. Limiting the interactions between commercial and recreational fishers, and sharks and dolphins is also important as often fishers see them as competitors and so for many years high mortalities were possible when the two interacted. Research in the World Heritage Area has shown that proximity to mangrove systems is one of the most important variables in shark recruitment success for several species. While management of by-catch has improved it has been too late for some species which have had significant population declines in estuarine systems in the World Heritage Area. For example, sawfish populations had disappeared from estuarine areas south of Cairns by the

1990s, largely believed to be as a result of their being a by-catch from gill-netting in estuaries and river mouths. Their decline is clearly recorded in shark net numbers between the 1950's through to the 1990s[9]. The impacts of the loss of these high-level predators in estuarine food webs is unknown.

Climate change is expected to increase the vulnerability of estuarine ecosystems[2]. A key threat is sea level rise. Even with the conservative temperature rises predicted in recent reports the predictions of sea level rise have doubled in the last decade as temperatures continue to rise. These predicted conservative estimates of temperature increases are likely to be exceeded under present trends[5]. Estuarine systems (especially mangroves) provide a protective buffer to even extreme weather events. However, in the developed Reef coast, much of the landward side for estuarine systems is heavily developed (as evidenced by bunding or revetment walls). This means that the landward movement by estuarine systems is already severely constrained, not only by existing human development[4] but also by the present policy environment[6]. Mangroves are likely to migrate into saltflats and saltmarshes as water levels rise severely impacting these ecosystems if they cannot themselves move with the changing sea level. Mangroves have been seen in recent extreme events to be susceptible to severe temperature influences with a major dieback event seen on the Gulf of Carpentaria between 2015-16 following an extensive dry period and unusually high temperatures. This coincided with the major extensive shallow water coral bleaching event in the Reef in 2016[8].

Monitoring needs to develop a better understanding of how effectively management actions are protecting these critical estuarine environments and the 'at-risk' species reliant on them. To do this some key indicators of estuarine ecosystem health need to be identified and monitored. As an example, some grapsid crab species are recognised as keystone species in mangrove communities because of the role they play in aerating the soil and cycling nutrients. Activities and associated pollutants that affect these crabs could cause fundamental changes to mangrove communities[4] and hence changes to their population can affect nutrient cycling thus affecting the health of the systems. Burrow density and presence or absence of species are indicators of changes in mangrove system health.[20] Many studies have also shown that mangrove species are sensitive to heavy metal pollution accumulating in different parts of the plants. [21]

1. 3 Relevant Reef 2050 Long-Term Sustainability Plan targets, objectives and outcomes

A foundational report in the development of RIMREP is Addison et al (2015) [7], *Towards an integrated monitoring program: Identifying indicators and existing monitoring programs to effectively evaluate the Long-Term Sustainability Plan*. This report identified 111 existing environmental monitoring programs relevant to evaluating the Reef 2050 Plan.

Addison et al (2015) determined criteria against which they assessed the ability of the respective environmental monitoring programs to track progress to targets, objectives and outcomes. These criteria included:

<u>Ecosystem Health</u>

- Connectivity: monitoring must occur across > 2 regions (note that this is a very simplistic criterion, and much more work is required to establish what monitoring programs will be able to provide data for meaningful indicators of connectivity in the future).

- Condition: abundance or per cent cover of species or groups of species must be monitored.
- Resilience: monitoring must occur for > 10 years (note that this is a very simplistic criterion, and much more work is required to establish what monitoring programs will be able to provide data for meaningful indicators of resilience in the future).
- Extent: the area of habitat that must be monitored.

Biodiversity

- Current and trend in condition: abundance or per cent cover of species or groups of species (accommodating for different programs that vary greatly in the taxonomic breadth and resolution that they record) in a location must be monitored through time.
- Diversity: multiple species (or genus, family or functional groups) of the same natural value (e.g. multiple species of reef fish) must be monitored.
- Species of conservation concern (habitat availability and condition): The condition of habitat used by species of conservation concern must be monitored.
- Species of conservation concern (incidental bycatch): Bycatch of species of conservation concern must be monitored.
- Species of conservation concern (population size): Abundance of species of conservation concern must be monitored.

Water Quality

- Wetland extent: the area of wetlands must be monitored.
- Wetlands ecological processes and environmental values: ecological processes and values of wetlands must be monitored.
- Chlorophyll a: Chlorophyll a must be monitored.
- TSS: TSS must be monitored.
- Pesticides: Pesticides must be monitored
- Nutrients: Nutrients must be monitored

Table 1 is drawn from Addison et al (2015)[7] and lists the 32 environmental monitoring programs that are either directly monitoring attributes of estuarine wetlands or are likely to include data from estuarine wetlands as well as other Reef habitats and/or species. The table identifies the relevant Reef 2050 Plan target, objective or outcome against which the respective monitoring programs would contribute information.

Few of these monitoring programs are designed to exclusively monitor estuarine wetlands. Instead, the authors of this report consider that all the programs listed are likely to include estuarine wetlands or relevant estuarine located species, however coverage of estuarine wetlands is likely to be patchy, and generally opportunistic.

Table 1. Assessment of environmental monitoring programs that include or take place in estuarine wetlands against Reef 2050 Plan targets, objectives and outcomes.

AIMS ID[a]	Program and organisation	Ecosystem health				Biodiversity						Water Quality					
		Connectivity (EHO2)	*Condition (EHO2; EHO3; EHT5)*	*Resilience (EHO2; EHT5)*	*Wetland extent (EHT3)*	*Current condition (BO4)*	*Trend in condition (BO3; BT5)*	*Diversity (BO5)*	*Species of conservation concern: habitat availability and condition (BO2; BT2)*	*Species of conservation concern: incidental bycatch (BT3)*	*Species of conservation concern: population size (BO2; BO3; BO4; BT4)*	*Wetland extent (WQO1; WQT2)*	*Wetlands ecological processes and environmental values (WQO1; WQT2)*	*Reef Water Quality: Chlorophyll a (WQO2; WQT3; WQT4)*	*Reef Water Quality: TSS (WQO2; WQT3; WQT4)*	*Reef Water Quality: Pesticides (WQO2; WQT3; WQT4)*	*Reef Water Quality: Nutrients (WQO2; WQT3; WQT4)*
10	Dugong Population Monitoring (JCU)										●						
17	Coastal Bird Monitoring (Joint Field Management Program, QPWS & the Authority)					●	●	●									
18	Shorebird monitoring (Qld Wader Study Group)					●	●	●									
19	Eastern Australian Waterbird Survey (UNSW)					●	●	●									
20	Queensland fishery independent surveys of specific species (DAF)[b]					●	●										
21	Queensland biological fishery dependent data collection (commercial and recreational) (DAF)[b]					●	●										
22	Queensland commercial fisheries monitoring (DAF)[b]					●	●										
31	Marine Wildlife Stranding and Mortality (DES)									●							
34	Seagrass Watch (separate to surveys under MMP) (Seagrass-Watch HQ)	●	●	●		●	●	●	●								

AIMS ID[a]	Program and organisation	Ecosystem health				Biodiversity						Water Quality					
		Connectivity (EHO2)	*Condition (EHO2; EHO3; EHT5)*	*Resilience (EHO2; EHT5)*	*Wetland extent (EHT3)*	*Current condition (BO4)*	*Trend in condition (BO3; BT5)*	*Diversity (BO5)*	*Species of conservation concern: habitat availability and condition (BO2; BT2)*	*Species of conservation concern: incidental bycatch (BT3)*	*Species of conservation concern: population size (BO2; BO3; BO4; BT4)*	*Wetland extent (WQO1; WQT2)*	*Wetlands ecological processes and environmental values (WQO1; WQT2)*	*Reef Water Quality: Chlorophyll a (WQO2; WQT3; WQT4)*	*Reef Water Quality: TSS (WQO2; WQT3; WQT4)*	*Reef Water Quality: Pesticides (WQO2; WQT3; WQT4)*	*Reef Water Quality: Nutrients (WQO2; WQT3; WQT4)*
35	Marine Monitoring Program – Inshore Seagrass (Seagrass-Watch HQ)	●	●	○ c		●	●	●	●								
41	Queensland wetland extent change mapping (Queensland Herbarium & DES)				●							●					
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)	●	●	●		●	●	●									
44	Queensland Ports Seagrass Monitoring (JCU)	●	●	●		●	●	●	●								
45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)													●	●		●
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)													●	●		●
46.3	Port Curtis and Port Alma Environmental Research and Monitoring Program - Dugongs (GPC)								●		●						
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)										●						

AIMS ID[a]	Program and organisation	Ecosystem health				Biodiversity						Water Quality					
		Connectivity (EHO2)	*Condition (EHO2; EHO3; EHT5)*	*Resilience (EHO2; EHT5)*	*Wetland extent (EHT3)*	*Current condition (BO4)*	*Trend in condition (BO3; BT5)*	*Diversity (BO5)*	*Species of conservation concern: habitat availability and condition (BO2; BT2)*	*Species of conservation concern: incidental bycatch (BT3)*	*Species of conservation concern: population size (BO2; BO3; BO4; BT4)*	*Wetland extent (WQO1; WQT2)*	*Wetlands ecological processes and environmental values (WQO1; WQT2)*	*Reef Water Quality: Chlorophyll a (WQO2; WQT3; WQT4)*	*Reef Water Quality: TSS (WQO2; WQT3; WQT4)*	*Reef Water Quality: Pesticides (WQO2; WQT3; WQT4)*	*Reef Water Quality: Nutrients (WQO2; WQT3; WQT4)*
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)					●	●	●									
47	Capricorn cetaceans project (SCU)								●								
49	Port of Townsville – Marine Water Quality Monitoring (PoT)													●	●	●	●
52	Qld Shark Control Program (DAF)							●			●						
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)													●	●	●	●
61	Ports North - Water Quality Monitoring (PN)													●	●		
64	Australian Marine Debris Initiative (TBF)[d]																
82	Long-term shark tagging program (OCR)										●						
84	CrocWatch (DES)					●	●										
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)										●						
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)										●						

AIMS ID[a]	Program and organisation	Ecosystem health				Biodiversity						Water Quality					
		Connectivity (EHO2)	*Condition (EHO2; EHO3; EHT5)*	*Resilience (EHO2; EHT5)*	*Wetland extent (EHT3)*	*Current condition (BO4)*	*Trend in condition (BO3; BT5)*	*Diversity (BO5)*	*Species of conservation concern: habitat availability and condition (BO2; BT2)*	*Species of conservation concern: incidental bycatch (BT3)*	*Species of conservation concern: population size (BO2; BO3; BO4; BT4)*	*Wetland extent (WQO1; WQT2)*	*Wetlands ecological processes and environmental values (WQO1; WQT2)*	*Reef Water Quality: Chlorophyll a (WQO2; WQT3; WQT4)*	*Reef Water Quality: TSS (WQO2; WQT3; WQT4)*	*Reef Water Quality: Pesticides (WQO2; WQT3; WQT4)*	*Reef Water Quality: Nutrients (WQO2; WQT3; WQT4)*
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)										●						
100	Gladstone Healthy Harbour Marine Debris (CQU)[d]																
101	Port Curtis Harbour Watch (BIEEC)[d]																
110	Eco Barge Marine Debris Cleanup and Monitoring (Eco Barge)[d]																

<u>Notes to table:</u>

a. ID used in Addison et al (2015).

b. These three monitoring programs focus on commercial and recreational caught fish species which should include species that are dependent on estuaries for at least part of their life cycle.

c. The MMP seagrass monitoring program is 10 years old, so just misses the criteria for addressing the resilience attribute (>10 years). However, this program does have indicators that could be used to infer the resilience of seagrass.

d. Program that is relevant but where Reef 2050 Plan objectives/targets are not well articulated for specific habitat, e.g. beaches, coastlines and islands.

1.4 Information needs for Great Barrier Reef management

Reef managers and partners need to understand if critical attributes of estuarine systems are changing, either improving in key health indicators of this ecosystem and its species in line with key outcomes outlined in the Reef 2050 Plan, or declining and thus requiring further management intervention. This information needs to be clear at a number of scales for management actions and reporting Reef-wide (e.g. Outlook Report) through to regional scales (regional report cards) down to local catchment scales (the action scale for reporting on impact assessments). This is because reporting on management actions and effectiveness will operate at all these scales. Outlook seeks to report on status and trend at ecosystem scales as well as population health for important iconic or threatened species. Thus, the program design will need to incorporate a stratified hierarchical monitoring framework to provide for these spatial and temporal changes across a system as large as the Reef coastal estuarine systems. Partners also need to understand and report on how commercially important species populations are trending, or be able to show that their actions are ecologically sustainable and are supporting, or at least not affecting the maintenance of a healthy World Heritage Area.

It is important that estuarine monitoring support the collection of data that helps researchers and managers better understand cause and effect relationships, changing risks with changing development or use pressures, and includes a capacity to map these temporal and spatial changes to support important management tools. This information needs to be available in a timely manner for the different timescales of Reef managers and partners decision and reporting needs, e.g. major synthesis compiled every four to five years for incorporation into the Outlook Report or State of the Environment Reporting, or annually for present regional reporting or as part of an annual industry performance report.

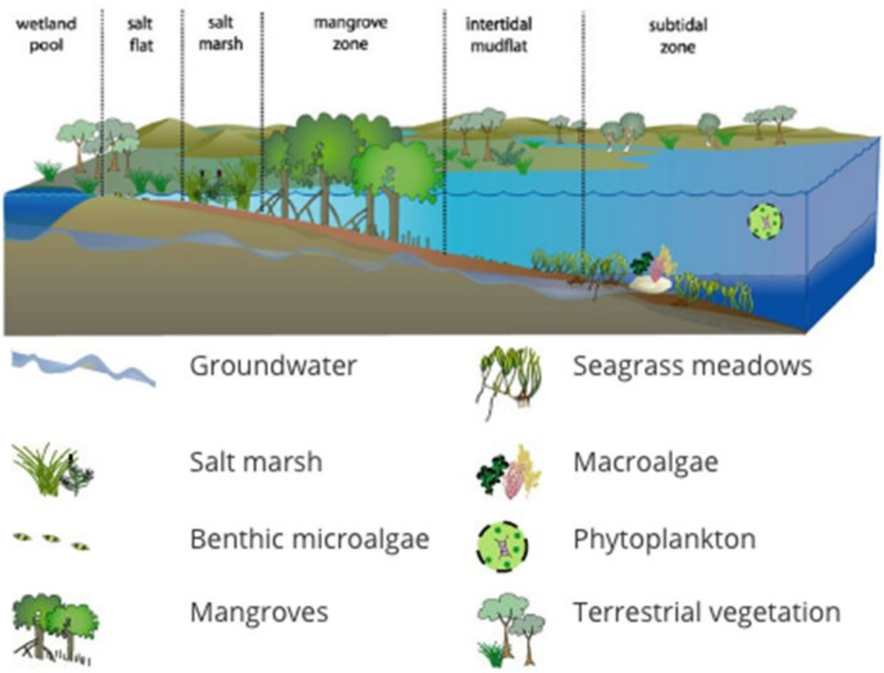
The estuarine monitoring program should also include extent elements to provide for that Reef-wide scale and, nested within that broader context, there should be representative areas where condition is measured using some key indicators of healthy systems. This should include some elements that can be used to integrate across larger monitoring programs such as the water quality, biodiversity and economic benefit monitoring programs.

2. Current understanding of estuarine wetland systems and status on the Great Barrier Reef

2.1 Estuarine wetland systems on the Reef

Estuarine systems are found all along the 2300 kilometres of the Reef coastline and on many islands of the World Heritage Area. There are even 105 mangrove islands found in inshore waters[4]. The aerial extent of estuarine systems is approximately 3969 square kilometers of combined mangrove (~60 per cent) and saltmarsh (~40 per cent) communities[2] and an unknown (and constantly shifting) area of mud and sandflats along their seaward margins (Figure 2). There are 192 estuaries within the 35 river basins that make up the Reef catchment. These fall into six geomorphic estuarine types, depending on the dominance of either tide, river or wave energy (https://ozcoasts.org.au). Because of the sheltered nature of the Reef coastline, protected as it is by barrier reefs, its estuarine systems are dominated by tidal energy, making up more than 50 per cent of the geomorphic types. These estuarine systems include five of the more iconic estuaries in eastern Australia: Princess Charlotte Bay, Hinchinbrook Island and Channel, Bowling Green Bay, Broadsound/Shoalwater and Corio Bays, and the Fitzroy River estuary[3]. Bowling Green Bay and Shoalwater/Corio Bays are also recognised internationally as listed Ramsar wetlands. All these estuarine systems fall partly or wholly within the World Heritage Area.

Figure 2. Typical estuarine structure (from Ozcoasts conceptual diagrams)



Estuarine plant communities (mangroves, saltmarshes, algae mats and seagrasses) play a critical role in driving primary production and so supporting the food chains in the coastal waters. They play an important part in the uptake and export of nutrients, in feeding and spawning and shelter for aquatic species. They capture and consolidate sediments, control and minimise shoreline erosion and act as buffers to other coastal plant communities, including for example endangered littoral vine forests. They provide breeding habitat and food for many commercial fish and crustacean species and foraging areas for iconic species such as turtles and dugongs. Estuaries are critical habitat for several threatened and endangered species including several marine species of sawtoothed sharks and inshore dolphins and terrestrial species such as the false water rat and yellow chat. They are also primary habitat for important commercial species like mud crabs, and several prawn and fish species.

The estuarine system is unique in regards to water quality dynamics. Salinity can range from hypersaline waters during low flow situations to hyposaline during high flow situations. Being low lying land with very low gradients, estuaries generally act as a sink in a hydrological context, slowing water flows and capturing varying proportions of the loads of sediments, nutrients and associated contaminants which flow into and through them. Many argue that in major rainfall events, during the tropical wet season, estuaries play a greatly diminished role in removing these materials given the short residency times for water flowing through the systems and the relatively limited area of estuaries in many locations. However, even small amounts of toxic contaminants can have detrimental impacts on estuarine ecology. Little work has been done on these issues in tropical Queensland, but work done in other tropical environments has shown the importance of intact mangrove systems and their role for example in nutrient capture.[15]

Estuaries are subject to impacts from activities upstream from them, especially actions that interfere with or modify the hydrological processes in the catchment. Given these biophysical links, the condition of an estuary is mediated by the condition of its catchment[2]. The historic and continuing loss of catchment ecosystem services that provide for sediment and nutrient regulation, and landscape water balance changes are now a primary source of cumulative pressures affecting estuaries[4]. Changes to river flow regimes and tidal connectivity between individual habitat components of estuaries has been known to cause phase shifts in estuarine communities.[2]

These issues can be critical given that estuarine areas play a significant role as nursery grounds for many species of crustaceans and fish and how mud and sandflats play a crucial role in feeding for a great number of shorebirds. This is especially important for migratory species which rely on specific areas as stop-over and recovery areas during their long migrations. An example of the importance of estuarine environments to individual species is where tiger prawns settle in estuarine seagrass areas in their post-larval stage and remain there exclusively until they become adults.

Seasonal freshwater flows are an important trigger for migration and breeding in many species using estuaries during critical parts of their life cycle. Barramundi, stimulated by the early wet season rains, move from connected freshwater systems into estuarine systems to spawn. Larval barramundi then disperse within the system moving with the tides to feed in vegetation fringed saltpans, remaining there in this critical early part of their lifecycle before dispersing more widely in the freshwater and marine environments. This connectivity across the broader marine and terrestrial wetland systems is critical to many species.

Climate change is expected to increase the vulnerability of estuarine ecosystems[2]. For example, in recent extreme events mangroves have been seen to also be susceptible to severe temperature influences with a major dieback event seen on the Gulf of Carpentaria between 2015-16 following an extensive dry period and unusually high temperatures. This coincided with the major bleaching event in the Reef[8].

While the aerial extent of estuarine systems has decreased by only around 10 per cent since settlement this does not suggest that estuarine systems are healthy along the Reef coast. While the *Great Barrier Reef Strategic Assessment Report* (2014)[28] did not look specifically at estuarine ecosystems as a whole, it identified the condition and trend in several elements of the estuarine systems. It reported that mangrove condition and trend was good and stable, while seagrass condition and trend was very poor and declining adjacent to the developed Reef coast. Other elements reported include sharks and rays and inshore dolphins in the southern inshore area (poor and declining) and shorebirds (poor and declining) suggesting that estuarine systems, at least in the southern two-thirds of the Reef coast, are not in good health [28].

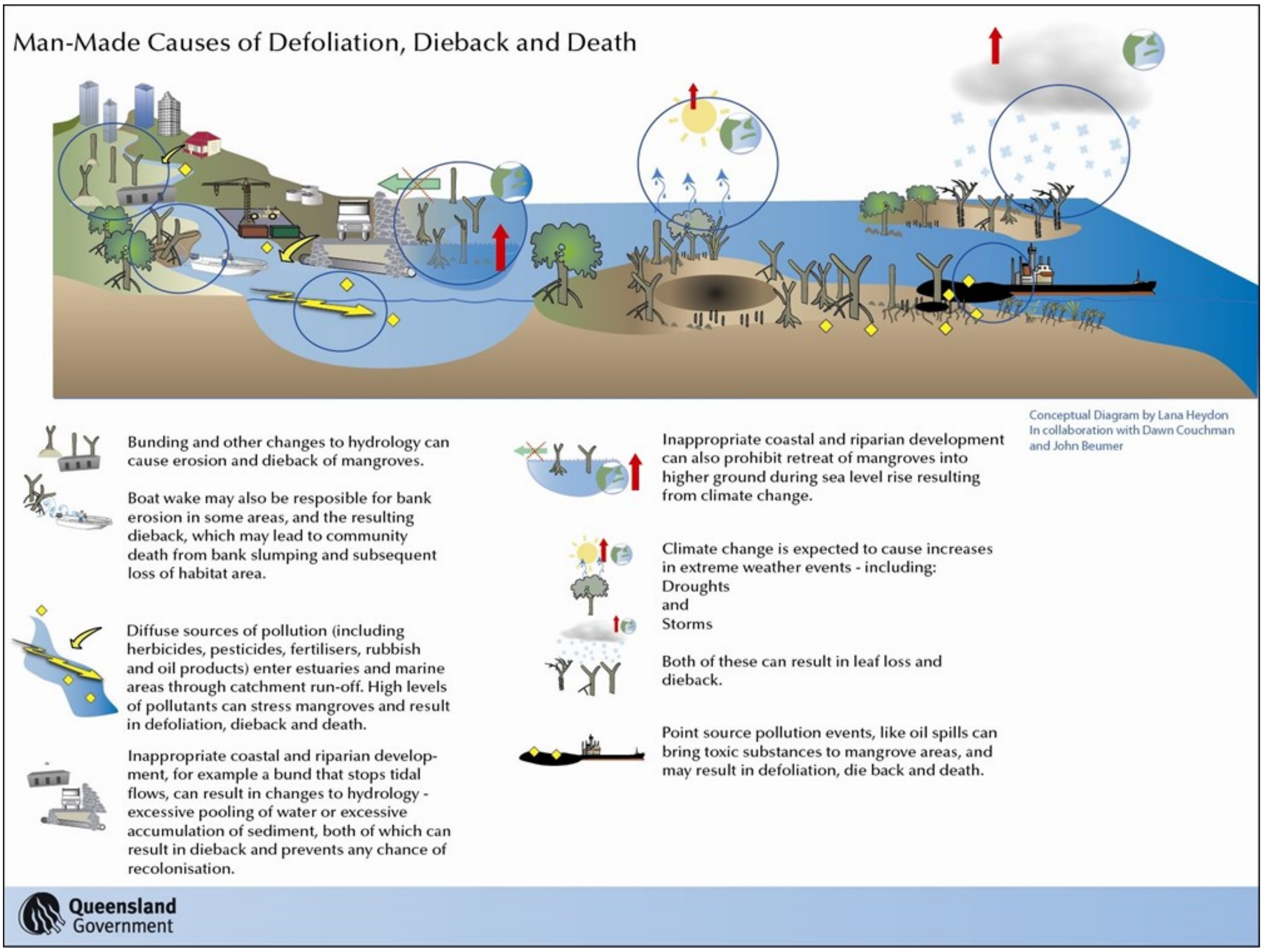
The 2014 Outlook Report[26] went further in identifying very high risks to the Reef ecosystem from nutrient and sediment loads, sea level and sea surface temperature rise and altered weather patterns. It also found that the outlook for ecosystems generally was poor and declining. It identified a number of risks specific to estuarine systems with increasing coastal development creating a moderate risk from potential acid sulfate soils (PASS) disturbance, a high risk from barriers to flow, high risks from disposal of dredge material and the extraction of predators, a very high risk from incidental catch of species of conservation concern and the modification of coastal habitats[26]. The recently completed Great Barrier Reef Marine Park Authority's Vulnerability Assessment for Estuaries (2016)[2] has just reinforced these risks.

2.2 Current status of estuarine wetland systems on the Great Barrier Reef

Overall the change in the extent of estuarine wetland ecosystems (namely combined mangroves and saltmarsh communities) has on average seen less than 10 per cent loss in area and only around 16 per cent in the worst regional case, the Fitzroy Basin. The percentage of mangroves remaining since European settlement is 97.5 per cent.[4] While there has been clearing of mangroves in some places, it is clear from vegetation mapping that mangroves have actually been expanding in many areas surrounding major river mouths, especially when associated with urban and industrial infrastructure. This is caused by the greatly increased loads of sediment being discharged and deposited about the river mouths.

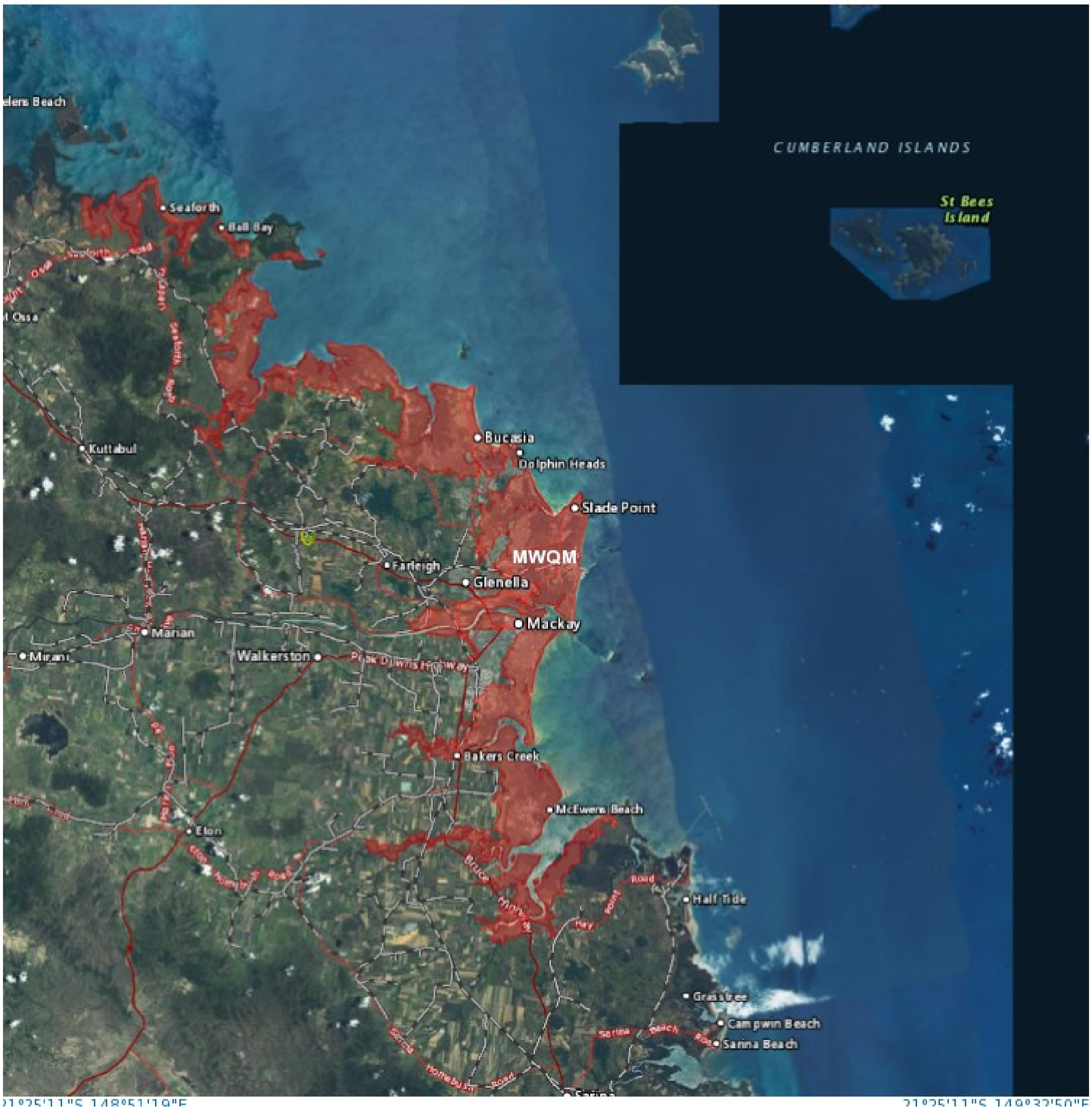
On the flip side, significant areas of saltmarsh have been modified or lost. While overall 85.3 per cent of saltmarsh remain, large proportions of this habitat have been lost in some regions (~25 per cent in Wet Tropics and Fitzroy Regions) with ~50 per cent loss in some catchments (e.g. Boyne, Burnett, Barron, Russell-Mulgrave, Shoalwater and Kolan). Further, recent work has identified up to 30 per cent of remaining saltmarsh communities have been modified through changes to hydrological flows caused by bunding for agricultural, industrial and urban developments[2]. Ponded pastures make up the largest portion of these modifications though tide gates, roads and other structures continue to restrict natural tidal movements across many areas of the developed coast in Queensland[4] (Figure 3).

Figure 3: Conceptual model of pressures and their impacts on estuarine systems (from Ozcoasts conceptual diagrams https://ozcoasts.org.au)



The modification of catchment hydrological regimes has other implications for estuarine systems. Many of the catchment areas immediately landward of estuarine systems, up to 10m AHD, has a high prevalence of PASS in the soil profile. PASS has only been mapped in detail in a few areas of the World Heritage Area coast since the early 2000s and then only in areas experiencing rapid urban or industrial growth. An example of the extent of PASS in the coastal areas of the Mackay region is shown in Figure 4. In many developed areas, PASS has been disturbed in the past and been exposed by these land use changes especially those involving modification of drainage systems. This has led and is leading to the slow release of acid waters and heavy metals into World Heritage Area estuarine systems from Port Douglas south. There have been a number of failed developments in the last few decades because of the consequences of PASS disturbance which led in the 1980s to the development of a State Planning Policy which places specific requirements on all development applications within the PASS risk zone. PASS is disturbed by draining water below the PASS layer and, once disturbed, PASS can release acids and heavy metals for many years. These toxic materials flow from the site following rain events entering creeks, rivers and estuaries, often with pH's as low as two (highly acidic) and soluble metals, especially iron and aluminium, at concentrations likely to be toxic to the plants and animals in the receiving environment. PASS discharges are implicated in fish kills, fish diseases and destruction of fish eggs, loss of crustaceans and high mortalities in other aquatic species and, in the long-term, alteration in aquatic plant communities and changes in food webs.[12] It is also responsible for damaging human infrastructure such as drain pipes and bridge and road foundations.

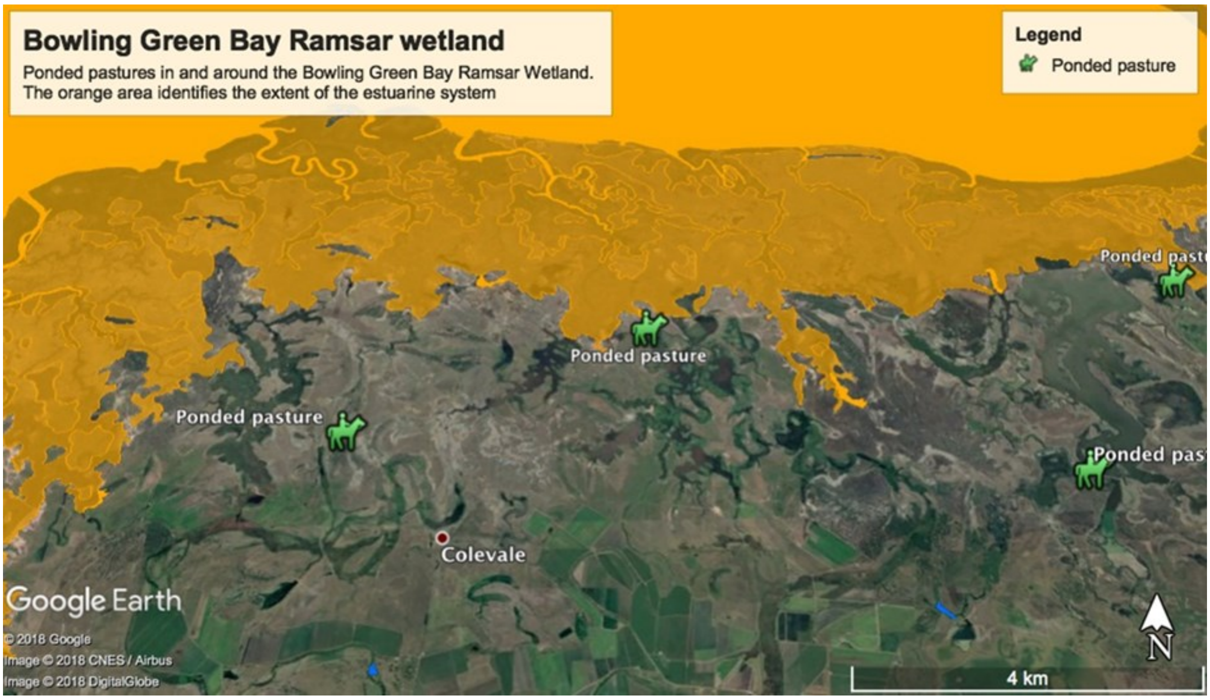
Figure 4. Mapping of PASS in the Mackay area showing the extent of PASS in the coastal area and the development footprint in areas with significant PASS in the soil profile.



Source: Map prepared by Qld ASS Team mapped at 1:50,000 displayed through Qld Globe 2018.

As identified earlier, this modification of water flows within estuarine areas is very widespread, even in very high value Ramsar and Directory of Important Wetlands (Figure 5). In many cases action plans have been developed for prioritising removal of these barriers[11]; monitoring this work and its outcomes could be of high value in understanding changes in the connectivity, health and resilience of these estuarine systems. This prevalence of increased freshwater flows has led to infestations of a number of environmental weeds such as pond apple which has been found in some 2000ha of mangrove forest in the Wet Tropics region.[13] There are also a number of non-native grasses that were introduced into ponded pastures, namely para grass and hymenachne which are now classed as serious and widespread environmental weeds in wetlands in Queensland.[14] These historic modifications to hydrological flows may also be a critical issue in addressing the risk to these systems from climate change. It is clear that estuarine systems play an important role in the sequestration of carbon and as a sink for it (blue carbon), though the potential importance of this sink and/or how it might be affected by human activities is still unclear. For this reason the Reef 2050 Plan has an action to better quantify this issue (MTR EHA 10 action). Hence improvements in the health of, or further loss of estuarine systems could have implications for overall carbon capture or release in the Reef and its catchment.

Figure 5. Bowling Green Bay Ramsar site showing a number of the ponded pastures.



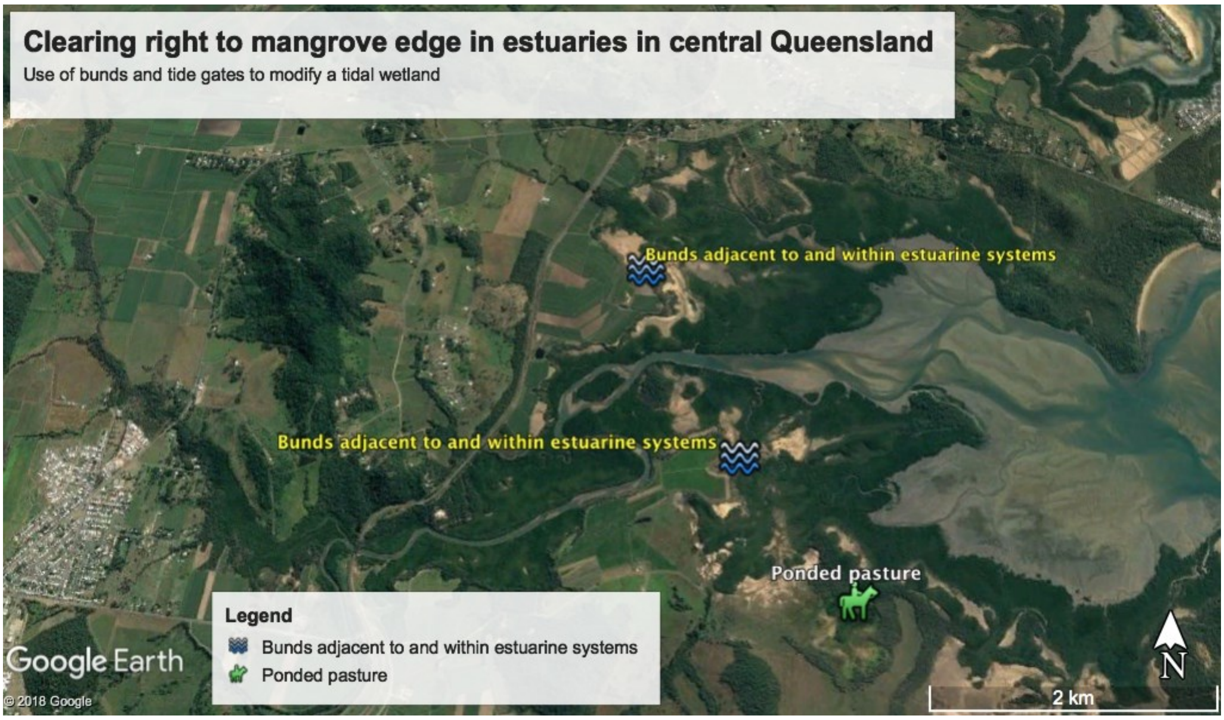
Source: Adapted from DES's Wetland info estuarine mapping and ponded pastures identified in the Authority's coastal ecosystem work (2012) using Google Earth.

While the estuarine systems in and adjacent to the World Heritage Area remain largely intact there is great variability in their condition and trend at regional and local scales. In the largely undeveloped area of the east coast of Cape York, as far south as Cooktown, the pressures on estuaries are largely confined to broad scale agricultural activities on the landward side and fishing (mainly but not exclusively commercial netting) on the seaward side. This area of estuarine coast represents about one-third of the Reef coastline and includes the iconic estuarine areas of Princess Charlotte Bay and the tidal wetlands of the Jardine River. Princess Charlotte Bay and surrounding areas contain areas of mangrove and seagrass habitat critical for foraging turtles, dugongs and saltwater crocodiles, still maintains populations of sawfish, and is one of only three known critical habitats areas for snubfin dolphins in the World Heritage Area.

South of Cooktown the estuarine systems have been affected by a range of coastal developments. These include bunding to allow for cane production in the Wet Tropics, Mackay Whitsunday and Burnett Mary regions. Ponded pastures are found in grazing lands adjacent to the coast from Ingham to Rockhampton (Figure 6). There are also a number of aquaculture facilities found up and down the Reef coast, including some failed facilities. These are often situated within and between estuarine areas to gain access to tidal waters. The level of disturbance to flows and fish passage has been assessed by identifying and categorising the types of barriers in a number of NRM regions and in a number of high value wetland systems, such as the Queensland Ramsar sites of Bowling Green Bay and Shoalwater/Corio Bay[36]. Assessments in the Wet Tropics region identified 85 significant barriers to water flows and fish passage and this Natural Resource Management (NRM) region, while the Wet Tropics and Mackay Whitsunday regional report card partnerships have developed a number of indicators to measure these hydrological changes[29,30]. In the Burdekin Dry Tropics region over 10,000 barriers to fish passage were identified in a 2007 assessment.[18]

Estuaries are susceptible to modification of freshwater flows and to the increased loads of pollutants now flowing from agricultural, industrial and urban developments. Pesticides have been implicated in the loss of mangroves and seagrasses in many areas in the past, and heavy metals have been found accumulating in estuarine substrates and in the leaves of seagrasses and mangroves and in other species e.g. mud crabs. Impacts of these contaminants on critical primary producers such as algal mats in tropical environments is unknown. There are a number of important estuarine areas that are downstream of areas where the risk from pesticide loads entering the marine environment is very high e.g. Bowling Green Bay[31]. Estuarine systems adjacent to irrigated areas in the lower Burdekin and Mackay Whitsunday can receive high levels of pesticides in flushes of freshwater all year round [16,17]. The impacts on estuarine plants and animals is largely unmonitored and undocumented, especially during seasonal rainfall events.

Figure 6. Google Earth view of a portion of central Queensland coast showing a variety of modifications to tidal movement in one estuary system.



Source: Adapted from mapping developed during the Authority's coastal ecosystem work program

Work undertaken in the lead up to the Great Barrier Reef Strategic Assessment (2013) and the 2014 Outlook Report identified estuarine ecosystems on the seaward side of the Burdekin Irrigation Area as receiving so much freshwater flows that there are ecotone shifts happening where estuarine systems are becoming freshwater systems with a subsequent loss of species and the invasion of freshwater plants and animals.[19] There are a number of indicators, both biological and water quality which should provide early warnings of such ecosystem shifts.

The extensive modification of estuaries is largely a historic issue which predates a number of legislative and planning changes dating back as far as the 1980s for PASS management through to the 1990s to 2000s with the introduction of state and regional coastal plans and associated regulations. There was also regulation introduced under fisheries legislation for protecting marine plants, especially in declared Fish Habitat Areas. Since the 2000s the development and implementation of water quality improvement plans has facilitated the scheduling of environmental values and water quality objectives across the Reef and its catchment under the Queensland Government's Environment Protection (Water) Policy (2009). These plans and their associated guidelines should underpin the future management of estuarine systems for their ecological health. Estuarine systems are largely classed as either Matters of State Environment Significance, with either high ecological value (HEVs) or slightly modified ecological value. The ongoing implementation of the Reef 2050 Water Quality Improvement Plan 2017-2022 (formerly Reef Water Quality Protection Plan) is slowly working to improve water quality in the Reef having developed and monitored the ongoing implementation of improved practices in the major agricultural industries adjacent to the

Reef for the last decade. This information is part of the foundation for reporting on progress to Reef 2050 Plan targets.

In the 2014 Outlook Report's independent assessment of management effectiveness, management of coastal development was rated as generally poor and stable, and water quality management as very good to good and stable [26]. This was due in part to a number of significant and potentially detrimental changes to environmental management in Queensland between 2013 and 2015 with changes introduced at the level of primary legislation, planning and policy. Coastal development, especially urban expansion to address the pressures from growing populations, remains a significant pressure on the coast. [22] The ramifications of these legislative and policy changes to estuarine health and resilience is as yet unknown, hence the need for an effective monitoring program. Some of these changes have since been reversed following a change in government in Queensland. A new State Planning Policy (2017) has been developed which includes requirements for managing wetlands in the Reef catchment but it is too early to know its effectiveness.

Effective coastal planning and the associated regulation including the effective implementation of Queensland's State Planning Policies (2017) and the Environment Protection (Water) Policy (2009) is critical to maintaining the health of the estuarine system. This group of ecosystems sit at the boundary of jurisdictional responsibility for Local, State and Federal government responsibilities. Thus, maintaining the extent and condition of estuarine wetland systems and ensuring their legislative and policy environments are strong and consistent in protecting the health of the system is a clear indicator of the governance outcomes performance under the Reef 2050 Plan. Other indicators of these governance outcomes could include how often the State Planning Policies and Environment Protection (Water) Policy requirements are being triggered by coastal developments or how often developments are being referred under the EPBC Act (2000).

3. Priority indicators to monitor estuarine wetlands on the Great Barrier Reef

A monitoring program within the estuarine system should look to incorporate a number of attributes that could be reported under the targets, objectives and outcomes of the Reef 2050 Plan. These attributes include information on condition and extent in ecological communities such as mangroves, seagrasses and saltmarshes. They should include information on population status and trends for specific sharks and rays, specific inshore dolphins, shorebirds, marine turtles, dugongs and crabs. The program could look at water quality issues potentially affecting estuarine systems and species especially pH, pesticides and soluble heavy metals. It also needs to identify if key attributes, such as connectivity, are being maintained and where necessary improved. It needs to be identifying if issues such as incidental catch is impacting on populations of threatened species, and if protection measures such as zoning are effectively maintaining species and areas in a good condition.

Some aspects are already being monitored, some more comprehensively than others (see Table 3 below). Mangroves and saltmarshes by default are monitored across the Reef coast for extent (and in some instances condition) as part of the annual reporting of Queensland's tree clearing monitoring program (SLATS) and the five-yearly wetland extent monitoring program (DES). Estuarine seagrasses are monitored regularly in all NRM regions under the

Marine Monitoring Program (MMP), with proposed expansion of this program under Seagrass RIMReP monitoring proposals to more comprehensively cover the full spatial complement of seagrasses in the World Heritage Area, especially expanding monitoring in Cape York. There is a water quality monitoring program in some estuarine systems in the World Heritage Area (CQAMP) but it is largely based on ambient monitoring and has little or no event coverage which limits its applicability. There are some monitoring activities for shore birds by the Queensland Parks and Wildlife Service (QPWS) and Queensland Wader Study Group, and some mangrove health monitoring (MangroveWatch) in limited locations along the Reef coast. Further, given that estuarine systems are one of the most heavily used areas of the World Heritage Area for recreation and fishing, it is important to find good indicators to show how their community and economic benefits are being maintained and protected.

Fishery take levels are monitored by Queensland's fisheries management agency and community-based monitoring of recreational catch happens intermittently in some locations. Marine turtle populations are monitored in key breeding sites and dugongs are surveyed every few years across the Reef inshore waters. Commercial crab and prawn species take is monitored by Queensland in certain areas but no program looks, for example, at ecologically important crab populations except occasionally as part of development assessments, e.g. on the impacts of industrial activities associated with infrastructure expansions or permitted levels of pollution discharge about ports.

Depending on how monitoring is undertaken there are indicators here that could support the integration of monitoring across programs, e.g. grapsid crab populations used to monitor the health in mangroves duly linked to water quality changes that might affect their health, linking to biodiversity and threatened species monitoring (grapsids being a primary food source for many species including the false water rat) or fishery management monitoring in estuaries as part of stock assessments. This could support integration of monitoring data across a number of Reef 2050 Plan outcomes such as Ecosystem Health, Biodiversity, Water Quality and Economic Benefits.

Table 2 lists the indicators recommended as priority monitoring indicators. Where applicable we have drawn on the proposed priority indicators identified by other RIMReP Thematic Expert Groups.

Table 2. Proposed priority indicators.

Indicator Group	Priority Indicator*	Justification for selection	Management use
Sea level rise	Spatial description and rate of sea level rise along the Reef coast [a]	Strategic; driver of increasing colonisation of saltmarshes and saltpans by mangroves.	Planning Reporting
Extreme events (cyclones)	Spatial description of cyclone impacts on estuarine wetlands [a]	Informs management response to cyclones. Identify spatial patterns in historic TC exposure to explain habitat condition trajectories.	Planning Tactical Reporting
	BoM cyclone tracking [a]		

Indicator Group	Priority Indicator*	Justification for selection	Management use
Nutrients	Nutrients (N and P species) [a] including dissolved inorganic nitrogen (DIN)	Nutrient delivery and enrichment are underpinning processes for many components of benthic and pelagic ecosystems. Considered a key pressure on marine ecosystems – primarily inshore.	Planning Management effectiveness Reporting
	Chlorophyll a [a]	A proxy for primary production; major controls on benthic light availability	Planning Management effectiveness Reporting
Sediments	Turbidity [a]	Lack of water clarity and resultant light attenuation is a key indicator of poor water quality and is an essential environmental factor.	Planning Management effectiveness Reporting
	Secchi depth [a]		
Sediment quality	Metals and metalloids	Based on risk assessment, identify and monitor sediment quality to determine actual/potential risks to ecosystem and human health.	Tactical Operational Planning Reporting
Pesticides	PSII herbicides [a]	Pesticides pose a risk to coastal and inshore species at some locations. Observed concentrations provide a measure of potential impact to inform prioritisation of catchment management action.	Planning Management effectiveness Reporting
	Non-PSII herbicides including emerging 'alternative' herbicides [a]		
	Pesticides/ Insecticides [a]		
Potential Acid Sulphate Soil disturbance	pH	Highly acidic water poses a risk to estuarine plants and animals, especially at the estuarine-freshwater boundaries	Tactical Operational Planning Reporting
	Soluble metals especially aluminium and iron	Concentrations of soluble metals or metals deposited in estuarine muds pose a risk to estuarine plants and animals	Tactical Operational Planning Reporting
Hydrological change	Barriers (proportion of modification to system connectivity)	Barriers act to restrict diadromous fish movements affecting breeding and recruitment activities which is detrimental to populations of affected species	Operational Planning Management effectiveness reporting
Flow	30th percentile of 10 flow metrics.	Freshwater surface flows into estuaries are important for maintaining overall health and resilience of the system.	Planning Management effectiveness Reporting
Seagrass	Habitat assessment: [b] - species present - abundance	Provides information on condition and trend of seagrass as well as providing information on how management actions impact on the health of seagrass meadows.	Tactical Operational Planning Management effectiveness Reporting
	Health assessment: [b] - size of meadows - sexual reproduction		

Indicator Group	Priority Indicator*	Justification for selection	Management use
	- biomass characteristics - meadow connectivity (if applicable)		
Mangroves	<u>Extent</u> - per cent mangrove loss since pre-clear <u>Condition</u> - mangrove cover	Provide information on condition and trend of mangroves as well as information on how management actions impact on the health of mangrove communities.	Tactical Operational Planning Management effectiveness Reporting
Saltmarshes	Extent	Provide information on extent and trend of saltmarshes as well as information on how management actions impact on the health of saltmarsh communities; also has implications for climate change impacts.	Tactical Operational Planning Management effectiveness Reporting
Mud crabs	Population	There has been a monitoring methodology developed through FRDC which provides for monitoring mangrove health based on mud crabs as a bioindicator.	Tactical Operational Planning Management effectiveness Reporting
Grapsid crabs	Diversity and zonation	There has been a monitoring methodology developed by researchers in a couple of Australian universities, including JCU. Grapsid crabs are considered a keystone species in estuarine systems because of the burrowing and nutrient cycling behavior but the monitoring methodologies remain largely experimental at this point in time	Tactical Operational Planning Management effectiveness Reporting
Coastal dolphin (snubfin)	Abundance, distribution, contaminants, proportion of calves in groups, environmental values [c]	Two of the three coastal dolphin species are listed as “near threatened” and listed under the EPBC Act. Monitoring would need to be consistent with proposals under RIMReP and focus on estuaries identified as significant sites.	Tactical Operational Planning Management effectiveness Reporting
Dugong	Data from aerial surveys, StrandNet and CPUE for traditional hunting. [d]	Important marine mega fauna species listed under the EPBC Act. Monitoring would need to be consistent with proposals under RIMReP and focus on estuaries identified as significant sites.	Tactical Operational Planning Management effectiveness Reporting
Fish	Indicators proposed in RIMReP Fisheries Expert Report relevant to estuarine dependent species including status of stocks, fishing effort & retained catch, discarded catch,	Provide an indication of state, drivers and pressures relevant to estuarine-dependent fish species.	Tactical Operational Planning Management effectiveness Reporting

Indicator Group	Priority Indicator*	Justification for selection	Management use
	biomass ratios, compliance statistics. [e]		
Social	Indicators utilised for GHHP social monitoring program adapted for each NRM regional circumstances.	Provide information on how local communities use, value and access estuarine wetlands.	Tactical Operational Planning Management effectiveness Reporting
Economic	Indicators utilised for GHHP economic monitoring program adapted for each NRM regional circumstances.	Provide information on the economic value of regional estuarine wetlands.	Tactical Operational Planning Management effectiveness Reporting
Indigenous cultural heritage	Indicators utilised for GHHP Indigenous cultural heritage monitoring program adapted for each NRM regional circumstances in consultation with traditional owner groups.	Provide information on the Indigenous cultural heritage value of regional estuarine wetlands.	Tactical Operational Planning Management effectiveness Reporting
Marine debris	Marine Debris [a] – density of plastics recovered (per unit effort) through beach cleanups.	Emerging contaminant of concern – broadscale ecosystem impacts unquantified at present - measure of effectiveness of (terrestrial) waste management activities	Planning Management effectiveness Reporting

Notes to table:

* Table 7 provides additional information on survey method, location and frequency

a. From Physical-Chemical Expert Group Final Report for RIMReP.

b. Summarised from Seagrass Monitoring Final Report for RIMReP.

c. Summarised from Coastal Dolphins Final Report for RIMReP.

d. Summarised from Dugong Final Report for RIMReP.

e. Summarised from draft Fisheries Report for RIMReP.

4. Evaluation of the adequacy of current monitoring of estuarine wetlands on the Great Barrier Reef

4.1 Synopsis of existing monitoring programs

We have reviewed Addison et (2015)[7] and various technical reports[29, 30, 32, 33, 34, 35] and identified at least 47 current monitoring programs covering either in totality, or partially attributes of estuarine wetlands. Table 3 lists these programs and includes the name of the program, its duration and frequency, the NRM region where the monitoring occurs, and the organisation responsible for the program. The programs are grouped according to the relevant attribute of estuarine wetlands, e.g. seagrass, mangroves, etc.

Table 3. Current environmental, social, cultural and economic monitoring programs relevant to estuaries.

Key: CY = Cape York; WT = Wet Tropics; B = Burdekin; MW = Mackay-Whitsunday; BM = Burnett Mary

AIMS ID [a]	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
ENVIRONMENTAL									
Seagrass (habitat and species) [b]									
34*	Seagrass Watch (separate from surveys under MMP) (Seagrass-Watch HQ)	≥ 20 years	6 monthly - quarterly	●	●	●	●	●	●
35*	Marine Monitoring Program – Inshore Seagrass (Seagrass-Watch HQ / JCU)	6 - 10 years	Annual - once every 2 years	●	●	●	●	●	●
44*	Queensland Ports Seagrass Monitoring (TropWATER, JCU)	≥ 20 years	Monthly - annual	●	●	●	●	●	●
Mangroves (habitat / species)									
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch) [c]	≥ 20 years	Annual	●	●			●	●
Wetlands (habitat)									
41*	Queensland wetland extent change mapping (Qld Herbarium, DES)	6 - 10 years	Once every 3 or more years	●	●	●	●	●	●
Bony fishes									
20	Queensland fishery independent surveys of specific species (DAF)	11 - 19 years	Annual					●	●
21	Queensland biological fishery dependent data collection (commercial and recreational) (DAF)	11 - 19 years	Daily	●	●	●	●	●	●
22	Queensland commercial fisheries monitoring (DAF)	11 - 19 years	Daily	●	●	●	●	●	●
N/A*	Gladstone Healthy Harbour Partnership – InfoFish	≤ 3 years	Monthly btwn Dec & March					●	
Dugong, dolphins and marine turtles									
10	Dugong Population Monitoring (JCU)	≥ 20 years	Once every 3 or more years	●	●	●	●	●	●
31	Marine Wildlife Stranding and Mortality (DES)	≥ 20 years	Opportunistic		●	●	●	●	●
46.3	Port Curtis and Port Alma Environmental Research and Monitoring Program - Dugongs (GPC)	3 - 5 years	Opportunistic					●	
46.4	Port Curtis and Port Alma Environmental Research	≤ 2 years	Annual					●	

AIMS ID [a]	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
	and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)								
47	Capricorn cetaceans project (SCU)	6 - 10 years	Monthly					●	
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)	≤ 2 years	Annual		●				
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)	≤ 2 years	Annual	●					
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)	≤ 2 years	Annual		●				
Sharks & rays									
52	Qld Shark Control Program (DAF)	≥ 20 years	Opportunisti c		●	●	●	●	●
82	Long-term shark tagging program (OCR)	3-5 years	Continuous tracking		●	●	●	●	●
Shorebirds & seabirds									
17	Coastal Bird Monitoring (Joint Field Management Program, QPWS & the Authority)	11 - 19 years	Quarterly	●	●	●	●	●	●
18	Shorebird monitoring (Qld Wader Study Group)	≥ 20 years	Monthly		●	●	●	●	●
19	Eastern Australian Waterbird Survey (UNSW)	≥ 20 years	Annual		●	●	●	●	●
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)	3 - 5 years	Annual					●	
Crocodile									
84	CrocWatch (DES)	3 - 5 years	Opportunisti c	●	●	●	●	●	●
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)	≤ 2 years	Annual	●					
Water quality									
45.3 *	Port Curtis Integrated Monitoring Program - Water quality (PCIMP)	11 - 19 years	Quarterly					●	
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)	3 - 5 years	Monthly					●	

AIMS ID [a]	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
49	Port of Townsville – Marine Water Quality Monitoring (PoT)	11 - 19 years	< hourly (i.e. continuous)			●			
55*	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)	3 - 5 years	< hourly (i.e. continuous)			●	●		
61*	Ports North - Water Quality Monitoring (PN)	≥ 20 years	Quarterly		●				
101	Port Curtis Harbour Watch (BIEEC)	≤ 2 years	Monthly					●	
N/A*	Central Queensland Ambient Monitoring Program (Qld estuaries) (CQAMP) (DES)	≥ 20 years	Monthly					●	●
N/A*	Additional pesticide monitoring program in estuaries (MWHR2RP)	Commenced Nov 2018	12 times/ wet season				●		
N/A*	Estuarine water quality monitoring program (DES)	≤ 3 years	6-12 times/ year		●		●		
N/A*	Douglas Shire Council (DSC) wastewater treatment plant monitoring program	TBC	3 times/year		●				
N/A*	Cairns Regional Council (CRC) wastewater treatment plants monitoring programs	TBC	3-6 times/year		●				
N/A*	Cassowary Coast Regional Council (CCRC) wastewater treatment plants monitoring programs	TBC	3-6 times/year		●				
N/A*	Catchment Loads Monitoring Program (CLMP, P2R) (DES)	≤ 13 years	Baseflow: monthly. High flow events	●	●	●	●	●	●
N/A	CSIRO water quality loggers	1-4 years	Continuous	●	●			●	●
Marine debris									
64	Australian Marine Debris Initiative (TBF)	Unconfirmed	Unconfirmed		●		●		
100	Gladstone Healthy Harbour Marine Debris (CQU)	6 - 10 years	Annual					●	
110	Eco Barge Marine Debris Cleanup and Monitoring (EB)	≥ 20 years	Annual				●		
Other									
N/A*	Fish barriers assessment, (Catchment Solutions)	≤ 2 years	4-yearly				●		
N/A*	Fish barriers assessment, (WTHWP)	TBC	4-yearly		●				
N/A*	Mud crab survey (GHHP)	≤ 2 years	annual					●	
N/A*	Coral survey (GHHP)	≤ 4 years	annual					●	
Social, cultural and economic									

AIMS ID [a]	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
N/A*	CATI social survey (GHHP)	≤ 5 years	annual					●	
N/A*	CATI cultural survey (GHHP)	≤ 5 years	annual					●	
N/A*	Indigenous cultural heritage assessment (CHA) (GHHP / Terra Rossa)	≤ 3 years	annual				● [d]	●	
N/A*	Economic assessment (EA) (GHHP / CQU)	≤ 5 years	annual					●	

Notes to table:

* Data from these programs are used as part of regional waterway / ecosystem health annual report cards.

a. ID used in Addison et al (2015).

b. Most seagrass monitoring programs occur outside of estuaries in adjacent inshore marine areas.

c. Whilst this program has been going for more than twenty years (e.g., MangroveWatch Daintree River commenced in 1986), it is entirely dependent on external funding which means that some monitoring sites in the three NRM regions are currently inactive (like MangroveWatch Daintree River). Currently CHAMP monitoring is undertaken in Port Curtis and Port Alma 2015 (frequency: annual to every two years) and Princess Charlotte Bay 2013 (frequency: annual) Addison et al (2015).

d. Indigenous cultural heritage assessment undertaken by MWHR2RP and includes estuarine sites if applicable.

Table 4 lists the estuaries where monitoring currently occurs on a regular basis as well as the main reporting product that utilises the data gathered.

Table 4. Estuaries regularly monitored.

NRM Region	Estuary	Main Monitoring Program	Reporting Product
Cape York (CY)	Pascoe River [a]		
	Endeavour River [a]		
	Annan River [a]		
Wet Tropics (WT)	Daintree River	DES	Wet Tropics annual regional waterway health report card
	Dickson Inlet	DES	
	Barron River	DES, CLMP	
	Trinity Inlet	DES	
	Russell-Mulgrave	DES, CLMP	
	Johnstone River	DES, CLMP	
	Tully River [a, b]	MMP, CLMP	
	Moresby	DES	
	Hinchinbrook Channel	DES	
Mackay-Whitsunday (MW)	Gregory River	DES	Mackay-Whitsunday annual waterway health regional report card
	O'Connell River	DES, CLMP	
	St Helens/Murray Creek	DES	
	Vines Creek	DES	
	Sandy Creek	DES, CLMP	
	Plane Creek	DES	

NRM Region	Estuary	Main Monitoring Program	Reporting Product
	Sarina Inlet	MMP	
	Rocky Dam Creek	DES	
	Carmila Creek	DES	
Fitzroy Basin (F)	Fitzroy River [a]	DES, CLMP	Fitzroy annual ecosystem health regional report card
- Gladstone Harbour (GH)	The Narrows	GHHP /PCIMP / GPC	Gladstone Harbour annual report card
	Graham Creek	GHHP /PCIMP / GPC	
	Western Basin	GHHP /PCIMP / GPC	
	Boat Creek	GHHP /PCIMP / GPC	
	Pelican Banks	MMP	
	Inner Harbour	GHHP /PCIMP / GPC	
	Calliope Estuary	GHHP /PCIMP / GPC	
	Auckland Inlet	GHHP /PCIMP / GPC	
	Mid Harbour	GHHP /PCIMP / GPC	
	South Trees Inlet	GHHP /PCIMP / GPC	
	Boyne Estuary	GHHP /PCIMP / GPC	
	Colosseum Inlet	GHHP /PCIMP / GPC	
	Rodds Bay	GHHP /PCIMP / GPC/MMP	
Burnett-Mary (BM)	Baffle Creek	CQAMP	
	Kolan River	CQAMP	
	Burnett River	CQAMP, CLMP	
	Burrum River	CQAMP	
	Mary River	CQAMP, CLMP	
	Tin Can Inlet	CQAMP	

Notes to table:

a. CSIRO estuarine water quality logger.

b. Tully River is not included in estuary reporting zone for the WTHWP, and is monitored for water quality by the MMP.

Table 5 lists the indicators that are currently monitored in Reef estuarine wetlands, the measures used and monitoring programs capturing the data, coverage by NRM region, and method.

Table 5. Current indicators monitored in Great Barrier Reef estuarine wetlands

Indicator	Existing measure	Primary Monitoring program	Coverage (region & location)	In situ, RS or modelled
Environmental				
Conductivity	Conductivity	CQAMP, DES	MW, F, BM	In situ, monthly
Temperature	Temperature	CQAMP, DES	MW, F, BM	In situ, monthly
pH	pH	PCIMP, CQAMP, DES	MW, GH, F, BM	In situ, quarterly (GH) CQAMP, monthly
Dissolved oxygen	% Saturation	DES	WT, MW, F, GH, BM	In situ, monthly
Turbidity	NTU	DES, PCIMP	WT, MW, F, GH	In situ, monthly (DES); quarterly (GH)
	Secchi depth	CQAMP, DES	MW, F, BM	In situ, monthly
Nutrients	DIN (ammonia + nitrate+ nitrite) μg/L	DES	WT, MW	In situ, monthly

Indicator	Existing measure	Primary Monitoring program	Coverage (region & location)	In situ, RS or modelled
	Organic nitrogen	CQAMP	F, BM	In situ, monthly
	Nitrate plus nitrite (NOx)	CQAMP, DES	MW, F, BM	In situ, monthly
	TN µg/L	PCIMP, CQAMP, DES	MW, F, GH, BM	In situ, quarterly (GH) In situ, monthly
	Ammonia as N µg/L	CQAMP, DES	MW, F, BM	In situ, monthly
	FRP (filterable reactive P) µg/L	DES, CQAMP	WT, MW, F, BM	In situ, monthly
	TP µg/L	PCIMP, CQAMP, DES	MW, F, GH, BM	In situ, quarterly (GH) In situ, monthly
Dissolved metals	Aluminium (Al)	PCIMP	GH	In situ, quarterly
	Copper (Cu)	PCIMP	GH	In situ, quarterly
	Lead (Pb)	PCIMP	GH	In situ, quarterly
	Manganese (Mn)	PCIMP	GH	In situ, quarterly
	Nickel (Ni)	PCIMP	GH	In situ, quarterly
	Zinc (Zn)	PCIMP	GH	In situ, quarterly
Sediment quality: metals and metalloid	Arsenic (As)	PCIMP	GH	In situ, quarterly
	Cadmium (Cd)	PCIMP	GH	In situ, quarterly
	Copper (Cu)	PCIMP	GH	In situ, quarterly
	Lead (Pb)	PCIMP	GH	In situ, quarterly
	Nickel (Ni)	PCIMP	GH	In situ, quarterly
	Mercury (Hg)	PCIMP	GH	In situ, quarterly
	Zinc (Zn)	PCIMP	GH	In situ, quarterly
Chl-*a*	Chl-*a* µg/L	DES, PCIMP, CQAMP	WT, MW, F, GH, BM	In situ, monthly (DES, CQAMP); quarterly (PCIMP)
Seagrass condition	Biomass	TROP-Water, JCU	WT, GH	In situ, annual
	Area	TROP-Water, JCU	WT, GH	In situ, annual
	Species composition	TROP-Water, JCU	WT, GH	In situ, annual
	Per cent cover	TROP-Water, JCU	WT, MW	In situ
	Tissue nutrients	TROP-Water, JCU	WT, MW	In situ
	Reproductive effort	TROP-Water, JCU	WT, MW	In situ
Pesticides	ms-PAF	DES, MWHR2RP	WT, MW	In situ, wet season months only
Riparian extent	Per cent riparian area loss since pre-clear using QLD herbarium's regional ecosystem mapping (version 9)	DES	WT, MW	RS, reported 4-yearly
Mangrove and saltmarsh extent	Per cent mangrove and saltmarsh area loss since pre-clear using Qld Herbarium's regional ecosystem mapping (version 9) of Res 8.1.1, 8.1.2, 8.1.3 & 8.1.5	DES	WT, MW	RS, reported 4-yearly

Indicator	Existing measure	Primary Monitoring program	Coverage (region & location)	In situ, RS or modelled
Fish barriers	Barrier density	CSIRO, Catchment solutions, DES, WTHWP	WT, MW	RS, reported 4-yearly
	Distance to first barrier			
	Distance to first low passability barrier			
Flow	30th Percentile of 10 flow metrics	Various	WT, MW	All
Barramundi recruitment	Number caught from January-May that are less than 300mm to the end of March and less than 350mm to the end of May	Info Fish	F	In situ, Jan-May each year
Corals	Combined cover, hard and soft coral (%)	GHHP	GH	In situ, annual
	Macroalgal cover (%)	GHHP	GH	In situ, annual
	Juvenile coral density (o.m-2)	GHHP	GH	In situ, annual
	Change in hard coral cover	GHHP	GH	In situ, annual
Fish recruitment	Fish length of two bream species	GHHP - InfoFish	GH	In situ, monthly between December and March
Mud crabs	Species	GHHP	GH	In situ, annual
	Sex	GHHP	GH	In situ, annual
	Carapace width (mm)	GHHP	GH	In situ, annual
	Mass (g)	GHHP	GH	In situ, annual
	Abnormalities (rust spot lesion)	GHHP	GH	In situ, annual
Social				
Usability: - Satisfaction with recreational activities	How satisfied with last trip	GHHP CATI	GH	In situ, annual
	Quality of ramps and facilities	GHHP CATI	GH	In situ, annual
- Perceptions of air and water quality	Water quality satisfaction	GHHP CATI	GH	In situ, annual
	Air quality satisfaction	GHHP CATI	GH	In situ, annual
	Water quality does not affect use of the harbour	GHHP CATI	GH	In situ, annual
- Perceptions of harbour safety for human use	Marine safety incidents	GHHP CATI	GH	In situ, annual
	Oil spills	GHHP CATI	GH	In situ, annual
	Safe at night	GHHP CATI	GH	In situ, annual
	Happy to eat seafood	GHHP CATI	GH	In situ, annual
Access: - Satisfaction with access	Fair access to harbour	GHHP CATI	GH	In situ, annual
- Satisfaction with ramps and public spaces	Frequency of use	GHHP CATI	GH	In situ, annual
	Number of ramps	GHHP CATI	GH	In situ, annual
	Access to public spaces	GHHP CATI	GH	In situ, annual
- Perceptions of air and water quality	Great condition	GHHP CATI	GH	In situ, annual
	Optimistic about future health	GHHP CATI	GH	In situ, annual
	Improved over the last 12 months	GHHP CATI	GH	In situ, annual
	Marine debris a problem	GHHP CATI	GH	In situ, annual

Indicator	Existing measure	Primary Monitoring program	Coverage (region & location)	In situ, RS or modelled
- Perception of barriers to access	Marine debris affects access	GHHP CATI	GH	In situ, annual
	Shipping reduced use	GHHP CATI	GH	In situ, annual
	Recreational boats reduced use	GHHP CATI	GH	In situ, annual
Liveability and wellbeing: - Contribution of harbour to liveability and wellbeing	Makes living in Gladstone a better experience	GHHP CATI	GH	In situ, annual
	Participate in community events	GHHP CATI	GH	In situ, annual
Cultural				
"Sense of place": - Distinctiveness	No place better	GHHP CATI	GH	In situ, annual
	Who am I	GHHP CATI	GH	In situ, annual
- Continuity	How long lived in the area	GHHP CATI	GH	In situ, annual
	Plan to be a resident in the next 5 years	GHHP CATI	GH	In situ, annual
- Self-esteem	Feel proud living in Gladstone	GHHP CATI	GH	In situ, annual
- Self-efficacy	Quality of life	GHHP CATI	GH	In situ, annual
	Input into management	GHHP CATI	GH	In situ, annual
- Attitudes to Gladstone Harbour	Key part of the community	GHHP CATI	GH	In situ, annual
	Great asset to the region	GHHP CATI	GH	In situ, annual
	Great asset to Queensland	GHHP CATI	GH	In situ, annual
- Values of Gladstone Harbour	Variety of marine life	GHHP CATI	GH	In situ, annual
	Opportunities for outdoor recreation	GHHP CATI	GH	In situ, annual
	Attracts visitors to the region	GHHP CATI	GH	In situ, annual
	Enjoy scenery and sights	GHHP CATI	GH	In situ, annual
	Spiritually special places	GHHP CATI	GH	In situ, annual
	Culturally special places	GHHP CATI	GH	In situ, annual
	Historical significance	GHHP CATI	GH	In situ, annual
Indigenous cultural heritage: - Cultural health	Spiritual and social values	GHHP CHA	GH	In situ, annual
	Scientific values	GHHP CHA	GH	In situ, annual
	Physical condition	GHHP CHA	GH	In situ, annual
- Management strategies	Protection	GHHP CHA	GH	In situ, annual
	Land use	GHHP CHA	GH	In situ, annual
	Cultural maintenance	GHHP CHA	GH	In situ, annual
Economic				
Economic performance: - Shipping activity	Shipping activity productivity – monthly shipping movements by cargo type	GHHP EA	GH	In situ and desk top
- Tourism expenditure	Gladstone Region's total tourism expenditure output	GHHP EA	GH	In situ and desk top

Indicator	Existing measure	Primary Monitoring program	Coverage (region & location)	In situ, RS or modelled
	Estimated spending from cruise ship passengers and crew	GHHP EA	GH	In situ and desk top
- Commercial fishing	Productivity of line (fish) fisheries	GHHP EA	GH	In situ and desk top
	Productivity of net (fish) fisheries	GHHP EA	GH	In situ and desk top
	Productivity of trawl (otter) fisheries	GHHP EA	GH	In situ and desk top
	Productivity of pot (mud crabs) fisheries	GHHP EA	GH	In situ and desk top
Economic stimulus: - Employment	Unemployment statistics for the Gladstone LGA	GHHP EA	GH	In situ and desk top
- Socio-economic status	Index of economic resources	GHHP EA	GH	In situ and desk top
Economic value (recreational): - Land-based recreation	Land-based recreation satisfaction and economic value	GHHP EA	GH	In situ and desk top
- Recreational fishing	Recreational fishing satisfaction and economic value	GHHP EA	GH	In situ and desk top
	Beach recreation satisfaction and economic value	GHHP EA	GH	In situ and desk top

4.2 Adequacy of existing monitoring programs

Sections 1 and 2 have noted proposed requirements for estuarine wetland monitoring programs to provide managers with relevant information to assist decision-making for a range of policy, research, reporting and management activities identified in Reef 2050 Plan and associated foundational activities. These requirements include:

- Understanding if critical attributes of estuarine wetland systems are changing, either improving in key health indicators of this ecosystem and its species in line with key outcomes outlined in the Reef 2050 Plan or declining and thus requiring further management interventions.
- Concise and clear Information at a number of scales for reporting Reef-wide (Outlook Report) through to regional scales (regional report cards) down to local catchment scales (the action scale for reporting on impact assessments and management effectiveness).
- Data that helps researchers and managers better understand cause and effect relationships, changing risks with changing development or use pressures.
- Capacity to map temporal and spatial changes to support important management tools.
- Information needs to be available in a timely manner for the different timescales of Reef managers and partners' decision, monitoring and reporting needs, e.g. major synthesis compiled every four to five years for incorporation into the Outlook Report

or State of the Environment Reporting, or annually for regional reporting, or as part of annual industry performance reporting.

These requirements are not exclusive to estuarine wetlands.

As this report has been undertaken in a very limited time-frame, our analysis of the adequacy of the existing monitoring programs is based on the authors' expert opinion only. We note the following:

Presently water quality monitoring programs are focused on ambient conditions and so there is a significant gap in our knowledge of event impacts on estuarine systems.

Sampling methods. The majority of the programs listed in Table 3 are undertaken by experienced science (e.g. DES, JCU, PCIMP) or industry delivery organisations and utilise accredited laboratories for their analyses. A number of the programs (e.g. CLMP, GHHP) are regularly reviewed by independent experts.

In the context of RIMReP, once the design for the physical-chemical, seagrass, marine mega-fauna and human dimensions sub-programs in particular are confirmed, then the current program designs and methods employed by relevant estuarine-focused programs should be assessed to ensure consistency of methods and capacity for sharing data as well as in-field operational efficiencies with relevant RIMReP sub-programs.

Spatial and temporal resolution. While the temporal resolution of many of the programs in Table 3 appears generally adequate (see earlier comment on event monitoring), the spatial resolution of current estuarine monitoring is woefully inadequate (see Table 4). Current monitoring in the estuaries appears to be focused on the estuaries in the four regional report card partnerships (Wet Tropics, Mackay Whitsunday, Fitzroy and Gladstone with Townsville Dry Tropics under development). This means that large tracts of the Reef coastline have no estuarine-focused monitoring including most of eastern Cape York, and most of the coastline between the mouth of the Fitzroy River north to Carmila which includes extensive and internationally significant estuarine wetlands such as Shoalwater Bay and Corio Bay. The Burdekin region is not monitored either despite having the other internationally recognised Ramsar wetland, Bowling Green Bay.

Further inquiries are needed to determine whether or not the Australian Defence Department undertakes any relevant estuarine monitoring in the Shoalwater Bay Defence Area. Local government and industry undertake monitoring for permitted environmentally relevant activities under the Environment Protection Act, Environment Protection Policy Water; these programs may also include monitoring in estuaries (e.g. local government and industry water quality monitoring contributing to current regional report cards).

Lastly, the focus of research shifted away from estuarine and coastal issues some years ago (with the closure of the Coastal Co-operative Research Centre) and so there is a significant lack of good information to inform management and monitoring in estuarine systems. It is important that research and monitoring are closely coordinated and supportive of one-another if management is to receive the best and most informative information to support its actions.

4.3 Gaps in current monitoring effort

Table 6 lists proposed additional indicators in estuaries by the four current regional report card partnerships or additional work that could add value to existing programs. These have been compiled from the relevant program designs of the regional report cards.

Table 6. Proposed improvements to the regional report card estuarine monitoring programs over the next 5 years [29, 30, 32, 33]

Indicator Group	Indicator	Regional Report Card			
		WT	M-W	F	GH
Pesticides (ms-PAF)	Install passive samplers in all non-CLMP estuaries to determine if risks are high.	●			
	Undertake grab samples in other estuaries identified as high risk in previous year	●			
	Increase confidence in pesticide reporting by increasing temporal sampling during the wet season. *		●		
	Include more pesticides into ms-PAF reporting when available.		●		
	Improve confidence by exploring inclusion of eReefs, if available.	●	●		
Estuarine riparian	Estuarine riparian extent and condition	●			
Mangrove and saltmarsh	Mangrove and saltmarsh extent and condition	●			●
Seagrass	Species composition, Area, Biomass – expand monitoring to all relevant estuaries	●			
Fish	Scope estuary fish indicators consistent with RIMReP design	●	●	●	
	Assess estuarine fish tissue mercury, pesticides, PCB congeners, PBDE, % moisture and lipid content			●	
Mud crabs	Expand present fisheries monitoring program to include a tag and release element			●	
Water quality	Indicators for metals, pH, salinity, micro-contaminants and endocrine disruptors including during events	●			
	Improve confidence by exploring inclusion of eReefs, if available.	●	●		
Flow	Fill indicator gaps for flow including establishing additional gauging stations upstream of relevant estuaries.	●	●		
Toxicants	Undertake risk assessment of toxicants of potential concern.			●	
Biomass assessments	Determine biomass proportion of top predators (trophic group 1); aquatic invertivores (trophic group 2); terrestrial insectivores (trophic group 3); and biomass ratio of top predators (TG1): detritivores (TG4)			●	

* To progress this improvement objective the MW Healthy Rivers to Reef Partnership initiated the 'Additional pesticide monitoring program in estuaries (MWHR2RP)' in November 2018, as listed in Table 3. Continuation of this program is dependent on maintenance of current Partnership funding.

Gladstone Healthy Harbour Partnership has developed a method to determine mangrove condition based on work undertaken by the MangroveWatch Hub and TropWATER Centre at JCU. The measures used to gauge mangrove condition include: % Extent; Canopy; and Shoreline. GHHP will be releasing soon a report detailing the methodology for these assessments.

5. New technologies for monitoring estuarine wetlands on the Great Barrier Reef

Monitoring in the World Heritage Area can be challenging because of its immense size, the inaccessibility of many areas at key times (e.g. wet season), or the lack of facilities and infrastructure to access the coast over large areas. This is particularly true for many coastal areas where literally no facilities for accessing the coast exist for hundreds of kilometers. Additionally, most World Heritage Area estuaries have a significant population of large saltwater crocodiles. This makes most monitoring costly and fraught with difficulties that can be insurmountable for any routine on-ground monitoring activities.

For this reason, monitoring technologies that can collect data remotely and cover large distances at the same time, or equipment that can be deployed to collect data over extended periods when access might otherwise be impossible, are ideal monitoring technologies for the World Heritage Area. This is especially relevant in remote areas like the east coast of Cape York Peninsula or during wet season flooding. It has been in this area, which represents approximately one-third of the World Heritage Area coast and is still considered to be generally in good condition, that monitoring in the past has been very patchy.

The technologies exist but are underutilised for monitoring estuarine communities across the World Heritage Area coastal systems. This includes high-resolution satellite imagery to map the health and community composition of mangrove species. The methodology being developed uses a normalised difference vegetation index based on a number of mangrove leaf surface reflectance mosaics as a measure of 'cover' which is compared with the mangrove and saltmarsh vegetation extent mapping tools already in place. This methodology is proposed for use in the Gladstone report card area and has been used to identify die back associated with climate change in the Gulf of Carpentaria [24]. This work could be value added to existing Paddock to Reef wetland mapping activities as part of the Reef 2050 Water Quality Improvement Plan monitoring program. Shortcomings of remote sensing are that it's a method that requires cloud free images which becomes a problem during the wet season especially in the north of the World Heritage Area.

The other technology at present underutilised in the World Heritage Area estuarine system is the range of continuous recording water quality measurement instrumentation being used by CSIRO as part of the calibration and validation work supporting the eReefs model [25]. This technology has been piloted and evaluated across several Queensland estuarine settings, using both existing and purpose-built infrastructure models. The work is addressing boundary issues along the coast that the eReefs model is experiencing. It is also in recognition that the present catchment modeling program does not recognise potential in-system transformations of pollutants that can occur in estuaries. Hence, using this technology is useful in providing for and reinforcing the connection between the catchment and marine modeling environments. The Great Barrier Reef Catchments Loads Monitoring Program (CLMP) has augmented some gauging stations with automated sampling stations and has investigated the use of continuous monitoring technologies at three estuarine sites already.

However, there are very few monitoring programs utilising advanced sensors for measuring nutrient, suspended sediment particle size and carbon parameters except for research focused activities. The advantage of using permanent or semi-permanent equipment is that this equipment can provide a continuous measure of the broad range of water quality parameters that require monitoring, and the instruments can be left in place for extended periods, minimising the need for short-term maintenance and data collection. This equipment can also be put in place to collect data at the critical times e.g. during floods when access is otherwise restricted or impossible.

New communication advancements and cheap data storage systems now allow easy retrieval of large quantities of data. Instrumentation requires regular recalibration to ensure data reliability and veracity but much of this can be accomplished in the field. Biofouling of instruments left in the field for extended periods, and equipment failure for a number of reasons including loss of power, loss of equipment during extreme weather and vandalism which then results in the loss of data, remain as ongoing issues.

6. Recommendations for integrated monitoring of estuarine wetlands on the Great Barrier Reef

Given the location of estuaries, being effectively the boundary area between marine and terrestrial systems, the estuarine wetlands monitoring program has the capacity to integrate a number of existing programs while focusing specifically on monitoring needs for this ecosystem. The program should be based on a stratified hierarchical monitoring framework to provide the best overall solution for capturing information that can meet the varied spatial and temporal management reporting requirements across a number of outcome areas. Such a program also provides a framework to capture, store and synthesise data collected for different purposes at different scales.

For example, estuarine plant monitoring would use the existing ecosystem mapping undertaken by the Queensland Herbarium to monitor change in the extent of mangrove, saltmarsh and salt flat areas. In conjunction with satellite mapping of ‘cover’, using the NDVI technique at selected sites will give a broad scale picture of extent and condition of estuarine ecosystem health in the World Heritage Area, suitable for reporting through Outlook. Nested within this broad picture should be a mud crab monitoring program already undertaken by Fisheries Queensland (in Gladstone presently but had much broader coverage in the past) but expanded to have monitoring in representative sites in all the major estuarine areas in the World Heritage Area. The mud crab monitoring program should also be expanded to include a tag and release element to its data collection, as outlined in the Fisheries Research Development Corporation (FRDC) study from 2005[37]. This would provide the basis for a nested ecosystem health monitoring program for estuarine systems using crabs as a bio-indicator of the health of the system. It would also provide a connection to support integration of the program with both community benefit and economic benefit monitoring programs. Developing and adding an estuarine fish diversity index as an additional independent ecosystem health indicator, as identified in recent regional report cards for the Wet Tropics and Mackay Whitsunday NRM regions would further support estuarine condition assessments. This should be developed through the other relevant RIMReP programs.

For water quality the program should utilise the existing DES Estuarine Ambient Monitoring Program with an expansion to provide sites in all Reef NRM regions with sufficient sites per region to be a statistically valid sample of the representative estuarine systems in the region. This would mean additional sites in Cape York, Burdekin Dry Tropics and Fitzroy regions in the first instance. The program should also introduce additional sampling during the wet season. This sampling method could include some additional continuous recording instrumentation at monitoring sites to ensure that monitoring is in place at the start of the wet season to capture first flush discharges. It should also include pesticide monitoring. Additional monitoring effort in estuarine systems via an expansion of sites in the CLMP to include an element of sediment sampling based on risk assessments should also be considered.

Seagrass monitoring is to be undertaken as part of the RIMReP seagrass monitoring program. There should be efforts made to ensure co-location of estuarine seagrass monitoring sites with other estuarine monitoring activities so that inferences can be made between changing ecosystem health indicators and physico-chemical or other pressure trends.

The recommendations for improved estuarine monitoring are summarised below:

1. The present ambient estuarine water quality monitoring program(s) should be expanded to include;
    a. A more comprehensive coverage of estuaries along the Reef coast including high value systems i.e. Shoalwater and Corio Bay Ramsar site,
    b. The program should include increased event sampling using continuous monitoring technologies and
    c. The data collection should be expanded to include a number of other contaminants or water quality components including pesticides, heavy metals and pH.
2. Estuarine ecosystem extent and condition monitoring should be expanded to include:
    a. Regular reporting of mangrove and saltmarsh (including saltpan) extent should be continued as part of Queensland's vegetation management arrangements but enhanced through;
        i. The addition of mangrove health assessments (as developed through GHHP) should be undertaken in all NRM regions and where possible to complement other monitoring efforts, especially water quality monitoring, and
        ii. Mud crab monitoring should be reinstated and enhanced with demographic assessment elements and mark, capture and release methodologies (as per published FRDC research methodologies).

iii. Investigate potential for a pilot of grapsid crab monitoring at a regional level to support improved understanding of estuarine health indicators.

Table 7 provides more detail on the proposed priority indicators across a range of monitoring programs that are relevant for improved estuarine monitoring. We have not provided further prioritisation of the proposed indicators as we consider that this is best done via the proposed workshop described below to confirm priority estuaries and risks in each Reef NRM region. This will need to be informed by the final program design for other relevant themes of RIMReP including water quality, seagrass and megafauna.

Overall, we are suggesting an enhancement and or expansion of existing programs with additional indicators for ascertaining the condition of key elements of estuarine wetlands. Importantly, this report highlights the patchy and opportunistic nature of existing monitoring of estuarine wetlands. Large areas of the Authority's estuarine wetlands are effectively not monitored including Cape York, the Burdekin Dry Tropics region and the northern central Queensland area (between Carmila and the Fitzroy River). This includes the two Ramsar wetlands of international importance, Shoalwater - Corio Bay and Bowling Green Bay.

To develop a comprehensive estuarine monitoring program, we recommend that a workshop of experts is convened to confirm which estuaries within each NRM region should be monitored, the priority ambient monitoring indicators based on an assessment of risk for each estuary, appropriate event-based monitoring, and critical links with relevant proposed RIMReP programs. This report should be used as the background report for the workshop.

Table 7. Proposed priority indicators for estuarine wetland monitoring

Priority Indicator	Survey Method	Survey Location (Spatial)	Survey Frequency (Temporal)	Other information
Spatial description and rate of sea level rise along the Reef coast.	BOM Australian Baseline Sea Level Monitoring Project	Reef-wide	Continuous	Strategic for overall RIMReP program
Extreme events (cyclones)	BoM cyclone tracking	Reef-wide	Continuous	Strategic for overall RIMReP program
Nutrients (N and P species) including dissolved inorganic nitrogen (DIN)	Mix of grab samples and instrument collection	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	Ambient (monthly) and event preferably continuous	Link with other RIMReP physico-chem sampling programs
Chlorophyll a	Mix of grab samples and instrument collection	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	Ambient (monthly) and event preferably continuous	Link with other RIMReP Chl-a sampling programs
Turbidity	Mix of grab samples and instrument collection	Representative estuarine systems in each Reef NRM region; sites per	Ambient (monthly) and event	Link with other RIMReP turbidity sampling programs

Priority Indicator	Survey Method	Survey Location (Spatial)	Survey Frequency (Temporal)	Other information
		estuary to be determined.	preferably continuous	
Secchi depth	Secchi disks	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	Ambient (monthly) and event	Link with other RIMReP sediment sampling programs
PSII herbicides	As for RIMReP Physico-chem method	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	Monthly in wet season	Identified in Table 6.
Non-PSII herbicides including emerging ‘alternative’ herbicides	As for RIMReP Physico-chem method	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	Monthly in wet season	Identified in Table 6.
Pesticide/ Insecticides	As for RIMReP Physico-chem method	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	TBD	Identified in Table 6.
pH	Mix grab sample and instrument collection	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	Ambient (monthly) and event preferably continuous	Part of DES ambient estuarine program. Identified in Table 6.
Soluble metals especially aluminium and iron	Grab sample	Representative estuarine systems in each Reef NRM region; sites per estuary to be determined.	Monthly and event	Require laboratory analysis. Identified in Table 6.
Barriers (proportion of modification to system connectivity)	Remote sense and in situ	Representative estuarine systems in each Reef NRM region	Annual	Method used by MWHR2RP regional report card.
Flow	Desk top; requires 10 flow metrics	Representative estuarine systems in each Reef NRM region	Annual	Method used by WTHWP and MWHR2RP regional report cards. Identified in Table 6.
Seagrass Habitat assessment: - species present - abundance	As for RIMReP seagrass method	Representative estuarine systems in each Reef NRM region	Annual	Identified in Table 6.

Priority Indicator	Survey Method	Survey Location (Spatial)	Survey Frequency (Temporal)	Other information
Seagrass Health assessment: - size of meadows - sexual reproduction - biomass characteristics - meadow connectivity (if applicable)	As for RIMReP seagrass method	Representative estuarine systems in each Reef NRM region	Annual	Identified in Table 6.
Mangrove extent	% mangrove loss since pre-clear using Qld herbarium's regional ecosystem mapping	Representative estuarine systems in each Reef NRM region	Annual	Identified in Table 6.
Mangrove condition	Assess mangrove cover using satellite imagery and the NDVI methodology	Representative estuarine systems in each Reef NRM region	Annual	GHHP method. Identified in Table 6.
Saltmarsh extent	% saltmarsh loss since pre-clear using Qld herbarium's regional ecosystem mapping	Representative estuarine systems in each Reef NRM region	Annual	Identified in Table 6.
Mud crab population	In situ sampling	Representative estuarine systems in each Reef NRM region	Annual/ seasonal	Identified in Table 6.
Snubfin dolphin	As for RIMReP snubfin dolphin program design	Estuarine systems identified as Snubfin dolphin range	TBD	
Dugong	Aerial survey and StrandNet data	Key sites determined by Reef dugong survey	TBD	Link with RIMReP Reef-wide dugong monitoring
Fish	TBD	Representative estuarine systems in each Reef NRM region	TBD	Link with RIMReP fish monitoring program. Identified in Table 6.
Social indicators	CATI survey and ABS and other data	Each NRM region	Annual	GHHP method and link with RIMReP Human Dimension monitoring

Priority Indicator	Survey Method	Survey Location (Spatial)	Survey Frequency (Temporal)	Other information
Economic indicators	CATI survey and ABS and other data	Each NRM region	Annual	GHHP method and link with RIMReP Human Dimension monitoring
Indigenous cultural heritage indicators	Field work and interviews	Each NRM region	To be determined	GHHP method and link with RIMReP Indigenous Cultural Heritage and Human Dimension monitoring
Marine Debris	Density of plastics recovered (per unit effort) through beach cleanups	Determined by risk assessment	To be determined	Link with regional report card and other programs

Because of the limited time available to prepare this report we have not undertaken an assessment of the resources required to implement the recommended monitoring programs.

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