Mackay-Whitsunday-Isaac 2020 Report Card Methods

Technical Report
Regional Report Cards Technical Working Group
July 2021

Authorship Statement

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HEALTHY RIVERS TO REEF PARTNERSHIP
MACKAY-WHITSUNDAY-ISAAC

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Terms and Acronyms

ABS	Absolute (positive) value
Adopted middle thread distance	The distance in kilometres, measured along the middle of a watercourse, that a specific point (in the watercourse) is from the watercourse's mouth.
AIMS	Australian Institute of Marine Science
AM	Annual median (AM) or the mean of a measured indicator.
AMDI	Australian Marine Debris Initiative
Basin	An area of land where surface water runs into smaller channels, creeks or rivers and discharges into a common point and may include many sub-basins or sub-catchments. Also known as river basin or catchment.
Biodiversity	The variability among living organisms from all sources. It includes diversity within species and between species, and the diversity of ecosystems.
Biomass	The total quantity or weight of organisms over a given area or volume.
BoM	Bureau of Meteorology
Chl-*a*	Chlorophyll-*a*: An indicator of overall phytoplankton biomass. It is widely considered a useful proxy for measuring nutrient availability and the productivity of a system.
CI	Confidence interval
COVID-19	Coronavirus Disease 2019 – in reference to the worldwide pandemic in 2020-2021
CTF	Cease-to-flow
CV	Coefficient of variation
DDL	Declared downstream limit
DES	Department of Environment and Science, Queensland Government
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
Ecosystem	A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.
Ecosystem health	A concept that integrates environmental state and conditions with the impacts of anthropogenic activities to provide information for the sustainable use and management of natural resources.
EC	An enclosed coastal (EC) water body includes shallow, enclosed waters near an estuary mouth and extends seaward towards deeper, more oceanic waters further out. The seaward cut-off of an EC water body is defined by the Great Barrier Reef Marine Park Authority (GBRMPA, 2010).
eReefs	A Commonwealth Scientific and Industrial Research Organisation (CSIRO) program to collate data, and new and integrated modelling to produce powerful visualisation, communication and reporting tools for the Great Barrier Reef.
ESF	Empirical survivor function

Estuary	The aquatic environment at the interface between freshwater and marine ecosystems.
Fish (as an index)	Fish community health is evaluated, and included in the ecosystem health assessment (coasters). Inclusion in the Report Card will contribute to an understanding of the health of local fish communities.
Fish Barriers (as an indicator)	Fish barriers relate to any man-made barriers which prevent or delay connectivity between key habitats which has the potential to impact migratory fish populations, decrease the diversity of freshwater fish communities and reduce the condition of aquatic ecosystems (Moore, 2015).
Flow (as an indicator)	Flow relates to the degree that the natural river flows have been modified in the region's waterways. This is an important indicator due to its relevance to ecosystem and waterway health.
FRP	Filterable reactive phosphorus
FSS	QLD Health Forensic and Scientific Services Laboratory
GBR	Great Barrier Reef
GBRCLMP	Great Barrier Reef Catchment Loads Monitoring Program
GBR Report Card	Great Barrier Reef Report Card developed under the Reef Water Quality Protection Plan (2013).
GBRMPA	Great Barrier Reef Marine Park Authority
GV	Guideline value
HEV	High ecological value: the management intent (level of protection) to achieve an effectively unmodified condition.
Impoundment (also impoundment length)	An indicator used in the 'in-stream habitat modification' indicator for freshwater basins in the region. This index reports on the proportion (%) of the linear length of the main river channel inundated at the Full Supply Level of artificial in-stream structures such as dams and weirs.
Index	Is generated by indicator categories (e.g. water quality made up of nutrients, water clarity, chlorophyll-*a* and pesticides).
Indicator	A measure of one component of an environmental dataset (e.g. particulate nitrogen).
Indicator category	Is generated by one or more indicators (e.g. nutrients made up of particulate nitrogen and particulate phosphorus).
Inshore (as a reporting zone)	Inshore is a reporting zone in the Mackay-Whitsunday-Isaac Report Card that includes enclosed coastal, open coastal and mid-shelf waters.
In-stream habitat modification (as an indicator)	This basin indicator category is made up of two indicators: fish barriers and impoundment length.
IQQM	Integrated water quantity and quality simulation model – used to model pre-development flow for the flow tool score calculations.
ISP	Independent Science Panel established under the Reef Water Quality Protection Plan (now Reef 2050 Water Quality Improvement Plan), who have independently reviewed the methodologies involved in the report card assessments.
JCU	James Cook University

LAT	Lowest astronomical tide
LOR	Limit of reporting
LTMP	Long-Term Monitoring Program – run by the Australian Institute of Marine Science (AIMS).
Macroalgae (cover)	An indicator used in part to assess coral health. Macroalgae is a collective term used for seaweed and other benthic (attached to the bottom) marine algae that are generally visible to the naked eye.
MD	The management intent (level of protection) to achieve a moderately disturbed (MD) condition.
Measure	A measured value that contributes to an indicator score for indicators that are comprised of multiple measures (e.g. flow, estuary fish barriers).
Mid-shelf (water body)	Mid-shelf water bodies begin 15 km from the enclosed coastal boundary and extend to 60 km in the Mackay-Whitsunday-Isaac Region (GBRMPA, 2010).
MMP	Marine Monitoring Program – Great Barrier Reef monitoring program, led by GBRMPA. This provides water quality, coral and seagrass data for the Central and Whitsunday reporting zones in the Report Card.
MoA	The mode of action is used to classify pesticides according to how they exert their effect on the target organism. The mode of action will be defined by its biochemical effects.
MPA	Management Practice Adoption
MWI	Mackay-Whitsunday-Isaac
n	Sample size
NATA	National Association of Testing Authorities
NB	Negative binomial
NO_x	Oxidised nitrogen (nitrate (NO_3) and nitrite (NO_2))
NQBP	North Queensland Bulk Ports Corporation Ltd
NRM	Natural resource management organisation
Offshore Zone	The Offshore Zone is a reporting zone in the Mackay-Whitsunday-Isaac Report Card that includes mid-shelf and offshore water bodies.
Offshore (water body)	Offshore water bodies begin 60 km from the enclosed coastal boundary and extend to 280 km in the Mackay-Whitsunday-Isaac Region (GBRMPA, 2010).
OC	Open coastal (OC) water bodies are delineated by the seaward boundary of enclosed coastal waters to a defined distance across the continental shelf. For the Mackay-Whitsunday-Isaac Region, open coastal waters extend from enclosed coastal waters to 15 km (GBRMPA 2010).
Overall Score	The overall scores for each reporting zone used in the Report Card are generated by an index or an aggregation of indices.
P2R	Paddock to Reef Integrated Monitoring, Modelling and Reporting Program

Palustrine Wetlands	Primarily vegetated non-channel environments of less than eight hectares. Examples of palustrine wetlands include billabongs, swamps, bogs, springs, etc.
Pesticides (as an indicator)	Incorporating up to 22 herbicides and insecticides with different modes of action. A list of the relevant chemical components is provided in Table 4.
Pesticide Risk Metric	Refers to the methodology for estimation of ecological risk associated with pesticide pollution.
Phys-chem	The physical-chemical indicator category that includes two indicators: dissolved oxygen (DO) and turbidity.
PN	Particulate nitrogen
PONSE	Proportion of native (fish) species expected
Ports	NQBP Port Authority
PP	Particulate phosphorus
Pre-clearing	Pre-clearing vegetation is defined as the vegetation or regional ecosystem present before clearing. This generally equates to terms such as ‘pre-1750’ or ‘pre-European’ used elsewhere (Neldner et al., 2019).
Pre-development Flow	The pattern of water flows, during the simulation period, using the IQQM computer program as if there were no dams or other water infrastructure in the plan area, and no water was taken under authorisations in the plan area[1].
PRM	Pesticide Risk Metric
PSII herbicides	Photosystem II inhibiting herbicides (ametryn, atrazine, diuron, hexazinone, tebuthiuron, bromacil, fluometuron, metribuzin, prometryn, propazine, simazine, terbuthylazine, terbutryn).
PSII-HEq	Photosystem II herbicide equivalent concentrations, derived using relative potency factors for each individual PSII herbicide with respect to a reference PSII herbicide, diuron (Gallen et al., 2014).
QPSMP	Queensland Ports Seagrass Monitoring Program
QLD Government	The Queensland Government includes several departments that provide data sources and support for the report card. Key departments for the report card are the Department of Environment and Sciences (includes management of the GBRCLMP), the Department of Regional Development, Manufacturing and Water (includes management of water monitoring), and the Department of Resources (includes management of Queensland Spatial).
RAP	In the context of freshwater flow - River analysis package, OR In the context of coral monitoring - Representative Areas Program – Great Barrier Reef Marine Park Authority (GBRMPA) coral monitoring program to develop and monitor new zoning in the Marine Park.
RCA	Reef Check Australia
RE	Regional ecosystem

[1] Queensland Government 2016. Water Plan (Wet Tropics) 2013. Water Act 2000.
https://www.legislation.qld.gov.au/view/pdf/2016-12-06/sl-2013-0282

RIMReP	Reef 2050 Integrated Monitoring and Reporting Program
Riparian extent (as an indicator)	An indicator used in the assessments of both basin and estuarine zones in Report Cards released to date. This indicator uses mapping resources to determine the extent of the vegetated interface between land and waterways in the region.
SD	The management intent (level of protection) to achieve a slightly disturbed (SD) condition.
Secchi	Secchi disk depth (m) - a measure of water clarity.
SF	Scaling factor
SIP	Southern Inshore Monitoring Program (Partnership-funded)
SMD	The management intent (level of protection) to achieve a slightly to moderately disturbed condition.
Standardised condition score	The transformation of indicator scores into the MWI Report Card scoring range of 0 to 100.
TSS	Total suspended solids
TWG	Technical Working Group for the Wet Tropics, Dry Tropics and MWI regional report cards.
UNSW	University of New South Wales
UQ	University of Queensland
Waterway	All freshwater, estuarine and marine bodies of water, including reefs, and storm drains, channels and other human-made structures in the MWI Region.
Water quality guideline	For purposes of waterway assessment, the term water quality guideline refers to values for condition assessment of water quality drawn from a range sources including water quality objectives scheduled under the Environmental Protection (Water) Policy 2009, and water quality guideline values obtained from the Queensland Water Quality Guidelines (DEHP 2009), the GBRMPA Guidelines (GBRMPA 2010) and the ANZG (2018)
Water quality objective (WQO)	Water quality objective refers to values for condition assessment of water quality scheduled under the Environmental Protection (Water) Policy 2009.

Executive Summary

The Mackay-Whitsunday-Isaac (MWI) Healthy Rivers to Reef Partnership (the Partnership) was established in October 2014 with the primary focus of producing an annual report card on the health of our region's waterways. The boundaries of the region extend latitudinally from the Don River in the north, to the Carmila coast in the south.

The 2020 Report Card, reporting on the 2019-20 financial year, is the Partnership's seventh report card, demonstrating the region's ongoing commitment to understanding and caring for the local environment. This commitment is matched outside of regional reporting boundaries, with the MWI Report Card being one of five regional report cards released annually in the Great Barrier Reef (GBR) region.

The 2020 Report Card contains data from a variety of condition assessments of our local waterways, which include freshwater, estuarine and inshore and offshore marine environments. For each of these waterway types, a series of environmental *indicators* are reported, which are aggregated into *indicator categories* and then into *indices*.

The purpose of this document is to provide the detailed methods of the 2020 MWI Report Card, including assessments of condition and state for freshwater, estuarine, inshore marine and offshore marine environments. Specifically, this methods report describes:

- Data collection methods,
- Development of condition assessments scoring methods,
- Development of progress to targets scoring methods, and
- Confidence associated with results

i. Freshwater Basins

Freshwater monitoring is conducted in five basins in the region, including the Don (Don River), Proserpine (Proserpine River), O'Connell (O'Connell River, two locations), Pioneer (Pioneer River), and Plane (Sandy and Plane Creeks) basins.

Monitoring within freshwater basins is grouped by water quality, habitat & hydrology, and fish indices (Figure I). Within these indices, indicator categories and indicators are updated either every year (water quality), every three years (fish), or between one and four years depending on the specific indicator (habitat & hydrology).

The water quality index includes sediment, nutrients, and pesticides (Pesticide Risk Metric (PRM) based on 22 pesticides). The habitat and hydrology index includes riparian extent, wetland extent, flow, and in-stream habitat modification. The fish index includes pest fish, native fish, and fish assemblage indicator categories (Figure I).

Data are sourced from a range of Partnership-funded and previous existing monitoring projects such as, the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP), fish barrier monitoring

(Catchment Solutions Pty Limited), Aquatic Ecosystem Health monitoring (Department of Environment and Science (DES)), as well as Regional Ecosystem (RE) mapping data contributed by DES and the Department of Resources. Data are collected using various techniques, including remote sensing, automated sampling, grab sampling, on-ground field assessments, and vessel electrofishing surveys.

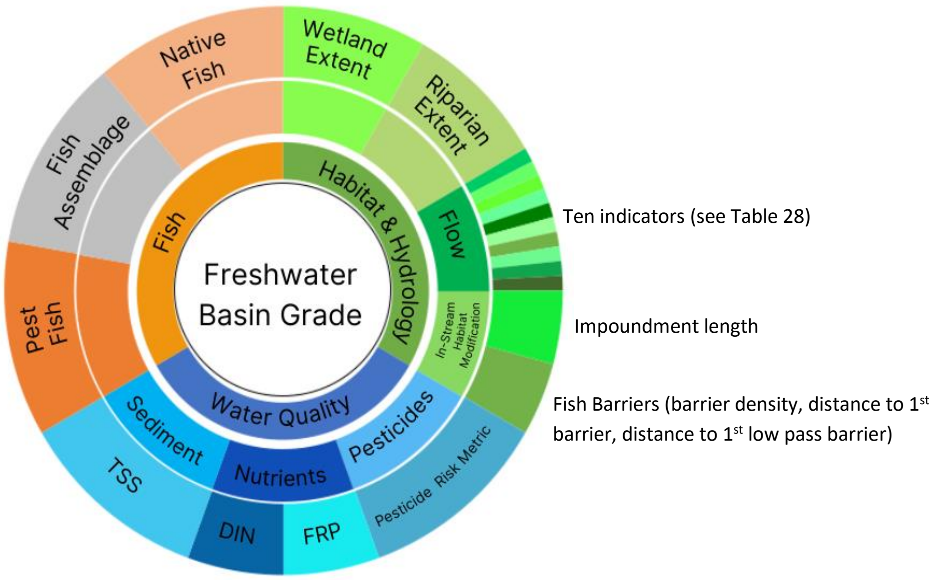


Figure I. Indicator/s (outer ring), indicator categories (middle ring) and index/indices (inner ring) that contribute to overall freshwater basin scores/grades. Where no indicator category is listed this represents that the indicator/s (e.g. native fish) do/does not fit into any specific category below the index level (e.g. fish). Note: TSS = total suspended solids, DIN = dissolved inorganic nitrogen and FRP = filterable reactive phosphorus.

ii. Estuaries

The MWI Report Card reports on eight estuaries within four basins:

- Proserpine Basin - Gregory River,
- O’Connell Basin – O’Connell River and St Helens/Murray Creeks,
- Pioneer Basin – Vines Creek*
- Plane Basin – Sandy Creek, Plane Creek, Rocky Dam Creek and Carmila Creek.

*Note: Vines Creek is more indicative of the urban Mackay city area rather than the greater Pioneer Basin.

Monitoring within estuaries is grouped by water quality, habitat and hydrology, and fish indices (Figure II). Within these indices, indicator categories and indicators are updated either every year (water quality) or between one and four years depending on the indicator (habitat & hydrology). The fish index and flow indicator category are still under development and therefore are not reported in the 2020 Report Card.

The water quality index includes physical-chemical, nutrients and pesticides (PRM based on 22 pesticides) indicator categories. The habitat and hydrology index includes mangrove and saltmarsh extent, riparian extent, flow, and fish barriers indicator categories (Figure II).

Data are sourced from a range of Partnership-funded and previously existing monitoring projects such as, the Regional Estuary Monitoring Program (DES), the Estuary Pesticide Monitoring Program (the Partnership and Reef Catchments), fish barrier monitoring (Catchment Solutions), as well as RE mapping data contributed by DES and the Department of Resources. Data are collected using various techniques, including remote sensing, grab sampling, and on-ground field assessments.

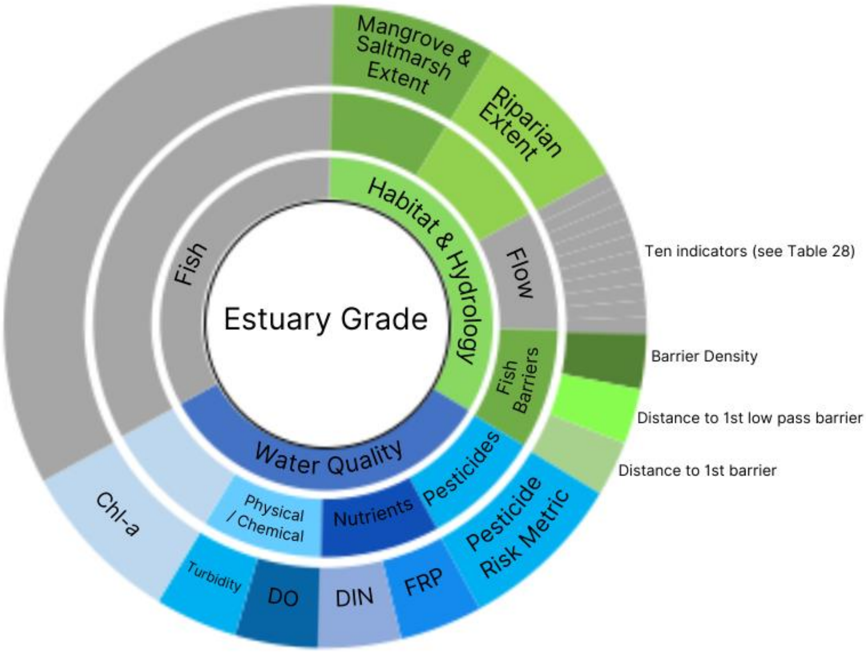


Figure II. Indicator/s (outer ring), indicator categories (middle ring) and index/indices (inner ring) that contribute to overall estuary scores/grades. Where no indicator category is listed this represents that the indicator/s (e.g. riparian extent) do/does not fit into any specific category below the index level (e.g. habitat & hydrology). Dark grey represents no data. Note: chl-*a* = chlorophyll-*a* concentration*,* DO = dissolved oxygen, DIN = dissolved inorganic nitrogen and FRP = filterable reactive phosphorus.

iii. Inshore and Offshore Marine

Reporting for the MWI marine environment is split into four inshore zones (the Northern, Whitsunday, Central and Southern Zones) and one offshore zone. Monitoring is done on coral, water quality and seagrass (inshore only) indices, with the fish index an aspirational goal for future report cards (Figure III). All indicators within these indices are updated annually. For the first time, the 2020 Report Card will also include an inshore and urban litter metric, although this does not contribute to overall zone scores.

In the inshore marine region, the water quality index includes water clarity, chlorophyll-*a* (chl-*a*), nutrients, and pesticides (PRM based on 22 pesticides) (Figure III). The seagrass index includes indicators of area, abundance, nutrient status, species composition, biomass, and reproductive effort. The coral index includes indicators of species composition, community change (%), macroalgal cover, juvenile density and total cover (%) (Figure III). In the offshore marine region, the water quality index includes sediment and chl-*a* indicators. The coral index includes community change (%), juvenile density and total cover (%) (Figure III).

Data are sourced from a range of existing monitoring programs such as, the North Queensland Bulk Ports Corporation Ltd (NQBP) environmental monitoring program, the GBR Marine Monitoring Program (MMP), the Australian Institute of Marine Science (AIMS) Long-term Monitoring Program (LTMP) and the GBR Marine Park Authority (GBRMPA) Representative Areas Program (RAP), as well as the Partnership-funded Southern Inshore Monitoring Program (SIP) and citizen science projects. Data are collected using various techniques, including remote sensing, boat, helicopter or shore-based coral and seagrass surveys, water grab samples, and in-situ turbidity loggers and pesticide samplers.

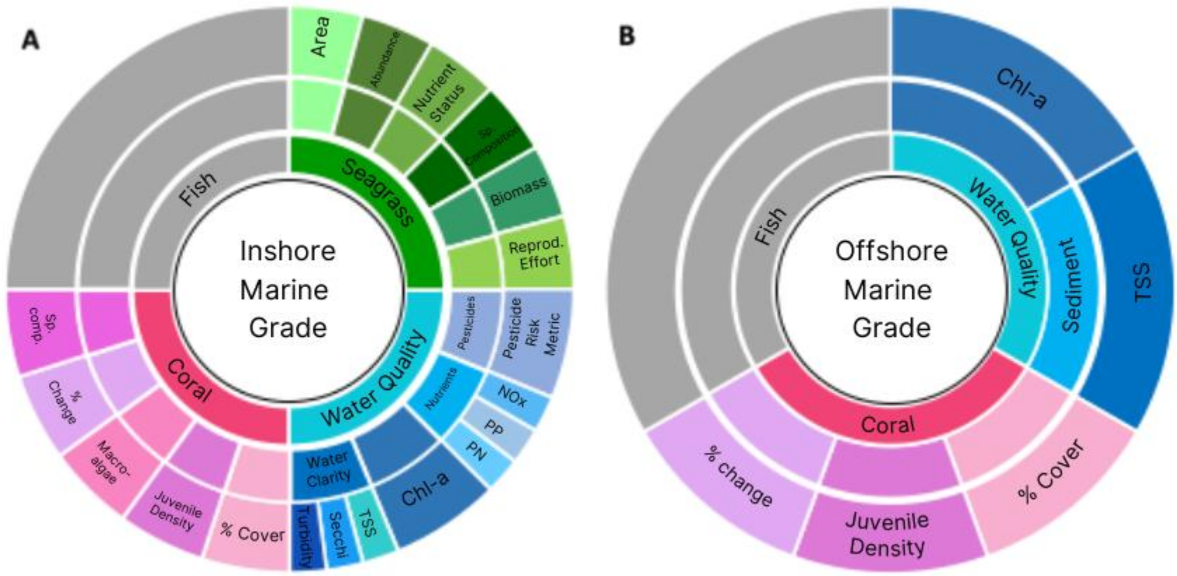


Figure III. Indicator/s (outer ring), indicator categories (middle ring) and index/indices (inner ring) that contribute to overall inshore (A) and offshore (B) marine zone scores/grades. Where no indicator category is listed this represents that the indicator/s (e.g. juvenile density) do/does not fit into any category below the index level (e.g. coral). Dark grey represents no data. Note: NO_x = oxidised nitrogen, PP = particulate phosphorus, PN = particulate nitrogen, TSS = total suspended solids, chl-*a* = chlorophyll-*a* concentration, sp. comp = species composition and reprod. effort = reproductive effort.

iv. Scoring

Ordinal categories are used to describe scores for the condition of indicators, indicator categories, indices and the overall basin/estuary/zone grade. This follows a five-point scoring system: very good (A), good (B), moderate (C), poor (D), very poor (E).

All indicators have specific scoring ranges and bandwidths which correspond to the five-point system. Results for indicators that have differing scoring ranges and bandwidths are translated into a common scoring range before aggregating. The common scoring range is based on that used by the GBR Report Card (Table I).

Table I. Overall scoring range, associated grades and colour codes as per the GBR Report Card.

Scoring Range	Condition Grade and Colour Code
81 - 100	A = Very good
61 to <81	B = Good
41 to <61	C = Moderate
21 to <41	D = Poor
0 to <21	E = Very poor

1. Introduction

1.1. Purpose of this Document

This document aims to detail the methods used in the production of the Mackay-Whitsunday-Isaac (MWI) Healthy Rivers to Reef Partnership (the Partnership) 2020 Report Card. This includes condition assessments and scoring of the environmental indicators in freshwater basins, estuaries and inshore and offshore marine environments, along with human dimensions such as cultural heritage and agricultural stewardship results. Specifically, this document describes:

- The indicator selection process,
- Data collection methods, and
- Scoring methods.

1.2. Background

The Partnership was established in October 2014, with the primary focus of producing an annual report card on the health of the MWI Region's waterways, including creek, river, estuarine, wetland and marine ecosystems (Figure 1).

The 2020 Report Card includes condition assessments of the freshwater, estuarine and marine ecosystems, extending to the eastern boundary of the Great Barrier Reef (GBR) Marine Park. Human Dimensions are also reported on in the region, including waterway stewardship and cultural heritage. For each index, a series of indicators, often broken into different indicator categories, is used to provide a holistic assessment of these environmental, social, cultural and economic factors.

Since the release of the Pilot Report Card in 2014, there has been significant review and refinement with new indices and indicators being added. The release of our seventh report card now includes a litter index for the first time and more use of citizen science than ever before. Filling additional knowledge gaps continues to be extremely important to the Partnership and our priorities for this will be revisited over the coming years and formalised in the program design revision scheduled to occur after the release of the 2021 Report Card. For more information on the MWI Report Card and Partnership, refer to the MWI Report Card Program Design 2017 to 2022[2]. The indicator selection process and descriptions of the environmental indicators are also detailed in the Program Design.

[2] https://healthyriverstoreef.org.au/report-card/program-design/

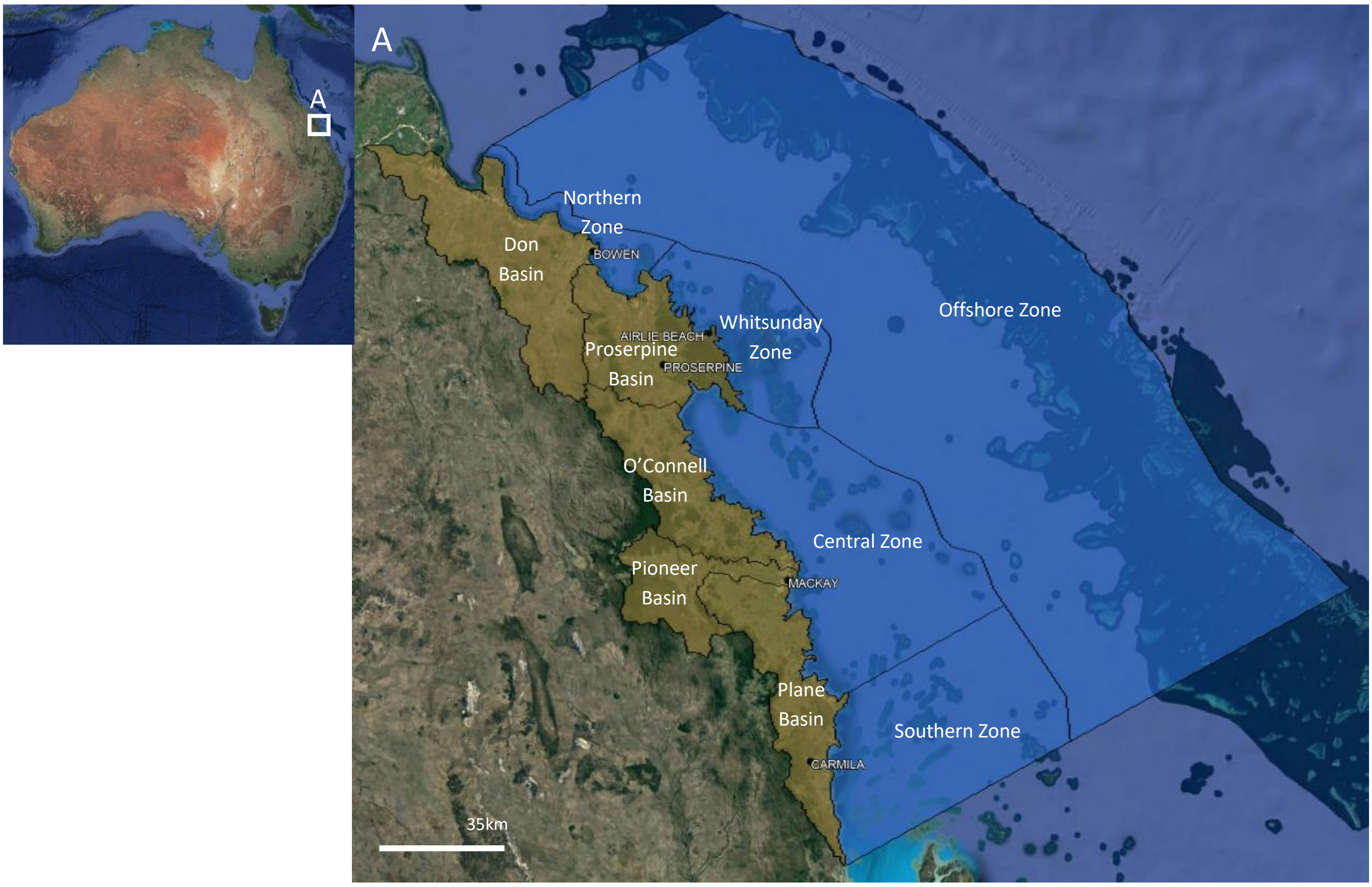


Figure 1. The MWI Healthy Rivers to Reef Partnership reporting region. Basins are shown in brown, while marine zones are shown in blue.

1.3. Terminology

The Report Card assesses different ecosystem health (environmental) indicators to report on the overall condition of MWI waterways. Scores for indicators are aggregated depending on the aspect of the environment they are assessing and typically follow three key themes: water quality, habitat and fish. From the 2020 Report Card onwards however, we will be reporting on a fourth theme in the inshore marine environment – litter (presented at the site level, and not rolled up into the overall zone score).

The terminology used in this document for defining the level of aggregation of indicators is as follows:

- The overall score is generated by the aggregation of indices or by a single index score,
- Index/indices (e.g. water quality) are generated by the aggregation of indicator categories,
- Indicator categories (e.g. nutrients) are generated by one or more indicators, and
- An indicator is measured (e.g. particulate nitrogen concentration).

In the Report Card, overall and index grades/scores are represented in the format of a coaster (Figure 2). Presentation of the coasters can vary as different levels of categorisation are used for each different ecosystem type.

Figure 2. Terminology used for defining the level of aggregation of indicators and how they are displayed in coasters in the Report Card.

2. Data Collection Methods

We report on the condition of freshwater basins, estuaries and inshore and offshore marine environments across the MWI Region. Across these ecosystems, a series of indices are assessed, divided into indicator categories and indicators (Figure 3).

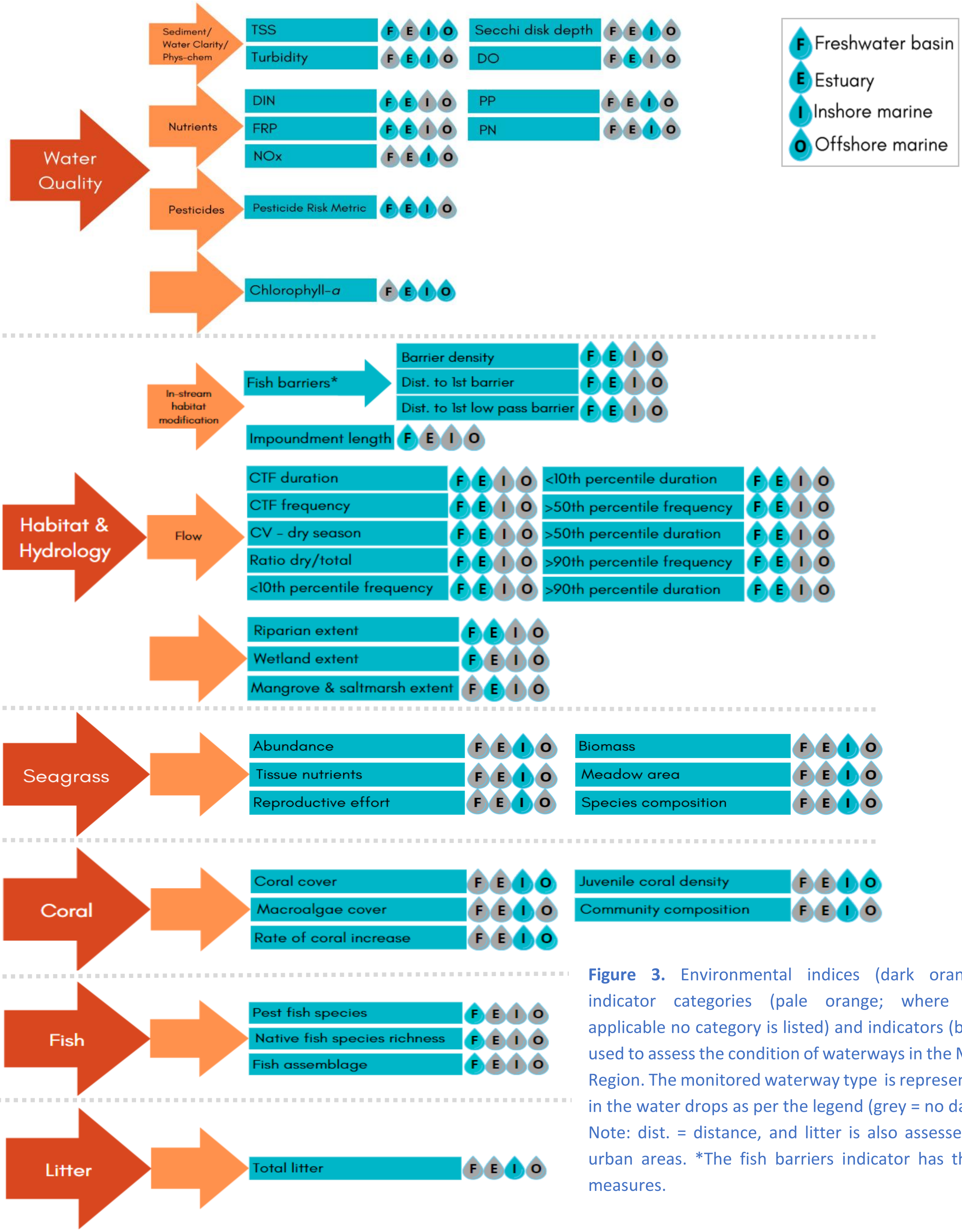


Figure 3. Environmental indices (dark orange), indicator categories (pale orange; where not applicable no category is listed) and indicators (blue) used to assess the condition of waterways in the MWI Region. The monitored waterway type is represented in the water drops as per the legend (grey = no data). Note: dist. = distance, and litter is also assessed in urban areas. *The fish barriers indicator has three measures.

2.1. Freshwater Basins

Freshwater basins are assessed using three indices: fish, habitat and hydrology and water quality (Figure 3 and Figure 4). Due to differences in the time scales at which notable changes typically occur for each indicator and/or logistical constraints, some are assessed annually while others are updated every three or four years (Table 1. F). The freshwater basin zones reported in the MWI Report Card are the Don, Proserpine, O'Connell, Pioneer and Plane basins (Figure 5). The boundaries of these zones are defined as per the Queensland (QLD) Government[3].

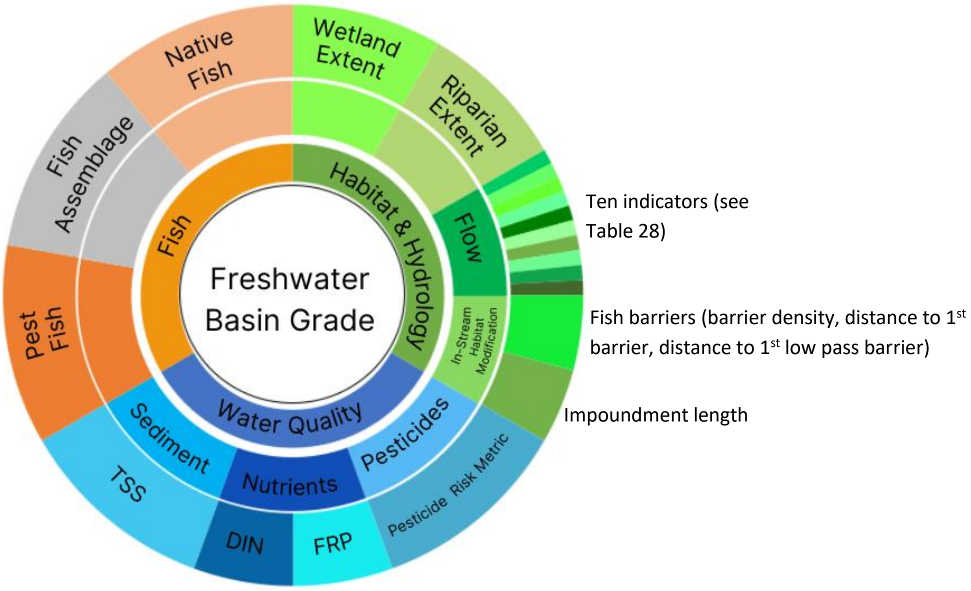


Figure 4. Indicator/s (outer ring), indicator categories (middle ring) and index/indices (inner ring) that contribute to overall freshwater basin scores/grades. Where no indicator category is listed this represents that the indicator/s (e.g. native fish) do/does not fit into any specific category below the index level (e.g. fish).

Table 1. Frequency of reporting for specific indicator categories, and their update status for the 2020 Report Card. Note: the reporting frequency is the same for each freshwater basin indicator within an indicator category.

Index	Indicator Categories	Frequency of Reporting	Last Updated
Water Quality	Sediment	Annually	**2020**

[3] Department of Resources; previously the Department of Natural Resources, Mines and Energy

Table 1. Frequency of reporting for specific indicator categories, and their update status for the 2020 Report Card. Note: the reporting frequency is the same for each freshwater basin indicator within an indicator category.

Index	Indicator Categories	Frequency of Reporting	Last Updated
	Nutrients	Annually	**2020**
	Pesticides	Annually	**2020**
Habitat and Hydrology	In-stream habitat modification	4 Yearly	**2019** - Impoundment Length
			2018 – Fish Barriers
	Flow	Annually	**2020**
	Riparian ground cover	4 Yearly*	**2014** (scores revised in 2016)
	Freshwater wetlands	4 Yearly	**2019**
Fish	Fish	3 Yearly	**2018**

*Due to methodology changes to riparian ground cover mapping (provided by the Queensland Herbarium), this indicator category has not been updated since 2014; it is expected to be updated for the 2022 Report Card, pending finalisation of methodology refinements.

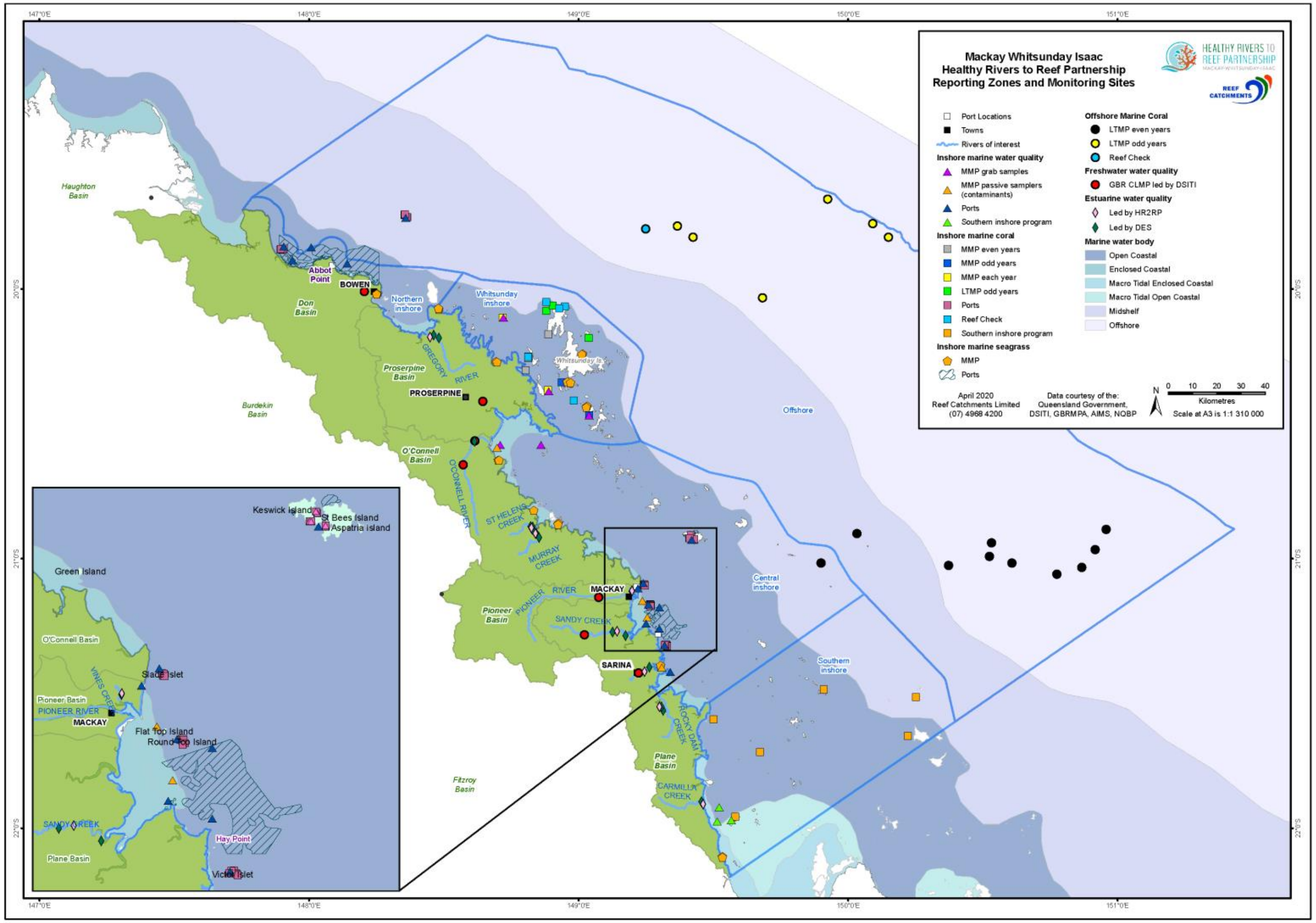


Figure 5. Sampling locations for water quality, coral and seagrass monitoring in the MWI Region for the 2020 Report Card. Blue lines in the marine environment delineate inshore and offshore marine zones.

2.1.1. Water Quality Index

The water quality index in freshwater basins is comprised of three different indicator categories and a series of indicators (Figure 4**; sediment (total suspended solids (TSS), nutrients (**

dissolved inorganic nitrogen (DIN), filterable reactive phosphorus (FRP)) and pesticides). TSS was selected as an indicator for sediment over turbidity (used for estuary and inshore marine environment) given the availability of data and published guideline values for freshwater systems (Newham *et al*., 2017).

Samples for all water quality indicators were collected concurrently through the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP), led by the QLD Government[4]. Water samples were collected for analysis using manual grab sampling techniques and automatic samplers (DES, 2009; Huggins et al., 2017).

Water quality condition scores in the 2020 Report Card represent the period between July 1st 2019 and June 30th 2020. Data were available from seven end-of-system GBRCLMP sites within the MWI Region (Figure 5):

- Don Basin: Don River at Bowen,
- Proserpine Basin: Proserpine River at Glen Isla,
- O'Connell Basin: O'Connell River at the Caravan Park and O'Connell River at Stafford's Crossing[5],
- Pioneer Basin: Pioneer River at Dumbleton Pump Station,
- Plane Basin: Sandy Creek at Homebush and Plane Creek at Sucrogen Weir[5].

High-frequency sampling (up to hourly) occurred during high flow events and monthly sampling was undertaken during ambient (low or base-flow) conditions (Table 2 and Table 3). Unlike other water quality parameters (Table 2), pesticide samples were only taken during a designated six-month period in the wet season (Table 3).

[4] Department of Environment and Science (DES).
[5] Sites were first included in the 2018 Report Card.

Table 2. Water quality monitoring within the MWI basins, where *n* denotes the number of samples analysed for pollutants of concern.

Year	Month	Don River (*n*)*	Proserpine River (*n*)	O'Connell (Stafford's Crossing) (*n*)	O'Connell (Caravan Park) (*n*)	Pioneer River (*n*)	Sandy Creek (*n*)	Plane Creek (*n*)
2019	July		1	1	1	8	1	1
	August		1	1	1	1	1	1
	September		1	1	1	1	1	1
	October		1	1	1	1	1	1
	November		1	1	1	1	1	1
	December		10	2	2	11	13	1
2020	January		16	19	18	17	25	15
	February	22	19	22	15	18	41	20
	March	12	12	13	10	15	19	16
	April	1	1	1	1	1	1	1
	May		4	3	2	3	3	1
	June		1	1	1	1	1	1
	TOTAL	35	68	66	54	78	108	60

*No samples were collected for the Don River between July 2019 and January 2020 due to lack of surface flow in the basin.

Table 3. Water quality monitoring within the MWI basins, where *n* denotes the number of samples analysed for pesticides. Grey highlighted cells represent where monitoring did not take place (e.g. outside of wet season) or where no data are available.

Year	Month	Don River (*n*)	Proserpine River (*n*)	O'Connell (Stafford's Crossing) (*n*)	O'Connell (Caravan Park) (*n*)	Pioneer River (*n*)	Plane Creek (*n*)	Sandy Creek (*n*)
2019	July							
	August							
	September							
	October							
	November							
	December		8	1	1	8	0	9
2020	January		15	16	12	12	10	21
	February	18	11	13	11	13	17	26
	March	12	9	8	8	11	10	15
	April	4	4	4	4	4	4	4
	May		3	3	2	3	1	3
	June		1	1	1	1	1	1
	TOTAL	34	51	46	39	52	43	79

To develop an overall score for the O'Connell and Plane basins, scores for each monitoring site were aggregated using a weighted average. Weighting was determined using the relative proportion of catchment area associated with each monitoring site.

The Don River is ephemeral in nature, characterised by episodic flow and periodic drying. Consequently, monitoring activity is limited to periods where there is sufficient surface flow, usually during or shortly after rainfall events. This is different to the other rivers reported in the MWI Region, which are typically permanent in nature. As a result, the sampling size used to inform water quality scores in the Don Basin will vary depending on the prevailing hydrological conditions. Due to a lack of surface flow in the Don Basin across much of the 2019-20 monitoring season, ambient conditions were only captured from February – April 2020. The results obtained from a total of 35 ambient and event samples were used to derive an indicator score for DIN, FRP and TSS (Table 2). This is compared to the previous year, where 54 samples were taken, with at least one sample taken per month for 2019 and 41 samples total for 2018. The result of this reduction in sample size makes the 2020 year less temporally representative of the ambient condition of the basin.

Similar to previous Report Cards, sediment and nutrient condition in the Proserpine Basin were not reported for the 2020 Report Card. In the 2018 review of water quality data, the concentration of TSS at this site was found to be confounded by tidally resuspended sedimentation and therefore, not fully representative of the freshwater environment. There was also a strong correlation between TSS, and the observed concentration of nutrients (DIN and FRP), suggesting nutrients are similarly confounded at this site. To fill this data gap, the Partnership began a pilot monitoring project in August 2020, using an upstream monitoring location that is largely outside of the range of tidal influence. The pilot project samples nutrients and suspended solids in the Proserpine Basin on a monthly basis, and the results from the project are set to be discussed in the 2021 Report Card. However, pesticides were still reported in the 2020 Report Card using data from the original Proserpine Basin site. This site was considered to still provide a reasonable estimate of pesticide pressures in the freshwater catchment. The pesticide risk score calculated from samples taken above the tidal zone would not necessarily provide a more accurate picture of the catchment's pesticide pressures, as it would likely miss some land-based inputs (see the 2018 Results Report[6] for more information).

Pesticide indicator scores for 2020 were developed by the QLD Government's GBRCLMP using the Pesticide Risk Metric (PRM). The aim of this approach is to quantify the ecological risk associated with exposure to a mixture of up to 22 pesticides (herbicides and insecticides) (Table 4) in any given sample. From the 2019 Report Card onwards, the PRM approach has been applied to pesticides with multiple modes of action (MoAs) to better represent pesticide risk (Table 4).

Table 4. Pesticides included in Pesticide Risk Metric. Note, not all of the listed pesticides were necessarily detected in every water sample.

Pesticide	Mode of Action	Pesticide Type
Chlorpyrifos	Acetylcholine esterase (AChE) inhibitor	Insecticide
Fipronil	Gamma-aminobutyric acid (GABA) gated chloride channel blocker	
Imidacloprid	Nicotinic receptor agonist	
Haloxyfop	Acetyl-coenzyme A carboxylase (ACCase) inhibitor	Non-PSII herbicides
Imazapic	Group 1 Acetolactate synthase (ALS) inhibitor	
Metsulfuron-methyl	Group 2 Acetolactate synthase (ALS) inhibitor	
Pendimethalin	Microtubule synthesis inhibitor	
Metolachlor	Inhib of VLCFA	
2,4-D	Auxin mimic (Phenoxy-carboxylic acid auxins)	
MCPA	Auxin mimic (Phenoxy-carboxylic acid auxins)	
Fluroxypyr	Auxin mimic (Pyridine-carboxylic acid auxins)	
Triclopyr	Auxin mimic (Pyridine-carboxylic acid auxins)	
Isoxaflutole	4-hydroxyphenylpyruvate dioxygenase (4-HPPD) inhibitor	
Ametryn	PSII inhibitor	PSII herbicides
Atrazine		
Prometryn		
Terbuthylazine		
Tebuthiuron		
Simazine		
Diuron		
Hexazinone		
Metribuzin		

[6] https://healthyriverstoreef.org.au/report-card/report-card-download/

2.1.2. Habitat and Hydrology Index

Indicators used to report on the habitat and hydrology index in freshwater basins are impoundment length, fish barriers, riparian extent, wetland extent and flow. Impoundment length and fish barriers are grouped together as the in-stream habitat modification indicator category.

2.1.2.1. In-stream Habitat Modification

Impoundment Length

This indicator was selected to describe how much 'natural' channel habitat remained in the region, compared to artificially-ponded channel habitat which has relatively little diversity in terms of depth (benthic light availability, oxygen availability), flow rate and natural wetting and drying cycles. The impoundment length indicator is updated every four years, and was last updated in the 2018 Report Card. As a result, impoundment length scores presented in the 2020 Report Card represent repeated data.

The impoundment length indicator reports on the proportion (%) of the linear length of non-tidal streams, of order three or higher, that are inundated at the full supply level of artificial in-stream structures such as dams and weirs. This is compared to the reference condition of no artificial impoundments (0%).

Impoundment locations and estimates of impounded lengths were derived from the QLD Government[3], including 1:100,000 ordered drainage network, Google Earth imagery, QLD Globe spatial layers (Dams, Weirs and Barrages, Referable Dams and Reservoirs) and local knowledge, including from regional hydrographic staff[3]. The proportion of impoundment length was calculated as a percentage of the total linear length of the river channel.

Fish Barriers

The majority of freshwater fish species in the MWI Region migrate between freshwater and estuarine habitats at some stage during their life cycle (Moore, 2015b). Therefore, barriers that prevent or delay connectivity between key habitats have the potential to impact migratory fish populations, decrease the diversity of fish communities in freshwater and estuaries, and reduce the condition of aquatic systems (Moore, 2015a).

The fish barrier index is based on an assessment of three indicators: 'barrier density', 'proportion of stream length to the first barrier' and 'proportion of stream length to the first low/no passability barrier' (Figure 6). Only barriers located on 'major' (Strahler stream orders 4-7) and 'high' (Strahler stream orders 2-3 with low gradient, Strahler stream order 3 with medium gradient) risk category waterways were included in the analysis[7] (Figure 6). A low "passability" barrier was defined as a barrier

[7] Queensland waterways that fall within these two risk categories were determined by Fisheries Queensland, based on the following criteria: stream order, stream slope, flow regime, number of fish present, and fish swimming ability. The combined analysis of these characteristics determined the classification, based on the risk of impact from fish barriers on fish movement and fish communities.

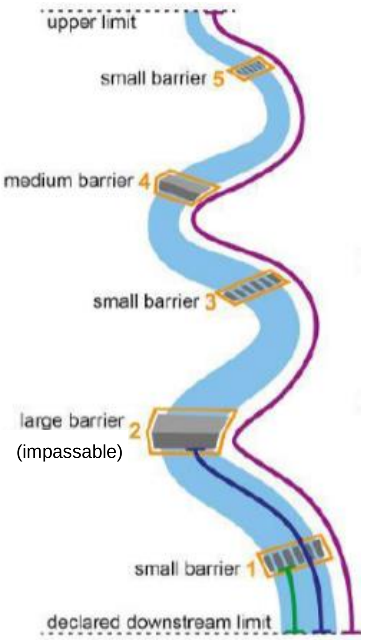
that never or rarely 'drowns out'[8] (<1 flow event per year), a dam or weir with >2m head loss, a causeway >2 m high with pipe/culvert configuration <10 % and/or bankfull stream width and head loss >1 m.

For the freshwater basins, all measurements were made upstream of the Declared Downstream Limit (DDL), defined as the lower-most freshwater reach of a stream as determined by the QLD Government[3]. The DDL was selected because any potential barriers downstream of this point clearly allow tidal movements and thus do not prevent connectivity with this interface.

To assess potential barriers to fish passage within the MWI Region, Geographic Information Systems (GIS) software was utilised to prioritise the large number of anthropogenic barriers that prevent, delay or obstruct fish migration within the region's waterways. On-ground validation of priority potential barriers was undertaken to determine the authenticity of barriers and collate important barrier characteristics (Moore, 2015b). In the Proserpine, O'Connell, Pioneer and Plane basins, fish barriers were assessed utilising known barriers that were identified and assessed in the MWI Region Freshwater Fish Barrier Prioritisation report (Moore, 2015a).

The fish barriers score is updated every four years, most recently in 2018-19. In the preceding assessment (2014-15) of the Don Basin, fish barriers were provisionally assessed using the Burdekin Dry Tropics Natural Resource Management Group Region Fish Passage Study (Carter et al., 2007). Due to recent improvements and availability of aerial imagery, a desktop study of potential barriers in the Don Basin was undertaken to complement the existing data. Despite this, insufficient data was available to inform the no/low "passability" barriers indicator using this method alone. Instead, expert opinion was used to assess the 'proportion of stream length to the first no/low "passability" barrier' indicator. In the 2018-19 assessment of the Don Basin, fish barriers were assessed based on updated desktop investigation of potential barriers (using spatial imaging and local knowledge) and subsequent field works.

[8] Denotes a barrier with potential to ascend only during very high flooding flow.



Barrier density = $\frac{\text{total stream length of major and high impact waterways}}{\text{total number of barriers on these streams within the basin}}$

Percent of stream length to the first barrier = $\frac{\text{stream length from declared downstream limit (DDL) to the first barrier}}{\text{total stream length of major and high impact waterways (km)}} * 100$

Percent of stream length to the first impassable barrier = $\frac{\text{stream length from DDL to the first impassable barrier}}{\text{total stream length of major and high impact waterways (km)}} * 100$

Fish barriers index score

Figure 6. Diagram of the three fish barrier indicators and how they are calculated. For the purposes of the diagram the declared downstream limit is equivalent to the upper tidal limit. The fish barriers indicator category comprises of three indicators, barrier density, percent of stream length to the first barrier, and percent of stream length to the first impassable barrier. Each indicator is scored separately and then the scores for these three indicators are summed together to produce the overall score for the fish barriers index.

2.1.2.2. Flow

The flow indicator follows a reference condition approach in which a waterway with a highly modified flow regime, resulting in large deviations from an unregulated reference condition, will score poorly. On the other hand, a waterway with an unmodified flow regime, resulting in a similar flow regime to a referenced condition, will score well. Flow metrics used to score the flow indicator for basins assess deviations of the observed flow data from the reference pre-development flow data (specific to each assessment site and against rainfall for each reporting year) (see Section 3.1.2.2 for further detail).

This is the third consecutive year for reporting of flow scores. For the 2020 Report Card, flow was assessed using all available basin flow monitoring sites, except those in the O'Connell Basin (Table 5). As done for the 2019 Report Card, this basin was removed due to the model not being suitable for prolonged low or no flow scenarios. The flow tool is scheduled to undergo a review process for future report cards in collaboration with the TWG and aquatic ecology experts to identify further refinements to the tool and methods, including rainfall seasonality.

For a site to be assessed for flow, the following criteria were required:

1) An operational stream gauging station that provides daily stream flow data.

2) Time series modelled pre-development daily flows to provide the reference condition.

Observed daily flows (ML/day) were obtained from stream gauging stations managed by the QLD Government[9] and reported via the QLD Government Water Monitoring Information Portal (*water-monitoring.information.qld.gov.au/*). Gaps in observed daily flow data were 'patched' using the River Analysis Package (RAP) developed by the Cooperative Research Centre for Catchment Hydrology at Monash University, Melbourne. Modelled pre-development time series (100+ years, date ranging typically from 1890-2008) of daily flows (ML/day) were obtained from QLD Government hydrologic models (Integrated Water Quantity and Quality Model (IQQM)) which were developed for QLD basin water resource plans. This model excludes storages and extractions.

Table 5. Flow assessment sites with QLD Government[9] gauging stations used for the flow indicator within each basin.

Basin	Flow Assessment Site	Gauging Station Number
Pioneer	Cattle Creek at Gargett	125004B
	Blacks Creek at Whitefords	125005A
	Finch Hatton Creek at Gorge Road	125006A
	Pioneer River at Mirani Weir TW	125007A
	Pioneer River at Dumbleton Weir TW	125016A
Plane	Sandy Creek at Homebush	126001A

The annual flow pattern in any given river will vary naturally with the prevailing rainfall conditions. To account for differences of rainfall between years, historical daily rainfall data (100+ years) were obtained from the QLD SILO program for the catchments (https://www.longpaddock.qld.gov.au/silo/) and the Bureau of Meteorology (BoM) (http://www.bom.gov.au/) (Table 6). The SILO rainfall record covers the entire hydrological modelling period (1890-2008) and continues to the end of the reporting year for each report card (Table 6).

Historical daily rainfall data were averaged from all rainfall sites within a basin and were used to define years within rainfall types using quartiles as follows:

- Drought: Annual rainfall ≤ 25th percentile year
- Dry: 25th percentile year < Annual rainfall ≤ 50th percentile
- Average: 50th percentile year < Annual rainfall ≤ 75th percentile year
- Wet: Annual rainfall > 75th percentile year

For a given basin, each year of the hydrological record was then ascribed a 'rainfall type'. As such, the flow measures used to produce the indicator scores each have a reference distribution for each rainfall

[9] Department of Regional Development, Manufacturing and Water (DRDMW)

type at each flow assessment site. Generation of rainfall types and determining rainfall type of the reporting year was conducted using the flow indicator tool (Stewart-Koster et al., 2018)[10].

Table 6. Rainfall site details used to present catchment rainfall for flow indicator sites.

Basin	Site	Station Name/Location	Station Number	Latitude	Longitude	Elevation (m)
Pioneer	PB1 S	Mackay Alert	33303	-21.1397	149.1883	11.0
	PB2 S	Dumbleton Rocks Alert	33300	-21.1439	149.0753	0.0
	PB3 GP	Mirani Post Office	33052	-21.1500	148.8667	50.0
	PB4 GP	Finch Hatton Cook St	33026	-21.1436	148.6322	105.0
	PB5 S	Sarichs Alert	33299	-21.2725	148.8203	47.8
	PB6 GP	Upper Pioneer catchment	N/A	-21.3000	148.6500	392.9
Plane	PB1 S	Plane Creek Sugar Milll	33059	-21.4300	149.2200	16.0
	PB2 S	Eton Sunwater	33134	-21.2700	148.9700	30.0
	PB3 S	Koumala Hatfields Road	33038	-21.6300	149.2400	30.0
	PB4 S	Carmila Beach Road	33186	-21.9200	149.4400	23.0
	PB5 P	Orkabie West Hill	33095	-21.8000	149.3600	22.0
	PB6 GP	Belgamba	33188	-22.0300	149.4900	30.0
	PB7 GP	Upper Plane Catchment	N/A	-21.2000	148.9000	51.7
	PB8 GP	Lower Plane Catchment	N/A	-21.2000	149.1500	7.5

Note: Sites are either station (S), grid point (GP) or point (P) locations.

2.1.2.3. Riparian Extent

The assessment of riparian extent follows the same methodology used for the GBR Report Card. This methodology first defines riparian areas using topographic drainage data and riverine wetlands derived from the 2009 QLD Wetland Mapping Programme data. The present extent of riparian forest is defined by those areas with a foliage projective cover of at least 11% (Folkers et al., 2014) using the 2013 Landsat foliage projective cover data. This is then compared against the pre-development extent of riparian forest Regional Ecosystem (RE) mapping data (based on RE mapping version 9) to estimate the amount of riparian forest remaining in the five basin areas. The method assumes that the pre-clearing riparian forest REs were 100% forested.

The riparian extent indicator is updated in broad accordance with mapping updates produced by the QLD Government Remote Sensing Centre[4]. Consequently, the update period is approximately four years. To date, the riparian extent scores reported in preceding report cards have been developed based on data collected in the previous assessment, which occurred in 2013-14. Scores for this indicator were due to be updated for the 2018 Report Card. However, the data collected are subject to considerable change in order to improve the resolution and accuracy of vegetation mapping. As a

[10] For the complete report for the report card's flow indicator project, see Stewart-Koster et al. (2018) by contacting *info@healthyriverstoreef.org.au*.

result, updated mapping methodology for this indicator is currently under review and will not be released until after the 2020 Report Card.

2.1.2.4. Wetland Extent

The assessment of wetland extent uses similar methods to those employed in the GBR Report Card, however only palustrine systems are reported for the MWI Report Card.

Palustrine systems were defined as wetlands with more than 30% emergent vegetation cover, or less than 8 ha. Wetland extent is defined as the aerial extent of a wetland. The condition of wetland extent was determined through a comparison of current extent against pre-clearing extent of vegetated freshwater swamp (palustrine) systems using the QLD RE mapping version 5. The RE mapping is derived by delineating pre-clearing REs using multiple lines of evidence, including stereo aerial photography, geology and soils mapping, historical survey records and field survey information.

A combination of automated and manual interpretation of imagery is used to delineate change in wetland extent due to clearing of vegetation, destruction of water bodies from draining or earthworks, or the creation of new water bodies through dam or weir construction. Changes in wetland extent due to seasonal wetting and drying are not recorded as wetland loss or gain. Natural wetlands are distinguished from hydrologically modified wetlands (i.e. human-made inputs such as levees or bunds) within this analysis, and artificial or highly modified wetlands are not reported (Australian and Queensland Governments, 2018).

The wetland extent indicator is updated every four years, and was last updated in the 2019 Report Card (2017-18 mapping). Due to refinements such as error correction and remapping to a finer scale compared to the previous 2013-14 assessment, scores are not directly comparable between years. To rectify this, wetland extent scores were back-calculated for the 2013 assessment using the updated mapping (see the 2020 Results Report[6]). The 2020 Report Card scores are therefore directly comparable only to the back-calculated scores, with results represented in Report Cards prior to 2019 all superseded.

2.1.3. Fish Index

The fish community index is based on the condition of native and pest fish, with field monitoring surveys, data collection and analysis conducted by the QLD Government[4]. The indicators for fish community condition in freshwater basins are assessed by comparing observed data to modelled data, and include:

- **Native richness**: The number of native fish species actually recorded in catches divided by the number expected to occur based on modelling (Proportion Observed Native Species compared to Expected, PONSE). Currently, fish native to QLD but not endemic to the region's waterways, and identified outside their natural distribution, are included within the native richness assessment. Future assessments will consider translocated fish under the pest fish umbrella.

- **Pest fish**: The proportion of fish catch that consists of individuals of alien species.

Fish survey sites were randomly selected using Generalised Random-Tessellation Stratified (GRTS) methods, weighted by stream order. An ordered list of sites was generated and reviewed to identify limitations to sampling, including dense vegetation which may restrict access and safety risks (e.g. presence of crocodiles). If a site was rejected on this basis, the next listed site was used. Fish surveys were conducted during October 2017 and June 2018, predominantly using backpack electrofishing techniques. Boat-mounted electrofishing techniques were used to assess sites unsuitable for wading (e.g. deeper water).

The model developed for the calculation of native species richness was reviewed by local experts to ensure validity. The model provides a means to compare fish species richness across basins to a reference. This reference was based on species richness at the 'least disturbed' site that had recent available data, which in the MWI Region was Repulse Creek. This approach does not compare to a pre-development baseline, so can only be considered as a comparison of current fish community condition between basins.

The fish assemblage indicator is currently under development and was not reported in the 2020 Report Card. Species distribution models are currently being developed by the QLD Government[4] in collaboration with local experts, to complete the fish assemblage indicator development project. It is expected this indicator will be finalised and reported in the 2021 Report Card.

Fish communities are assessed every three years, reflecting the lifespan of many local freshwater fish species and budgetary constraints. The results presented in the 2020 Report Card are repeated from 2018.

2.2. Estuaries

The eight estuaries reported on in the MWI Report Card are associated with the Gregory River, O'Connell River, St Helens/Murray Creeks, Vines Creek, Sandy Creek, Plane Creek, Rocky Dam Creek and Carmila Creek (Figure 5). Indicator categories and indicators within two indices, habitat and hydrology and water quality, are reported annually or on four-year cycles (Figure 7, Table 7).

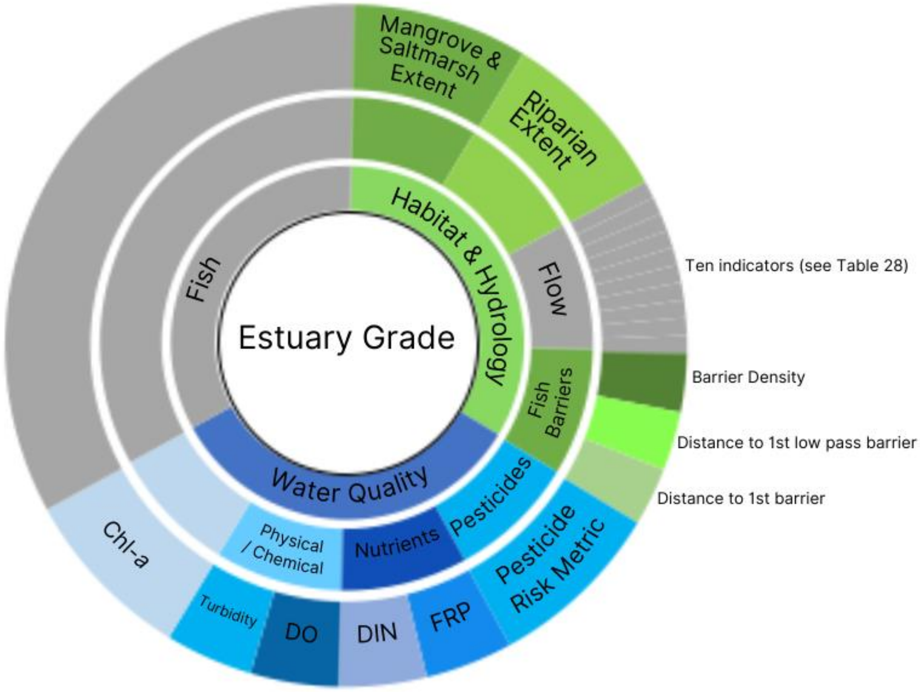


Figure 7. Indicators (outer ring), indicator categories (middle ring) and indices (inner ring) that contribute to overall estuary scores/grades. Where no indicator category is listed this represents that the indicator/s (e.g. riparian extent) do/does not fit into any specific category below the index level (e.g. habitat & hydrology). Dark grey represents no data.

Table 7. Indicator categories (outer ring) and indices (inner ring) that contribute to overall basin scores, frequency of reporting and update status for the 2020 Report Card.

Index	Indicator Categories	Frequency of Reporting	Last Updated
Water Quality	Phys-chem	Annually	**2020**
	Nutrients	Annually	**2020**
	Chlorophyll-*a*	Annually	**2020**
	Pesticides	Annually	**2020**
Habitat and Hydrology	Flow		
	Riparian Vegetation	4 Yearly	2019
	Mangrove and Saltmarsh	4 Yearly	2019
	Fish Barriers	4 Yearly	2019
Fish			

2.2.1. Water Quality Index

The indicator categories used to report on the water quality index in estuaries are (Figure 7):

1) Nutrients: DIN and FRP
2) Physical-chemical (phys-chem): Turbidity and dissolved oxygen (DO)
3) Pesticides: PRM
4) Chlorophyll-*a* (chl-*a*)*

*While chl-*a* concentration is considered a useful proxy for nutrient availability, it was not grouped into the nutrients category given its linkages also to measures of turbidity; and instead, is considered as an indicator in itself as a representative of the productivity of a system.

2.2.1.1. Indicator Category Details (Nutrients, Chl-a, Phys-chem and Pesticides)

Water quality data used to report the condition of the eight estuaries were obtained through the Estuary Monitoring Program led by the QLD Government[4], with supplementary data added through the GBRCLMP and a Partnership-led Estuary Pesticide Monitoring Program. The Estuary Monitoring Program commenced in 2014 and is conducted once per month at between one and three sites in each estuary (Table 8). Sampling sites are located at varying distances upstream of the mouth of each estuary (Table 8 and Figure 5). Distance of sampling sites are reported as adopted middle thread distance[11]. Hereafter, monitoring sites associated with this program will be referred to as 'mid-river' sites.

To increase the temporal representation of pesticide data, the supplementary monitoring program (Partnership-led Estuary Pesticide Monitoring Program) was established and funded by the Partnership in November 2018. Monitoring was conducted twice per month from a single site in each estuary. Sites were selected based on their proximity to existing mid-river sites, site accessibility and safety risks. Hereafter, monitoring sites associated with this program will be referred to as 'land-based sites' (see 2019 Results Report[6]). The result of this program is increased confidence in our estuary pesticide scores.

Given the Murray and St Helens Creeks are reported as one estuary (St Helens/Murray Creek estuary), the inclusion of sites upstream of both creeks collectively results in a greater representation for the is large area. For the O'Connell River estuary only, pesticide and nutrients data were reported using the freshwater basin GBRCLMP water quality monitoring site (Table 8). As a result, estuary pesticide monitoring is not conducted in the O'Connell River at mid-river or corresponding land-based sites, and estuary monitoring O'Connell data are only used for dissolved oxygen and chl-a indicators.

[11] Denotes the distance in kilometres, measured along the middle of a watercourse that a specific point in the watercourse is from the mouth or junction from the main watercourse. Australian Bureau of Meteorology. Australian Water Information Directory. http://www.bom.gov.au/water/awid/id-771.shtml

Table 8. Estuaries monitored for water quality, the location of sampling sites upstream of the estuary mouth reported as 'middle thread distance' and number of monthly samples (n) for each indicator. Notably, water quality monitoring data for Murray Creek and St Helens Creek are combined to produce one score for the 'St Helens/Murray Creek estuary'.

Monitoring Sites	Sites (km from estuary mouth)	Nutrients* (n)	Phys-chem* (n)	Chl-*a** (n)
Gregory River	5.1	10	10	9
	9.9	9	9	9
O'Connell River	7.5	9	9	9
St Helens Creek	7.5	0	9	0
	8.9	9	9	9
Murray Creek	10.0	0	9	0
	12.5	9	9	9
	16.5	9	9	9
Vines Creek	2.0	9	9	9
Sandy Creek	4.5	9	9	9
	13.5	9	9	9
Plane Creek	6.0	9	9	9
	9.0	9	9	9
Rocky Dam Creek	8.9	9	9	9
	12.9	9	9	9
Carmila Creek	2.9**	9	9	9

* Due to logistical impacts from the COVID-19 pandemic, QLD government estuary monitoring could not take place from April – July 2020. As a result, the sample size of the data in the 2019-20 season is ~3/4 of previous years.
** The Carmila Creek estuary monitoring site was moved from 3.4 km to 2.9 km from the mouth in the 2019-20 monitoring season, due to access restrictions with the previous site.

Data samples collected between July 1st 2019 and June 30th 2020 were used to calculate water quality condition scores for estuaries in the 2020 Report Card. Due to monitoring restrictions associated with COVID-19, the MWI Estuary Monitoring Program was not able to collect samples from April to June 2020.

Notably, pesticide monitoring routinely occurs across the wet season for a period of six months (Table 9). This contrasts to the monitoring program for water quality, where ambient sampling activity occurs once per month, for the duration of the monitoring year. To ensure the conditions at each monitoring event are comparable, sampling was conducted on the ebb of neap tides, to minimise the effect of tidal variation. All water quality samples were collected, stored, and transported in accordance with the QLD Government's Monitoring and Sampling Manual (DES 2009).

Laboratory analyses for chl-*a* and nutrients were conducted in-house at the QLD Government[4] Science Division Chemistry Centre (Ecoscience Precinct, Dutton Park, QLD). The laboratory is accredited by the National Association of Testing Authorities (NATA) for the chemical and physical analysis of water and soil, including for the assessment of chl-*a* and dissolved nutrients. This is to ensure compliance with relevant international and Australian standards and competency in providing consistent quality of results. As done for freshwater basins, to derive DIN from estuary data, oxidised nitrogen (NO_x) is summed with ammonia nitrogen.

To maintain consistency in the quality of results, pesticide samples across the ambient and supplementary monitoring program were both submitted to the QLD Health Forensic and Scientific Services Laboratory (FSS) for analysis. This laboratory is also accredited by NATA for the chemical and physical analysis of water, including for the assessment of toxicants such as pesticides.

Table 9. Water quality monitoring for pesticides within the MWI estuaries. Where no monitoring data was available, cells have been highlighted in grey.

Year	Month	Gregory River	O' Connell River*	St Helens Creek	Murray Creek	Vines Creek	Sandy Creek**	Plane Creek	Rocky Dam Creek	Carmila Creek
2019	July									
	August									
	September									
	October									
	November	3		3	3	3	1[y]	3	3	3
	December	3	1	3	3	3	3	3	3	3
2020	January	3	12	3	3	3	3	3	3	3
	February	3	11	3	3	3	3	3	3	3
	March	3	8	3	3	3	3	3	2	3
	April***	2	4	3	3	3	3	3	3	3
	May		2							
	June		1							
	TOTAL	17	39	18	18	18	15	18	17	18

*Pesticide data (and nutrients) in the O'Connell River estuary are derived from samples collected through the GBRCLMP rather than the mid-rover site referenced in Table 8. Changes in sample numbers across years for this site are due to the nature of event sampling.

** Pesticide data in the Sandy Creek estuary are derived from samples collected through a standalone monitoring program, led by the Water Quality and Investigations team[4].

*** In the 2019-20 monitoring season, QLD Government monitoring was restricted from April – June 2020. However, an extra sample was collected in April 2020 by the Partnership-led program to supplement this change in sample size.

[y] Due to logistical error, the Estuary Pesticide Monitoring Project did not collect samples in the Sandy Creek estuary in November 2019.

2.2.2. Habitat and Hydrology Index

Indicators used to report on the habitat and hydrology index in estuaries are riparian extent, mangrove/saltmarsh extent, and fish barriers. Insufficient information was available to report on the condition of flow within estuaries.

2.2.2.1. Riparian Extent

The assessment of riparian vegetation extent in the estuarine environment was conducted by reviewing the proportion of riparian area that had been cleared of natural vegetation. The riparian area was determined to be any vegetation within 50 metres (m) of the bank of the estuarine environment. The area assessed was from the estuary mouth, upstream to the tidal limit. The tidal limit was determined based on vegetation species distribution observed in situ and expert opinion relating to these species. The actual spatial area assessed along the length of each estuary was recorded so that the same spatial layer for each assessment could be used in subsequent assessments allowing for comparability of report cards over time. The data prepared by the QLD Government[4] were obtained through Google Earth and the QLD Herbarium's RE (version 9) mapping.

The procedure for the spatial estimation of the proportion of the estuary area where natural vegetation (of any sort) has been cleared within 50 m of the water's edge was:

1. Start from the upstream point that was considered by signs (vegetation) to be the tidal limit.
2. Construct lines from the tidal limit downstream, following the outermost waterline for both sides of the stream.
3. Construct areas 50 m wide as 'buffer strips' on the edge of the constructed lines.
4. Select all data within these defined areas to extract the latest Herbarium data (2013 Remnant REs of QLD, version 9 (April 2015)).
5. Using the non-ocean data within the selected area, calculate the proportional area of non-remnant vegetation as the estimated result of the proportional area of natural vegetation (of any sort) that has been cleared within 50 m of the water's edge.

Data for riparian extent was initially assessed in 2013-14 and again for the 2019 Report Card, based on mapping which depicts condition in 2017, as per its four-year assessment cycle. As noted in Section 2.1.2.4, the 2017 updates to this source mapping, including refinements such as changes in source data, error correction and mapping to a finer scale, were substantial and therefore, the resulting data are not directly comparable to those previously reported inhibiting any interpretation in change between years. To rectify this, riparian extent results have been back-calculated for the 2013 assessment using updated mapping (see 2020 Results Report[6]). The 2020 Report Card scores are directly comparable only to the back-calculated scores, with all previous scores superseded.

2.2.2.2. Mangrove/Saltmarsh Extent

To assess the condition of mangrove/saltmarsh extent in the estuaries, the aerial extent of intertidal habitat categories (listed below) was compared to the same habitat areas in their pre-clearing condition. The spatial data were prepared by the QLD Government[4] and derived from the QLD Herbarium's RE (version 7.1.1, 7.1.2, 7.1.3, and 7.1.5) data. The 2013 aerial extent and pre-clearing data layers were compared and the proportion of loss since pre-clearing was presented.

The procedure for the spatial estimation of the percentage loss (pre-clearing to 2013) of the four important dominant vegetation categories from the RE mapping data was:

1. Start with the defined area of each estuary.
2. Using the proportion of each of the selected REs of mangrove (8.1.1), samphire (8.1.2), tussock (8.1.3) and melaleuca (8.1.5) within these defined areas used as a "cookie cutter" to extract from the three Herbarium datasets of pre-development, 1997 and 2013 Remnant REs of QLD.
3. Calculate the percentage loss from the difference in pre-development to 2013 combined area of the mangrove, samphire, tussock, and melaleuca in the RE data.

All data for mangrove/saltmarsh extent results were last assessed for the 2019 Report Card, based on mapping which depicts condition in 2017 (as per its four-year assessment cycle). As for riparian extent, data are not directly comparable to those previously reported, and therefore, results have been hindcasted for the 2013 assessment using updated mapping (see 2019 Results Report[6]).

2.2.2.3. Flow

Due to a lack of availability of pre-development or observed flow data, flow for estuaries was not reported for the 2020 Report Card. Considerable work is currently being undertaken to explore opportunities to fill data gaps and is currently progressing in collaboration with the TWG and BoM. A review of the flow indicator tool developed for regional report cards is expected to go through a review with the TWG and aquatic ecology experts to identify further refinements to the tool and methods, including rainfall seasonality applied within the tool.

2.2.2.4. Fish Barriers

Assessment of fish barriers in the estuarine environment was last undertaken in 2018-19 (as per the four-year reporting cycle), using the same indicators and scoring ranges described for freshwater basins. All barriers on 'major' or 'high' impact tributaries were included in the analysis, up to the threshold of 18.5 m above DDL. Barriers were assessed on waterways that intersected the Fisheries QLD 'Estuary Extent' Layer regardless of the size of the waterway (Figure 8).

The elevation threshold (18.5 m above the DDL) was selected based on Fisheries QLD fish community monitoring data and local expert knowledge (Fisheries Biologists Matt Moore and Trent Power, from the environmental consultancy Catchment Solutions Pty Limited). This was determined based on the highest known upstream location where diadromous and/or marine vagrant estuarine fish species were known to occur and were known to be important to estuarine fish habitat, particularly for QLD's most iconic estuarine fish species, barramundi. The minimum elevation was selected as the threshold value that would incorporate all upstream sites across the estuaries where such occurrence was known.

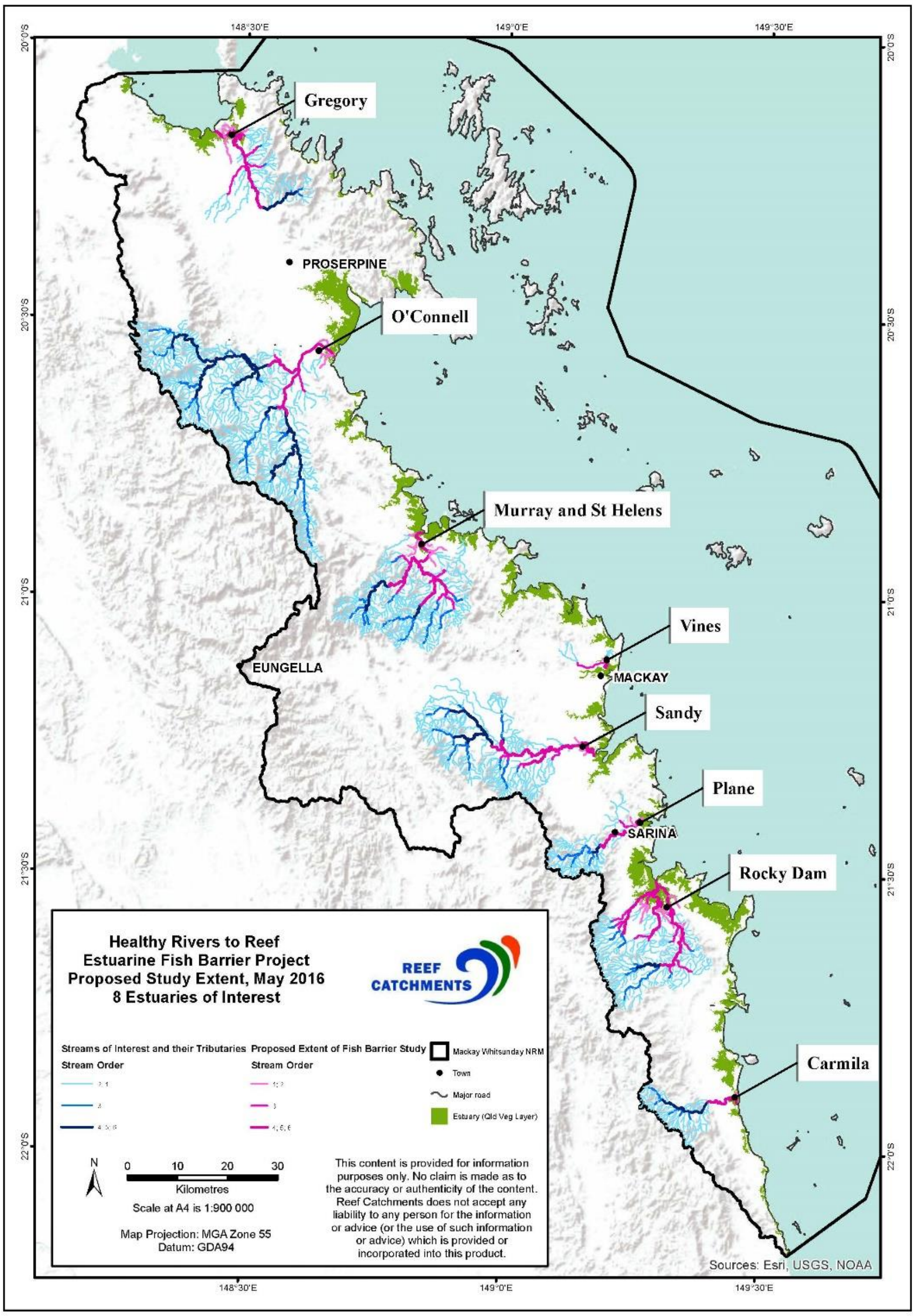


Figure 8. Extent of estuary assessment of fish barriers. Only pink/magenta waterways are included in the estuary barrier assessment; blue waterways are excluded as they do not intersect the estuary layer, are not 'Major' or 'High' impact tributaries and/or are higher than 18.5m above DDL. **Note:** the major river near Mackay is the Pioneer River, however it is not assessed for estuary condition and thus does not feature on this map.

2.2.3. Fish Index

Assessments of fish community health were deemed important across all aquatic environments of the MWI Report Card. The development of estuarine fish indicators and methods is still progressing and thus this index was not included in the 2020 Report Card.

2.3. Inshore and Offshore Marine Zones

The inshore and offshore marine environments are reported separately in the MWI Report Card, with the State Jurisdiction Boundary separating the two reporting areas. The inshore environment is further divided into four zones, from north to south: the Northern, Whitsunday, Central and Southern Inshore Marine Zones (hereafter referred to as the Northern, Whitsunday, Central and Southern Zones, respectively) (Figure 1). The Offshore Marine Zone (hereafter referred to as the Offshore Zone) is not divided any further and extends from the State Jurisdiction Boundary to the eastern boundary of the GBR Marine Park (Figure 1). Indicators for the inshore and offshore zones differ depending on the availability of data (Figure 9). Water quality data in the Offshore Zone are collected using remote sensing, compared to grab samples and *in-situ* loggers in the inshore zones. Litter scores are also presented for the first time in the 2020 Report Card, but do not contribute to the overall zone scores.

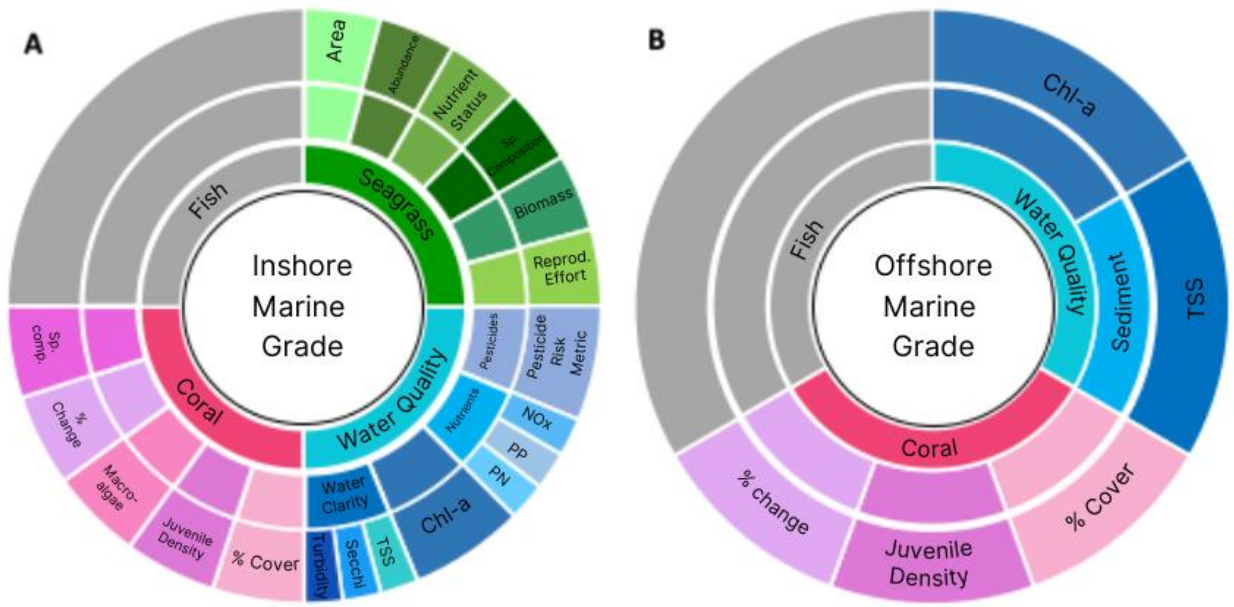


Figure 9. Indicators (outer ring), indicator categories (middle ring) and indices (inner ring) that contribute to overall inshore (A) and offshore (B) marine zone scores/grades. Where no indicator category is listed this represents that the indicator/s (e.g. juvenile density) do/does not fit into any category below the index level (e.g. coral). Dark grey represents no data. Note: sp. comp = species composition and reprod. = reproductive.

2.3.1. Water Quality Index

2.3.1.1. Inshore Water Quality

Water quality in the inshore marine environment was monitored using eight indicators, across four indicator categories (Figure 9A). Data for these indicators in the Northern, Whitsunday and Central Zones are sourced from three existing marine water quality monitoring programs (Appendix A):

1) The Inshore Marine Water Quality Monitoring program led by the Australian Institute of Marine Science (AIMS) as part of the GBR Marine Monitoring Program (MMP)
2) The North QLD Bulk Ports Corporation Ltd (NQBP) Abbot Point Ambient Marine Water Quality Monitoring Program, and
3) The NQBP Mackay and Hay Point Ambient Marine Water Quality Monitoring Program.

The NQBP programs were commissioned to establish a long-term understanding of the natural variability in key marine water quality characteristics for the region and to facilitate effective management of Port activities (Waltham et al., 2015).

Aligning closely with the data collected under the NQBP programs, water quality monitoring in the Southern Zone is part of the Southern Inshore Monitoring Program (SIP) (Appendix A). This program is Partnership-funded and highlights our commitment to improving our understanding of the region's waterways. The relevant program, number of sampling events (grab samples), water type and indicators measured by each monitoring program are summarised for each site and inshore reporting zone in Table 10.

It is also worth noting that water clarity indicators are related but not completely comparable. The characteristics of suspended sediments can greatly influence turbidity measurements where darker and finer grained sediment will result in much higher turbidity readings than lighter-coloured and coarser sediments. The former are considered the most damaging to seagrass and coral growth (Bainbridge et al., 2018; Storlazzi et al., 2015). Turbidity is recommended as the 'primary' measure of water clarity, with secchi and TSS providing supporting evidence to clarify patterns.

Pesticide condition was calculated using the PRM based on the monitored concentrations of up to 22 pesticides in passive sampler devices over the 2019-20 reporting year (Table 11). This method differs from pesticide condition in basins and estuaries, which are based on multiple grab samples over the wet season (see Section 2.2.1.1). Passive samplers provide a single time-integrated concentration for each sampler representing the entire deployment time (typically four to six weeks). Grab samples have the potential to identify acute, rapid, irregular peaks in pesticide concentration only if taken at the opportune time. As a result, only pesticide data collected by passive samplers were used to calculate the scores for the inshore marine zones. Pesticide grab samples for the NQBP programs are only collected once per wet season and once per dry season (compared to more frequent sampling in the basins and estuaries (see Table 3 and Table 9)) and were therefore, presented for reference only. The NQBP programs have now deployed passive samplers to collect pesticide data across the 2020-21 reporting period, and as such pesticide data will be available for the Northern Zone and for an increased spatial representation in the Central Zone from the 2021 Report Card onwards.

All water quality data were collected in accordance with the QLD Water Quality Monitoring and Sampling Manual (DES, 2009). The water type at each monitoring location is defined by the Environmental Protection (Water) Policy 2009 for Central QLD.

All sample sites are detailed in Table 10 and Figure 10. Details on sample sites, sampling methodology and laboratory analysis can be found in the relevant reports for Abbot Point (Waltham et al., 2018), MMP (Gallen et al., 2016) and Mackay and Hay Point (Waltham et al., 2015) water quality monitoring programs (also see Appendix A).

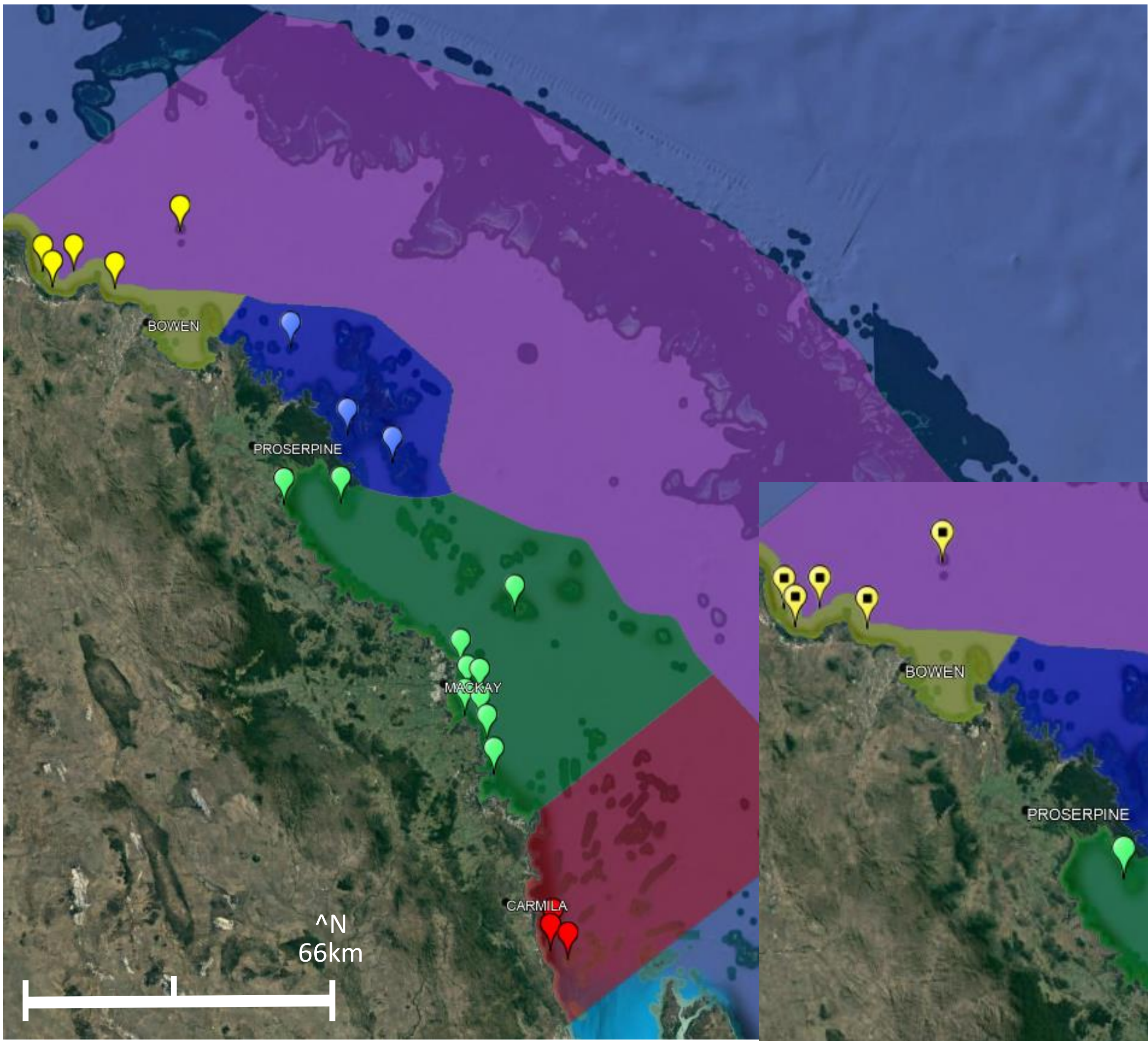
Table 10. Summary of the water quality sampling done in each of the four inshore marine zones. Closed circles in green cells (●) represent data that are included in report card scores, open circles in orange cells (o) show data that are collected at these sites, but no score is calculated due to lack of relevant guideline values, or the site has been deemed not representative of inshore marine condition (i.e. MKY_AMB11), and open squares in orange cells (□) represent pesticide data that were used for reference only. Note: AP = Abbot Point Ambient Water Quality Monitoring Program, MMP = Marine Monitoring Program, MHP = Mackay and Hay Point Ambient Water Quality Monitoring Program, SIP = Southern Inshore Monitoring Program, OC = open coastal, EC = enclosed coastal.

Inshore Zone	Site Name	Program	No. of Grab Sampling Events	Water Type	Indicators Monitored by Sample Type								
					Grab							Passive	Logger
					PN	PP	NO_x	Chl-*a*	TSS	Secchi	Pesticides^		Turbidity
Northern	AP_AMB1	AP	7	OC	●	●		●	●	●	□		●
	AP_AMB2		7	OC	●	●		●	●	●	□		●
	AP_AMB3		7	OC	●	●		●	●	●	□		●
	AP_AMB4a		7*	OC	●	●		●	●	●	□		●
	AP_AMB5		7	OC	●	●		●	●	●	□		●
Whitsunday	Double Cone Is. (WHI1)	MMP	5	OC	●	●	●	●	●	●			●
	Pine Is. (WHI4)		5	OC	●	●	●	●	●	●			●
	Seaforth Is. (WHI5)		5	OC	●	●	●	●	●	●			●
Central	MKY_AMB1	MHP	9	OC	●	●		●	●	●	□		●
	MKY_AMB2		9	OC	●	●		●	●	●	□		●
	MKY_AMB3B		9	OC	●	●		●	●	●	□		●
	MKY_AMB5		9	OC	●	●		●	●	●	□		●
	MKY_AMB6		8	OC	●	●		●	●	●	□		●
	MKY_AMB8		9	OC	●	●		●	●	●	□		●
	MKY_AMB10		9	OC	●	●		●	●	●	□		●
	MKY_AMB11°°		9	EC	o	o		o	o	o	□		o
	MKY_AMB12		9**	OC	●	●	●	●	●	●	□		●
	Repulse Is. Dive Mooring (WHI7)	MMP	5	OC	●	●	●	●	●	●			●
	O'Connell River Mouth (WHI6)		5	EC	o	o	●	●	o	o			o
	Round Top		NA	OC								●	
	Sandy Creek		NA	OC								●	
	Repulse Bay		NA	EC								●	
Southern	MKY_CAM1	SIP	9'	OC	●	●	●	●	●	●		●	●
	MKY_CAM2		9"	OC	●	●	●	●	●	●			
	MKY_CAM3		7°	OC	●	●	●	●	●	●			

* 8 secchi samples
' 8 NO_x, chl-*a* and secchi samples
° 5 NO_x, chl-*a* and secchi samples
** 8 NO_x samples
" 7 NO_x and 8 secchi samples
^ pesticides are either sampled using grab samples (□) or passive samplers (●). Only data collected from passive samplers are used in the Report Card.
°° Whilst MKY_AMB11 allows for monitoring of potential marina influences to water quality in the immediate area, it is not considered reflective of inshore marine conditions from a regional perspective. This site will therefore, be removed from the 2020 Report Card onwards.

Table 11. The 22 pesticides used to calculate Pesticide Risk Metric scores for regional report cards, and in which inshore marine zones these pollutants were captured in their 2019-20 sampling regime (●). Note Northern and Central Zone NQBP data are used for reference only as they are collected from grab samples only (*).

Name of Pesticide	Mode of Action	Pesticide Type	Zone			
			Northern*	Central		Southern
				NQBP*	MMP	
Chlorpyrifos	Acetylcholine esterase (AChE) inhibitor	Insecticide	●	●	●	●
Fipronil	Gamma-aminobutyric acid (GABA) gated chloride channel blocker	Insecticide				
Imidacloprid	Nicotinic receptor agonist	Insecticide			●	●
Haloxyfop	Acetyl-coenzyme A carboxylase (ACCase) inhibitor	Non-PSII herbicides			●	●
Imazapic	Group 1 Acetolactate synthase (ALS) inhibitor	Non-PSII herbicides			●	●
Metsulfuron-methyl	Group 2 Acetolactate synthase (ALS) inhibitor	Non-PSII herbicides			●	●
Pendimethalin	Microtubule synthesis inhibitor	Non-PSII herbicides	●	●	●	●
Metolachlor	Inhib of VLCFA	Non-PSII herbicides			●	●
2,4-D	Phenoxy-carboxylic acid auxin	Non-PSII herbicides			●	
MCPA	Phenoxy-carboxylic acid auxin	Non-PSII herbicides			●	●
Fluroxypyr	Pyridine-carboxylic acid auxin	Non-PSII herbicides			●	●
Triclopyr	Pyridine-carboxylic acid auxin	Non-PSII herbicides				
Isoxaflutole	4-hydroxyphenylpyruvate dioxygenase (4-HPPD) inhibitor	Non-PSII herbicides				
Ametryn	PSII inhibitors	PSII herbicides	●	●	●	●
Atrazine	PSII inhibitors	PSII herbicides	●	●	●	●
Prometryn	PSII inhibitors	PSII herbicides	●	●	●	●
Terbuthylazine	PSII inhibitors	PSII herbicides	●	●	●	●
Tebuthiuron	PSII inhibitors	PSII herbicides			●	●
Simazine	PSII inhibitors	PSII herbicides	●	●	●	●
Diuron	PSII inhibitors	PSII herbicides	●	●	●	●
Hexazinone	PSII inhibitors	PSII herbicides	●	●	●	●
Metribuzin	PSII inhibitors	PSII herbicides			●	●



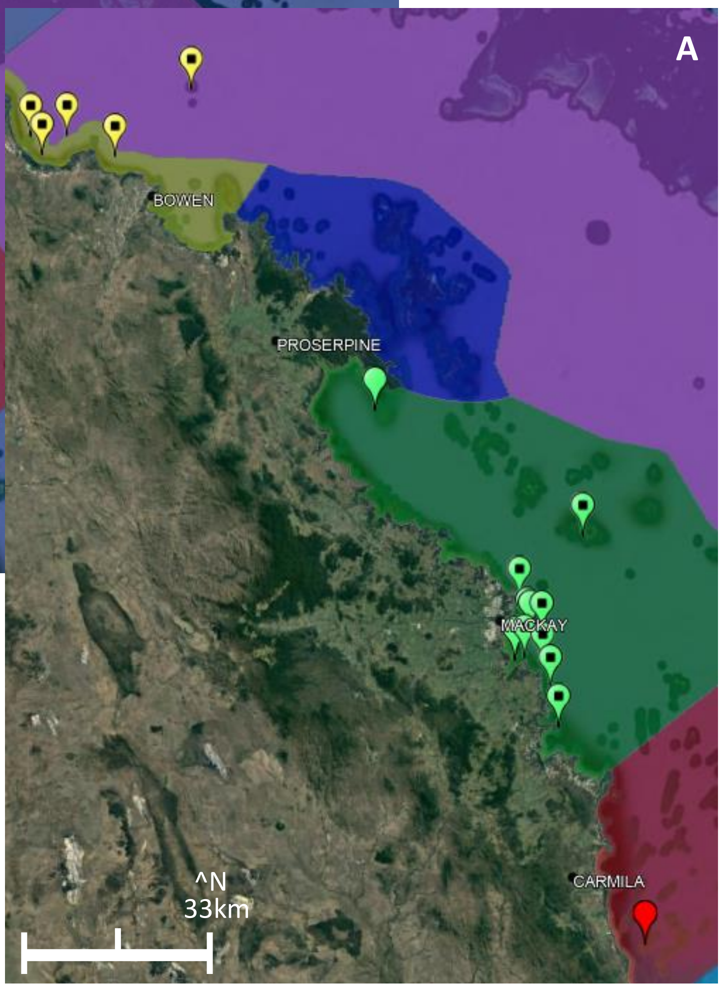


Figure 10. Water quality monitoring sites for the inshore marine zones. Sites in each zone are shown as per: Northern (yellow), Whitsunday (blue), Central (green), Southern (red) and Offshore (pink). Offshore sites are not shown as data are collected by remote sensing. Inset A displays pesticide sampling. Sites with a passive sampler are displayed as a blank marker, and grab sample sites are shown with a square in the marker.

2.3.1.2. Offshore Water Quality

The Offshore Zone extends from the State jurisdictional boundary to the eastern boundary of the GBR Marine Park; however, mid-shelf waters within this zone were excluded from condition assessments. In this zone, only two indicators over two categories are used to assess water quality (Figure 9B; chl-*a* and sediment). These data were extracted from the BoM dashboard for the 2019-20 year (Appendix A). The score was calculated from the percent of the MWI Offshore Zone that exceeds the Great Barrier Reef Marine Park Authority (GBRMPA) offshore and mid-shelf guidelines for annual means (GBRMPA, 2010). Pesticide and nutrients indicators were excluded for the Offshore Zone due to distance from land and consequently the reduced impact from land-based run-off compared to inshore waters. Chl-*a* is also widely considered as a proxy for nutrient availability in the marine environment.

2.3.2. Coral Index

The coral indicators used in the MWI Report Card closely follow those used in the GBR Report Card. In the Whitsunday Zone, coral health data are drawn from the MMP and the Long-Term Monitoring Program (LTMP) (both also used by the GBR Report Card), as well as, for the first time, the citizen science program, Reef Check Australia (RCA). In the Northern and Central Zones, data are collected by the NQBP coral monitoring programs which aligns with indicators used in the MMP and LTMP (Appendix A). In inshore zones, five indicators are used to produce scores: coral cover, composition (Whitsunday Zone only as this is a relatively new addition to the monitoring program), change, macroalgae and juvenile density. This Report Card marks the second year that coral condition scores are reported for the Southern Zone, with four years of baseline data now collected through the Partnership-funded SIP. Coral change and composition indicators both require a longer period of baseline data before they can be reported on in the Southern Zone. As a result, only the three indicators of coral cover, macroalgae and juvenile density were used to generate coral scores in 2020. As more temporal data become available, the full suite of indicators will be reported on in all inshore marine zones. Coral condition scores for the Offshore Zone also make use of the LTMP and RCA coral data, reporting on coral cover, change and juvenile density.

2.3.2.1. Survey Methods

Coral community health data are supplied by a number of different programs, with only data from the most recent survey used to calculate scores. The MMP, LTMP, NQBP Abbot Point Coral Monitoring Program and the SIP employ the photo point intercept method to record percentage cover estimates of the benthic communities (Table 12). In contrast, the NQBP Mackay and Hay Point Coral Monitoring Program and RCA use the line intercept technique which records the intercept lengths for all colonies of a species or benthic group along each transect. These are totalled and converted to a percentage cover measurement. The NQBP Abbot Point program utilises line intercept transects in addition to the photo point intercept method (Table 12).

All programs, excluding RCA, record juvenile abundance within narrow belt transects from which the density of juvenile corals can be estimated (Table 12). These transects are 34 cm wide for all surveys, except those under the NQBP programs, which are 30 cm. The LTMP Whitsunday surveys also assess the size structure and density of juvenile coral communities. Juvenile coral surveys aim to provide an estimate of the number of both hard and soft coral colonies that are successfully recruiting and surviving early post-settlement pressures. Importantly, this method aims to record only those small juvenile colonies (<5cm), which result from the settlement and subsequent survival and growth of coral larvae. It does not include small coral colonies that result from fragmentation or partial mortality of larger colonies. Both this method and the photo point intercept method closely follow the AIMS Standard operational procedure number 10 of the LTMP (Jonker et al., 2008). Despite some differences in survey methodology and transect dimensions, comparable data were collected across the various monitoring programs (Table 12). For further detail on the MMP and LTMP methods, refer to Thompson et al., (2021), the AIMS Reef Monitoring website[12] and standard operating procedures respectively. The RCA methods can also be viewed online[13].

Table 12. Survey methods for relevant coral monitoring programs reporting in the MWI Region.

Zone	Program	Survey Method	No. of Reefs and Sites	Depths Sampled per Site	Transects per Survey
Northern	NQBP (Abbot Point)	Photo point intercept transect	4 reefs (2 sites per reef)	1 survey at both 2 m and 5 m depths*	5 x 20m
		Line intercept transect			
		Belt transect			
Whitsunday	MMP	Photo point intercept transect	7 reefs (2 sites per reef)	1 survey at both 2 m and 5 m depths	5 x 20m
		Belt transect			
	LTMP	Photo point intercept transect	3 reefs (2 sites per reef)	1 survey at 5 m depth	5 x 50m
		Belt transect			5 x 5m
	RCA	Line intercept transect	6 reefs (1 site per reef)**	1 – 2 surveys at various depths	5 x 20m
Central	NQBP (Mackay & Hay Point)	Line intercept transect	8 reefs (3 sites per reef)	1 survey at <1m depth	4 x 20m
		Belt transect			
Southern	SIP	Photo point intercept transect	6 reefs (2 sites per reef)	1 survey at both 2 m and 5 m depths^	5 x 20m
		Belt transect			
Offshore	LTMP/RAP	Photo point intercept transect	9 reefs (3 sites per reef)	1 survey at 6-9 m depth	5 x 50m
		Belt transect			5 x 5m
	RCA	Line intercept transect	1 reef (2 sites per reef)	1 survey at 5 m depth	5 x 20m

* Due to the reef structure, Camp Island is surveyed at a single depth of 2m only.
**The reef at Peter's Bay is monitored at two sites.
^Due to the reef structure, Temple and Aquila Islands are surveyed at a single depth of 1m only.

Northern Zone

Coral data for the Northern Zone are collected under the NQBP Abbot Point Coral Monitoring Program from reefs around two island locations (Ayling et al., 2020a) (Table 13; Figure 11). At each island, two reefs are surveyed, with two sites per reef (Table 12). Coral community structure and disturbance

[12] http://www.aims.gov.au/docs/research/monitoring/reef/sops.html

[13] https://d3n8a8pro7vhmx.cloudfront.net/rca/pages/202/attachments/original/1528099563/RCA_methods_2015.pdf?1528099563

exposure differ markedly with depth. To account for this, the coral monitoring programs has stratified sampling efforts, completing replicate transects at multiple depths where applicable. For each site at Holbourne Island surveys were stratified by depth at 2 m and 5 m below lowest astronomical tide (LAT), while at Camp Island, sampling could only be done at 2 m depths due to reef structure (Ayling et al., 2020a) (Table 12). Holbourne Island technically falls within the Offshore Zone (and mid-shelf water type) (Figure 11), however surrounding reefs include species typical of both inshore and mid-shelf reefs. As such, for the Report Card, these reefs are included in the Northern Zone.

Whitsunday Zone

Photo point intercept and belt transect data were collected from MMP, LTMP and RCA sites in the Whitsunday Zone (Table 12). The MMP stratify survey efforts at 2 m and 5 m, while LTMP sample at 5 m depth (Table 12). Due to the shallow nature of some survey sites, stratified sampling is not always possible, and as such, RCA surveys are done at a range of depths to accommodate for the location of coral communities at the monitored sites.

The MMP and LTMP programs have a biennial sampling design, meaning each reef is surveyed every second year (see Table 13 for the most recent Whitsunday sample dates; also see Table 14). Values of each indicator from the most recent surveys are used to calculate the score each year. The MMP will also conduct contingency sampling of certain unscheduled reefs if acute disturbances, such as cyclones, are suspected to have impacted them during the preceding summer. As such, data for the 2020 Report Card are repeated from 2018-19 for LTMP sites, while MMP surveys were updated in 2019-20. For full details refer to Thompson et al., (2021).

Central Zone

Coral community health data for the Central Zone were collected from four island locations under the NQBP Mackay and Hay Point Coral Monitoring Program (Ayling et al., 2020b) (Table 13; Figure 11). At each island, two reefs are surveyed, with three sites per reef. At each site, cover of benthic reef organisms was assessed along transects between 0.5 m and 0.7 m below LAT (Ayling et al., 2020b) (Table 12).

Southern Zone

Inshore coral data for the SIP were collected from six island locations (Table 13; Figure 11). Transects were replicated at both 2 m and 5 m depths below LAT at Pine Peak Island, Pine Islets, Henderson Island and Connor Island. At Temple Island and Aquila Island however, the reef slope transitioned to sand at 1.0 - 1.5 m below LAT and therefore, transects were set at 1 m below LAT only (Table 12).

Offshore Zone

Offshore Zone coral data were collected from 17 sites that were surveyed by RCA and as part of the LTMP and RAP to assess the effects of rezoning the GBR Marine Park in 2004 (Figure 11). Reefs in the LTMP are surveyed in alternate years (odd years), while surveys done for the RAP are done every other year (even years) (Table 14). Data for LTMP sites are therefore repeated from 2018-19 and 2016-17 surveys (one site only) for the 2020 Report Card, while data from the RAP were updated in 2019-20 (except at two sites surveyed in 2017-18) (Table 14). However, these offshore coral scores for each reporting year are calculated based on the rolling mean of data collected over a four-year period.

The intensive survey sites are located in the first stretch of continuous reef encountered when following the perimeter from the back-reef zone towards the front-reef in a clockwise direction, usually on the north-east flank of the reef. Where possible, sample sites were a minimum of 250 m apart, and five 50 m transects were completed at each site (Table 12). Transects follow depth contours on the reef slope parallel to the reef crest (at approximately 6-9 m depth). Coral community change with depth is most pronounced in inshore areas where the turbidity of waters causes a rapid attenuation of light, and as such only one depth was sampled at each site.

Technically, Penrith Island falls just within the Central Zone for the MWI Report Card, but the Penrith Island reef is characterised as 'mid-shelf' (Figure 11), and as such is included with the offshore reefs for the Report Card. All coral reef sites included for assessment were selected based on expert advice and to meet the purposes of each specific coral monitoring program.

Table 13. Coral monitoring for inshore marine zones in the 2020 Report Card, displaying survey frequency (●) for each site and program. The MMP program normally surveys reefs across a two-year period, however in response to thermal stress and acute disturbance from TC Debbie some reefs were sampled out of schedule (+). Note, although surveys were undertaken, RCA data were not included in the MWI Report Card prior to 2019-20.

Zone	Program	Reef	Most Recent Survey	Year Updated				
				2019-20	2018-19	2017-18	2016-17	2015-16
Northern	NQBP	Camp Is. - East	May 2020	●	●	●	●	
		Camp Is. - West		●	●	●	●	
		Holbourne Is. - East		●	●	●	●	
		Holbourne Is. - West		●	●	●	●	
Whitsunday	LTMP	Langford-Bird Reef	April - May 2019		●		●*	
		Hayman Is. Reef			●		●*	
		Border Is. Reef (No.1)			●		●*	
	MMP	Double Cone Is.	June 2020	●	●	●	+	●
		Hook Is.		●		●		●
		Daydream Is.		●		●	+	●
		Shute Harbour		●		●	+	●
		Dent Is.		+	●		●	
		Pine Is.		+	●	+	●	
		Seaforth Is.		+	●		●	
	RCA	Blue Pearl Bay	May 2020	●	●			●
		Butterfly Bay		●		●		
		Luncheon Bay		●				●
		Lovers Cove		●		●		●
		Mermaids Cove		●		●		●
		Peter's Bay		●				
Central	NQBP	Keswick Is.	Oct – Nov 2019	●	●	●	●	
		Round Top Is.		●	●	●	●	
		Slade Islet		●	●	●	●	
		Victor Islet		●	●	●	●	
Southern	SIP	Pine Peak	May 2020	●	●			
		Pine Islets		●	●			
		Henderson Is.		●	●	●		
		Connor Is.		●	●			
		Temple Is.		●	●			
		Aquila Is.		●^	●			

* Reefs that were surveyed prior to the passage of TC Debbie in March 2017.
^ Surveyed just outside of the 2019-20 FY (12th July 2020), but included in the 2020 Report Card.

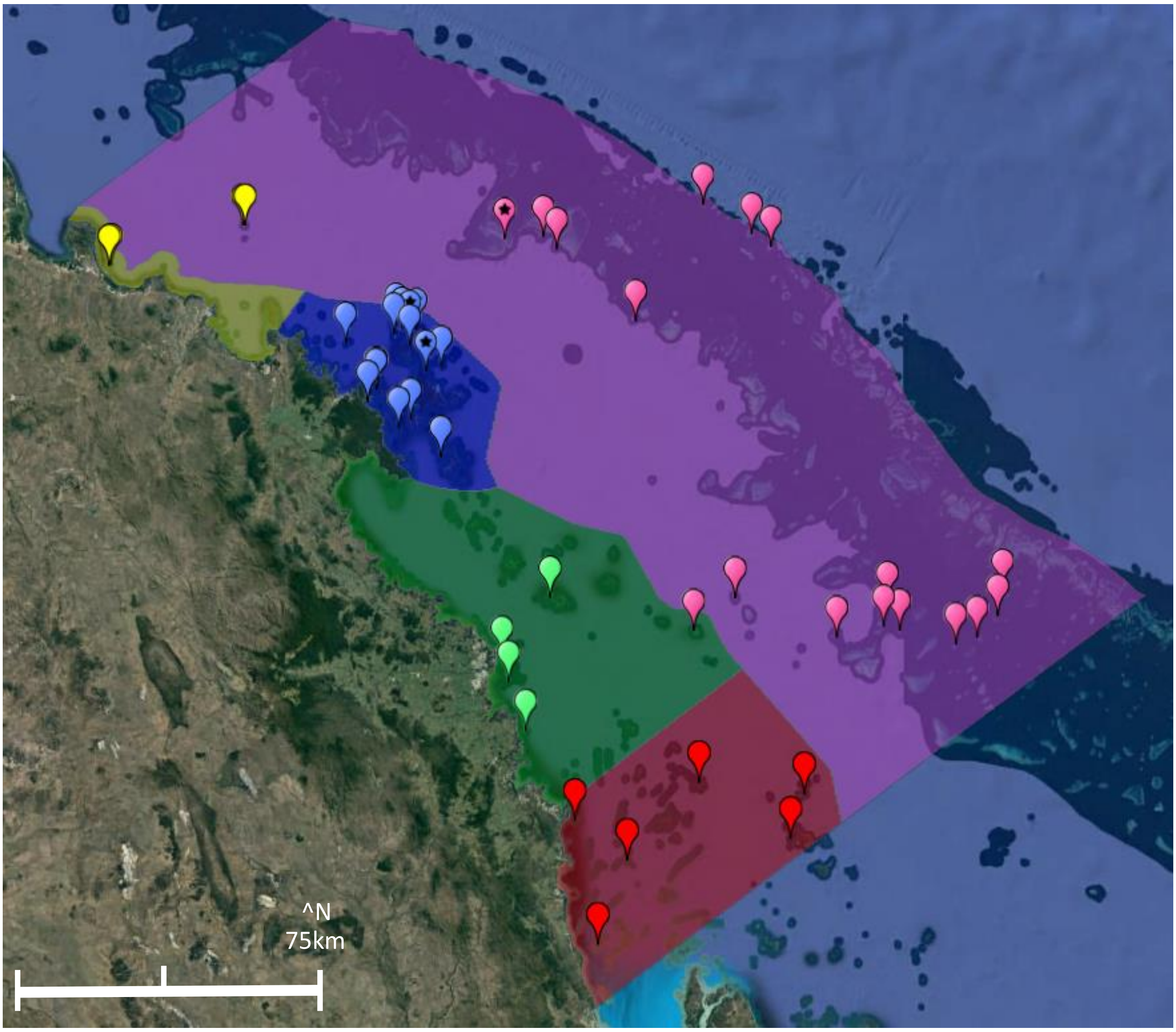


Figure 11. Coral monitoring sites for the inshore and offshore zones. Sites in each zone are shown as per: Northern (yellow), Whitsunday (blue), Central (green), Southern (red) and Offshore (pink). Reef Check Australia sites are shown with a star in the marker.

Table 14. Coral monitoring for Offshore Zone in the 2020 Report Card, displaying survey frequency (●) for each site and program. The LTMP and RAP survey in alternate years and scores for each reporting year for these programs are calculated based on a four-year rolling mean. Note, although surveys were undertaken, RCA data were not included in the MWI Report Card prior to 2019-20.

Zone	Program	Reef	Most Recent Survey	Year Updated				
				2019-20	2018-19	2017-18	2016-17	2015-16
Offshore	LTMP	Slate Reef	April 2019		●		●	
		Hyde Reef			●		●	
		Rebe Reef			●		●	
		19-131S			●		●	
		19-138S			●		●	
		20-104S	Feb 2017				●	
	RAP	Pompey Reef (No. 1)	Sept 2019	●		●		●
		Pompey Reef (No. 2)		●		●		●
		21-060S		●		●		●
		21-591S		●		●		●
		20-353S		●		●		●
		21-064S		●		●		●
		Tern Reef (20-309)		●		●		●
		Penrith Reef		●		●		●
		20-348S	May 2018			●		●
		21-062S				●		●
	RCA	Hardy Reef	March 2020	●		●	●	●

2.3.3. Seagrass Index

The seagrass indicators used in the MWI Report Card are based on those used in two existing monitoring programs (Figure 12, Table 15, Appendix A). The first program is the MMP, used in the GBR Report Card results, which provides data for the Whitsunday and Central Zones. This also includes data from the citizen science monitoring program, Seagrass Watch (McKenzie et al., 2003). The second is the QLD Ports Seagrass Monitoring Program (QPSMP) in the Northern and Central Zones. A Partnership-funded seagrass monitoring program was established in the Southern Zone in 2017, monitoring the same indicators as in the QPSMP. To report on seagrass condition over time however, a baseline or reference condition needs to be ascertained through five years' worth of monitoring. As a result, seagrass condition has not yet been reported on in the Southern Zone, and will be included for the first time in the 2021 Report Card.

2.3.3.1. Marine Monitoring Program

The MMP seagrass sampling design was developed to detect change in inshore seagrass meadows in response to improvements in water quality parameters associated with specific catchments or regions and in the context of disturbance events (McKenzie et al., 2015). This program monitors the percentage cover of seagrass (McKenzie, 2009; McKenzie et al., 2003), tissue nutrient status (carbon:nitrogen ratio) (McKenzie et al., 2015) and reproductive effort (production of spathes, flowers and fruits per unit area) (McKenzie et al., 2015) (Table 15). Monitoring occurred during the late dry (growing) season and late wet season in order to obtain information on the seagrass communities' status pre- and post-wet season.

The reproductive effort indicator has been identified as negatively biasing scores and not reflect the true condition of seagrass meadows as it does not take into account differing life histories among seagrass species. From 2021 onwards, the MMP will be replacing the reproductive effort indicator with a resilience metric, and will also be removing the nutrient status indicator. These changes will be reflected in future MWI Report Cards.

The meadows monitored within the MMP were selected by the GBRMPA using expert advice (McKenzie, 2009; McKenzie et al., 2010, 2015). This was done using mapping surveys to select representative meadows, which were those that had a greater extent of seagrass. They were also generally the dominant community type and within GBR average abundances (McKenzie et al., 2015). Meadows in both lower littoral (rarely exposed to air) and sub littoral (permanently covered with water) zones were sampled. Two sites (transect blocks) were selected at each location to account for spatial heterogeneity. Additionally, the minimum detectable difference between sites had to be below 20% (McKenzie et al., 2015). Where both transect blocks occur within the same meadow and at the same depth, they are treated as replicates and the two scores are averaged to provide a location score.

Seagrass Watch contributes data to the Whitsunday and Central Zones, and for the Northern Zone for the first time in the 2020 Report Card from sites at Bowen (Table 15 and Figure 12). Seagrass Watch is also collecting seagrass monitoring data from sites at Clairview in the Southern Zone (Table 15), although this is not comprehensive enough to calculate a score for the zone. These data will be combined with data collected by TropWATER as part of the SIP to calculate seagrass health scores in the 2021 Report Card onwards (currently being collected to establish a baseline).

2.3.3.2. Queensland Ports Seagrass Monitoring Program (QPSMP)

The objective of the QPSMP is to report on the condition of seagrass in the highest risk areas of QLD and use this information to assist in the planning and management of anthropogenic activities (Carter et al., 2019). The QPSMP monitors and reports on seagrass condition for entire meadows (Figure 12) and sampling occurs annually during the peak of the seagrass growing season in late spring/early summer, at the end of the dry season. Meadow selection is based on the representation of the range of meadow types found in each. The indicators surveyed by this program are mean above-ground biomass, meadow area and species composition (York & Rasheed, 2019) (Table 15).

The QPSMP report card approach was developed in consultation with the Gladstone Healthy Harbours Partnership (GHHP) to report on seagrass condition for the Gladstone region (Carter et al., 2015) and was implemented across the QPSMP ports in 2014. The methods for setting baseline conditions, score calculation and indicator assessment (Bryant et al., 2014; Carter et al., 2015) have received independent analysis and review through the GHHP Independent Science Panel (ISP), and the wider program's results are published in peer-reviewed journals (Carter et al., 2016). For further information on site selection and methods in the MWI Region, refer to previous QPSMP reports for Abbot Point (McKenna et al., 2019) and Mackay and Hay Point (York & Rasheed, 2019).

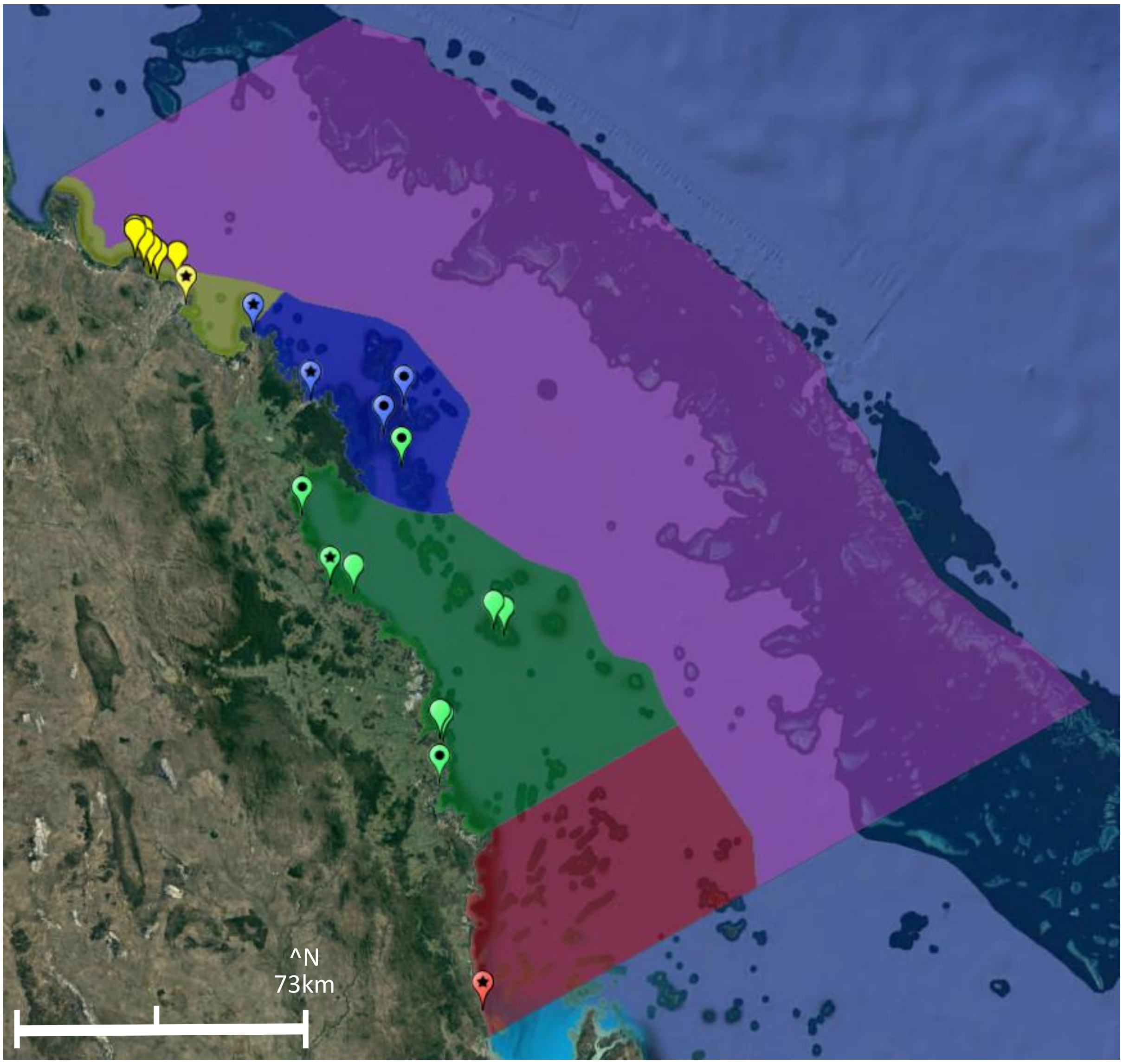


Figure 12. Seagrass monitoring sites for the inshore zones. Sites in each zone are shown as per: Northern (yellow), Whitsunday (blue), Central (green) and Southern (red). Seagrass is not currently reported on in the Offshore Zone (pink). MMP sites are shown with a black circle in the marker, while Seagrass Watch sites are shown with a star in the marker.

Table 15. Seagrass monitoring programs and indicators in the MWI 2020 Report Card. A green cell with a cross (●) marks an indicator that is measured at that given site. Note, Abund. = abundance, Reprod. Effort = reproductive effort, Sp. Comp. = species composition.

Zone	Habitat	Depth	Location	Site	Program Indicators: MMP Abund.	MMP Reprod. Effort	MMP Nutrient Status	QPSMP Biomass	QPSMP Area	QPSMP Sp. Comp.
Northern	Coastal	Intertidal	Bowen	BW1*	●					
				BW2*	●					
		Inshore	Abbot Point	API3				●	●	●
				API5				●	●	●
				API7				●	●	●
				API8				●	●	●
				API9				●	●	●
		Subtidal		APD1				●		●
				APD2				●		●
				APD3				●		●
				APD4				●		●
Whitsunday	Reef	Intertidal	Hydeaway Bay	HB1*	●					
				HB2*	●					
			Hamilton Is.	HM1	●	●	●			
				HM2	●	●				
		Subtidal	Tongue Bay	TO1^	●					
				TO2^	●					
	Coastal	Intertidal	Pioneer Bay	PI2*	●					
				PI3*	●					
Central	Coastal	Intertidal	Midge Point	MP2	●	●	●			
				MP3	●	●	●			
			St. Helens Beach	SH1*	●					
		Subtidal	Lindeman Is.	LN1	●	●	●			
				LN2	●	●	●			
			Newry Bay	NB1^	●					
				NB2^	●					
			St. Bees Is.	SB10				●	●	●
			Keswick Is.	KW14				●	●	●
			Hay Point	HPD1				●	●	●
		Intertidal /Subtidal	Dudgeon Point	DP1				●	●	●
	Estuarine	Intertidal	Sarina Inlet	SI1	●	●	●			
				SI2	●	●	●			
Southern	Coastal	Intertidal	Clairview	CV1*	●					
				CV2*	●					

*Seagrass Watch
^QLD Parks and Wildlife Service (QPWS) drop-camera

2.3.4. Litter

Litter is included as a formal indicator for the first time in the 2020 Report Card. Currently this indicator has only one category, total litter, with the goal to divide this into plastic bags, single-use items and cans/bottles in the near-future. Total litter is compared against a baseline derived from four years of data from July 1st 2014 until June 30th 2018 (before management restrictions were imposed in QLD). Data are sourced from the Australian Marine Debris Initiative (AMDI) Database (Appendix A) as collected by volunteers from across Australia, including at Tangaroa Blue Foundation and ReefClean events. Technical expertise for the calculation of scores and grades was provided to this project by Bill Venables and Tegan Whitehead (model development), and by Jordan Gacutan from the University of New South Wales (UNSW) (data filtering and processing).

As this metric is based on a dataset collected by volunteers there is some inconsistency with sample sizes and sampling locations across zones and years. Scores and grades are therefore presented at the site level, rather than rolled up into a zone-level score. This reduces biases on scores that would come with changes in sampling effort from year-to-year, and will allow better representation and comparison of how the amount of litter has changed at particular sites across report cards.

The following method is described as per that designed for the Dry Tropics Partnership for Healthy Waters Report Card (Whitehead, 2020) with filtering methods as per Appendix B1.

2.3.4.1. Clean-up Sites and Methods

Thirty-three clean-ups were recorded in the AMDI Database in 2019-20 across inshore and urban zones in the MWI Region (Figure 13). These clean-ups were one of two types, 1) standardised 'ReefClean' sampling or 2) non-standardised clean-ups.

Standardised 'ReefClean' Sampling

The ReefClean project began in early 2019 with funding from the Australian Government's Reef Trust, led by the Tangaroa Blue Foundation and several partner organisations. Volunteers collected litter along measured transects for a designated length of time. Standardised clean-ups began in mid-2018 and will continue quarterly until June 2023. This standardised method enables comparisons across years. All debris were sorted into one of 127 categories and recorded in the AMDI Database. ReefClean data are incorporated into the litter metric where available.

Non-standardised Clean-ups

Non-standardised clean-ups were also conducted across the MWI Region, varying in location and frequency across years. Generally, easy-to-access and 'volunteer friendly' sites (such as popular beaches) are cleaned more frequently than other beaches. Non-standardised clean-ups have no defined boundary and while the number of participants and the total duration of the clean-up event is recorded, individual effort is not (i.e. unequal effort of individuals across the duration of the event). All debris collected was sorted into the AMDI categories and entered into the database. Due to inconsistency in how rigorous the debris sorting and recording process was among volunteers, the litter could not be divided into individual categories, so litter was totalled into a 'total litter' category.

2.3.4.2. Establishing the Reference Baseline

Between 1st July 2014 and 30th June 2018, clean-ups occurred at nine inshore sites in the Northern Zone, four urban and 44 inshore sites in the Whitsunday Zone, six urban and 19 inshore sites in the Central Zone and two inshore sites in the Southern Zone (Appendix B2: Table B3). The frequency that each site was cleaned during this four-year baseline period varied.

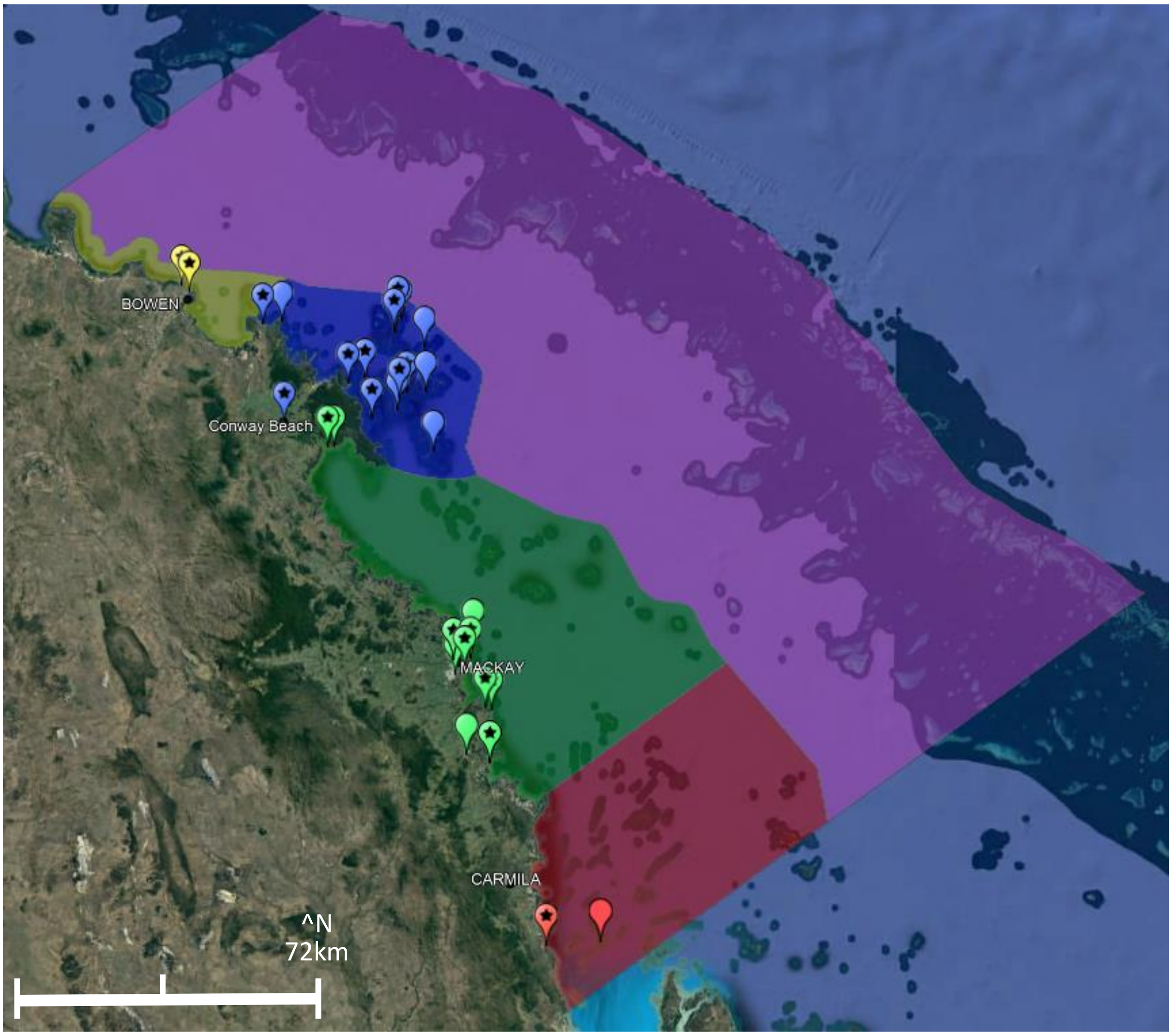


Figure 13. Urban and inshore litter survey sites for the MWI Region for 2019-20. Sites are coloured as per the zone they were sampled in – Northern (yellow), Whitsunday (blue), Central (green) and Southern (red) – but are not rolled into zone-level scores. No sites were sampled in the Offshore Zone (pink). ReefClean sites are indicated with a star in the marker.

2.3.5. Fish Index

Assessments of fish community health were deemed important across all aquatic environments of the MWI Report Card. Potential marine fish indicators and assessment methods are still being explored and therefore, are not included in the 2020 Report Card.

2.4. Stewardship

Stewardship is defined as "the responsible and sustainable use, and protection of water resources, waterways and catchments to enhance the social, cultural, environmental and economic values of the region". Stewardship is represented as the level of effective environmental management practice implemented across the region in relation to waterways and the marine environment. Stewardship is an important aspect to include in the Report Card, as it provides information on the voluntary actions local landholders and organisations are implementing (such as improved land management practices) to provide benefits to ecosystems. Stewardship activities have a direct link to water quality in the region and can be used to demonstrate how on-ground activities (responses undertaken by landholders/organisations in the region) impact water quality (the state of the natural environment). Agricultural stewardship was not reported due to a review of the Management Practice Adoption (MPA) targets, but is intended to be included in future report cards. Non-agricultural stewardship will be reported in future report cards, with agricultural and non-agricultural management activities highlighted in the Partnership's stewardship reporting, which was released for the first time with the 2018 Report Card.

2.4.1. Agricultural Stewardship

The MWI Report Card aligns its agricultural stewardship reporting with the GBR Report Card, which is reported through the Paddock to Reef (P2R) program[14]. Each year, significant investment from the QLD State and Federal Governments is directed towards adoption of best practice farm management systems with the aim of achieving the Reef 2050 Water Quality Improvement Plan's outcomes and targets and improve the quality of water flowing into the GBR (Australian and Queensland Governments, 2019a).

Farm management practice adoption benchmarks are reviewed and revised every five years and annual change is based on data reported each year. The 2016-17 year is currently set as the benchmark from which improvements are measured and aligns to the GBR Report Card. P2R program management practice and management system benchmarks were developed for each agricultural industry sector, and in each of the five major river basins within each region. Best management practices for water quality outcomes are defined in the P2R program water quality risk frameworks[15] for each major agricultural industry.

Available environmental management practice frameworks are used to provide the basis for stewardship reporting. In agriculture, frameworks that have been developed, reviewed, and endorsed

[14] https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card/2017-2018
[15] https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/management-practices

by industry are currently available for grazing, sugarcane, and horticulture and are based on P2R reporting that uses "Water Quality Risk Frameworks" (previously "ABCD Frameworks") (Australian and Queensland Governments, 2019b).

As mentioned above, due to a review of MPA targets, agricultural stewardship results were not available for the MWI Region prior to the release of this report. It is anticipated that results will be updated again in the 2021 Report Card.

2.4.2. Urban Water Stewardship

An Urban Water Stewardship Framework (UWSF) indicator category is under development by the Partnership. The framework is an initiative led by the Office of the Great Barrier Reef (OGBR) within the QLD Government[4] and in collaboration with local regional councils. This indicator sits in the non-agricultural stewardship category and is designed to provide more information on the stewardship efforts of regional councils to manage urban water in the MWI Region. The first round of UWSF assessments were conducted in late 2020, and information and scores from this assessment is set to be first reported in the 2020-21 Stewardship Report (released in late 2021), and subsequently included in the 2021 Report Card (released in July 2022).

3. Development of Condition Assessments Scoring Methods

Ordinal categories are used to describe scores for the condition of indicators, indicator categories, indices and the overall basin/estuary/zone grade. This follows a five-point grading system: very good (A), good (B), moderate (C), poor (D), very poor (E).

Numerical scores are aggregated (rolled up by calculating an average) from the indicator level to an overall score for an individual reporting zone in an environment as per Figure 2 (i.e. indicators > indicator categories > index > overall zone score).

Decision rules were developed for the minimum information required to generate the rolled-up scores:

- ≥ 50% of measured indicators to generate the indicator category score (where relevant), and
- ≥ 60% of indicator categories to generate an index score
- Overall scores for reporting zones are presented in the Report Card, even if not all indicator categories are available. However, the coaster visually shows what components contribute to the overall grade.

All indicators have specific scoring ranges and bandwidths which correspond to the five-point system. Specific scoring ranges for each indicator are described in detail in subsequent sections. Results for indicators that have divergent scoring ranges and bandwidths must be translated into a common scoring range before aggregating. The common scoring range used for reporting is based on that used by the GBR Report Card (Table 16). Where required, indicator scores were standardised into the GBR scoring range by linear interpolation (scaling) within bandwidths. In the following sections, individual indicator scoring and associated formula for scaling are presented. Once standardised, relevant scores were averaged to aggregate into the higher category.

For presentation purposes in the technical documents and online, scores are shown as integers. The exception to this rule is for coral and seagrass scores, which are presented as rounded scores to ensure alignment with the MMP and QPSMP. Importantly, all significant figures are retained when averaging scores to roll up to category, index and overall scores.

Table 16. Overall scoring range, associated grades and colour codes.

Scoring Range	Condition Grade and Colour Code
81 - 100	Very good
61 to <81	Good
41 to <61	Moderate
21 to <41	Poor
0 to <21	Very poor

3.1. Freshwater Basins and Estuaries

Indicators in freshwater basins and estuaries have closely aligned approaches to determine their condition. The following section therefore describes individual indicator scoring approaches and associated formula for indicators in both freshwater basins and estuaries.

3.1.1. Water Quality Index

3.1.1.1. Nutrients, Sediments and Phys-chem

To calculate a condition score for individual nutrients, sediments and phys-chem indicators, annual median concentrations of TSS, DIN, FRP, DO and/or turbidity are compared to local guideline values. Annual median concentrations are calculated from monthly samples, where a monthly median concentration is calculated when multiple samples were taken within the same month[16].

Only annual medians that meet, or are better than, the guideline value achieve a good or a very good score (Figure 14). Medians that do not meet the guidelines achieve a moderate, poor or very poor grade, depending on where the median falls between the guideline value and a scaling factor (SF). This approach is very similar to the MMP system used in the marine inshore waters, where the cut-off between good and moderate grades is where the indicator's annual median concentration (or mean) is equal to or better than the guideline value.

The approach to calculating a condition score (from 1 to 100) and translating this to the report card five-point grading is:

1. If the measured concentration of an indicator is less than the limit of reporting (LOR), then use a value of 0.5 x LOR,
2. Calculate monthly median concentrations (where relevant),
3. Calculate annual median from monthly medians (where relevant),
4. Compare annual median to the relevant local guideline value,
5. Calculate condition score (0 – 100) following rules and formula in Table 17 and Table 18, and
6. Aggregate indicator scores into indicator category scores (where relevant) and the water quality index (following decision rules for minimum information).

[16] Multiple samples are taken during rainfall events at GBRCLMP sites. Using a monthly median removes bias towards event concentrations.

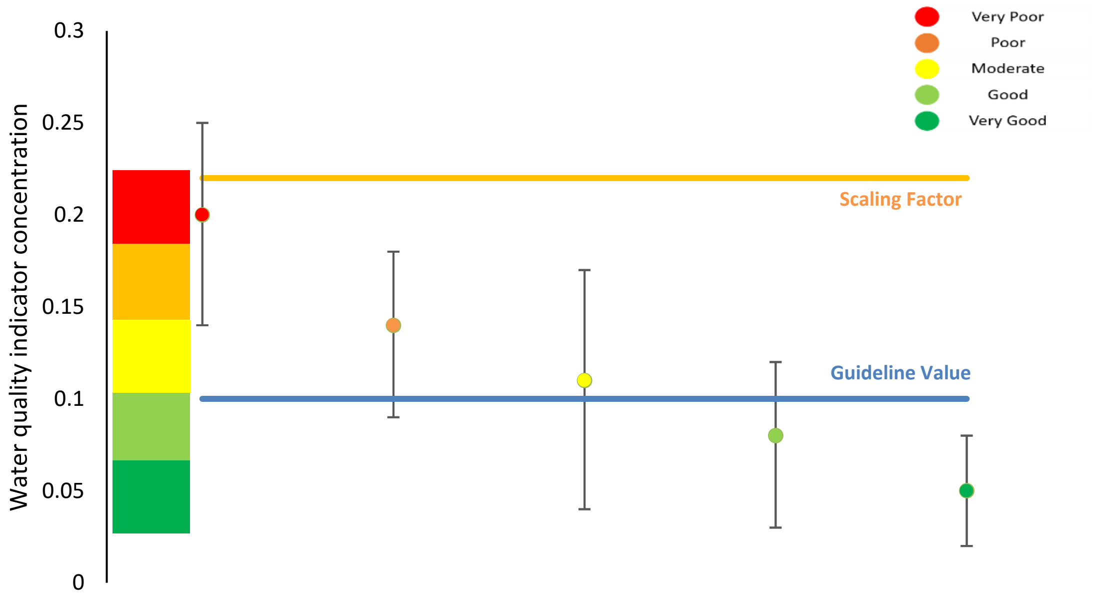


Figure 14. An example of how water quality grades are assigned. Where the middle point represents the annual median, the top whisker the 80th percentile and the bottom whisker the 20th percentile of the data. Only when the median meets or is better than the guideline (in this case meeting the guideline means the value must be at or below the guideline) can good or very good be scored. Scores for moderate, poor and very poor are equally scaled between the guideline and scaling factor.

Table 17. Rules, formulae and scoring ranges for associated grades for TSS, DIN, FRP, chl-*a*, Turbidity and DO (when comparing to the upper guideline value) in freshwater basins and estuaries of the MWI Report Card.

Rule	Formula	Scoring Range	Grade
Median meets GV and ≥80% of data meets GV	Assigned 90[17]	81 to 100	Very good
Median meets GV, but 80% of data does not meet GV	80.9-(19.9*(((80th-GV)/(80th-median))))	61 to <81	Good
Median does not meet GV	60.9-(60.9*(ABS((median -GV)/(SF-GV))))	41 to <61	Moderate
		21 to <41	Poor
		0 to <21	Very poor

Where: 80th = 80th percentile of the data; median = annual median; SF = scaling factor based on 90th percentile[18] of available data.

[17] QLD water quality guidelines 2009 recommend protocols for testing against 20th, 50th (median) and 80th percentiles. There is no *a priori* knowledge or guidelines regarding the entire distribution of water quality parameters in our systems, so assumptions/decisions regarding the other 20% of the data (between 80-100%) and how it should be distributed around the GV cannot be made. Thus, a discrete value within the very good range to systems if the 80th percentile meets the GV was assigned. The middle (i.e. 90) of the very good range (Table 17) is used to assign a score for very good.

[18] Scaling Factor for DO is varied to be based on the 99th percentile of all values – further discussion below under 'Scaling Factors (SF)'.

Table 18. Rules, formulae and scoring ranges for associated grades for DO (when comparing to the lower guideline value (GV)*) in estuaries of the MWI Report Card[10].

Rule	Formula	Scoring Range	Grade
Median meets GV and ≥80% of data meets GV	Assigned 90	81 to 100	Very good
Median meets GV, but 80% of data does not meet GV	80.9 - (19.9 * (((GV - 20^{th}) / (median - 20^{th}))))	61 to <81	Good
Median does not meet GV	60.9 - (60.9 * (ABS((median - GV) / (SF - GV))))	41 to <61	Moderate
		21 to <41	Poor
		0 to <21	Very poor

Where: 20^{th} = 20^{th} percentile of the data; median = annual median; SF = scaling factor based on 90^{th} percentile of available data.
* To meet the lower DO guideline value, % saturation must be higher than the GV; this is inverse to how other indicators meet GV, thus the formula to calculate grade must also be the inverse.

Guideline Values

Guideline values used for freshwater basins are based on the QLD Water Quality Guidelines 2009 (DES, 2009) and are related to the individual river or creek (Table 19). For the Don River, guideline values used are based on the 'Draft environmental values and water quality guidelines: Don and Haughton River Basins, MWI estuaries, and coastal/marine waters' (Newham et al., 2017). These draft guideline values are listed as 20^{th}, 50^{th} and 80^{th} percentiles, rather than single values. Annual medians were compared to the middle value of this range of guidelines. This aligns with the approach used to score annual values in the inshore marine environment where 20^{th}, 50^{th} and 80^{th} percentile guideline values are scheduled. This document is also used for the guideline values for estuaries (Table 20).

Draft guidelines for DIN for the Don Basin and monitored estuaries were not available, therefore guideline values were created by summing ammonia nitrogen and NO_x draft guideline values. There is a precedent for this approach in the EPP 2009 'Proserpine River, Whitsunday Island and O'Connell River Basins environmental values and water quality objectives'[19] which, in reference to DIN guideline values, states: "DIN = ammonia nitrogen + NO_x" (page 47). This is reflected in the additive nature of the scheduled water quality objectives for the mid and lower-estuaries in this document.

[19] https://ehp.qld.gov.au/water/policy/pdf/plans/proserpine-river-ev-wqo.pdf

Table 19. Water quality indicator categories, associated indicators and guideline values for freshwater basins in the MWI Report Card.

Indicator category	Indicator	Unit	Don (Don River)	O'Connell (O'Connell River)	Pioneer (Pioneer River)	Plane (Sandy Creek)	Plane (Plane Creek)
Nutrients	DIN	mg/L	0.03	0.03	0.008	0.03	0.008
	FRP	mg/L	0.045	0.006	0.005	0.015	0.008
Sediment	TSS	mg/L	5	2	5	5	3

Table 20. Water quality indicator categories, associated indicators and guideline values for estuaries in the MWI Report Card. DO guideline values are presented as lower and upper limits.

Indicator Category	Indicator	Unit	Gregory	O'Connell	St Helens/Murray	Vines	Sandy	Plane	Rocky Dam	Carmila
Nutrients	DIN	mg/L	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
	FRP	mg/L	0.03	0.03	0.03	0.03	0.06	0.06	0.06	0.06
Phys-chem	DO	% sat	70-105	70-105	70-105	70-105	70-105	70-105	70-105	70-105
	Turbidity	NTU	10	10	10	10	Too variable to derive GV			
Chl-*a*	Chl-*a*	µg/L	2	2	2	2	5	5	5	5

Scaling Factors (SF)

To set a SF for freshwater nutrient and sediment indicators (DIN, FRP and TSS), the historical GBRCLMP data was pooled for each basin and the 90th percentile was used as the SF. The advantage of this approach is that the SF's were derived from the largest sample size available. For new sites, including the Don and Proserpine GBRCLMP sites, the same SF used for existing sites will be applied to new sites. This will mean the number of SF values across the Report Card will be minimised, making the assessments between basins more consistent.

For the estuarine indicators turbidity, DIN, FRP and chl-*a*, the SF is based on the 90th percentile of all values of the relevant indicator collected from estuarine monitoring in the MWI Region. The SF for DO is based on the 99th percentile of all values for DO collected from estuarine monitoring in the MWI Region. This is because the adoption of the 90th percentile would have resulted in adoption of a SF value of 70% saturation. Most significantly, this is the same as the lower guideline value for DO. This value was unsuitable as the SF needs to be some distance from the guideline value in order to provide a scoring range that will determine the grade of annual medians that do not meet guidelines. Further, values below 70% saturation occur reasonably frequently in the reference estuary, the Gregory, and therefore the use of a 90th percentile SF value would put the least impacted estuary in a poor category.

Therefore, the SF that was adopted to DO was the 99th percentile (~60% saturation), which avoids giving the Gregory a poor score and still provides a reasonable scoring range.

The Sandy, Rocky Dam, and Carmila Creeks estuaries are strongly tidal influenced, and this may be apparent in the results. This could affect turbidity values through increased suspension of sediments by tidal currents. Additionally, at the time of setting SF values estuarine monitoring in the MWI Region is a newly commenced program, therefore only one year of data were available for calculation of the SF. SF values will be re-visited in the future as more data are collected.

Limits of Reporting (LOR)

Rules have been set around how to deal with samples where concentrations of an indicator are below the LOR:

- Where a monitoring program reports a LOR that is greater than the guideline value, data from that program where a concentration was reported as <LOR is not used (because this does not allow for valid interpretation of whether guidelines are met within the State of QLD), and
- Where a monitoring program reports a LOR that is less than the guideline value, a value of 0.5 x LOR is applied to data where <LOR is reported in a sample.

When a monitoring program reports a LOR where the magnitude of difference between the guideline value and the LOR is less than two-fold, applying a value of 0.5 x LOR may have the impact of biasing results towards better scores than is true in the field. Therefore, the number of samples where data are reported as <LOR, should be considered when reporting confidence of the results when the magnitude of difference between the guideline value and the LOR is less than two-fold.

Table 21. Water quality indicator categories, associated indicators and LOR values for estuaries in the MWI Report Card. DO guideline values are presented as lower and upper limits.

Indicator Category	Indicator	Unit	LOR
Nutrients	Ammonium Nitrogen (NH_4)	mg/L	0.002
	NOx	mg/L	0.001
	FRP	mg/L	0.002
Phys-chem	DO	% sat	-
	Turbidity	NTU	-
Chl-*a*	Chl-*a*	µg/L	0.100
Sediment	TSS	mg/L	1.000

Aggregation of Scores

Multiple monitoring sites were used to inform water quality scores within the O'Connell and Plane basins. The addition of these sites into the Report Card assessment occurred for the first time in 2018. The following steps were applied for the aggregation of scores in the O'Connell and Plane basins:

1. The total catchment area upstream of the monitoring site was obtained from the QLD Government[4],
2. The adjusted upstream catchment area for each monitoring site was determined. Where multiple monitoring sites are present along the same system, the adjusted catchment area reflects:
    a. The total upstream catchment area from the start of the system, or
    b. The total upstream catchment area as measured from the (first) upstream monitoring station to the next monitoring station,
3. The proportion of total catchment area for each monitoring site was determined and multiplied by the standardised score for each monitoring site,
4. All scores were summed to provide the final basin score.

3.1.1.2. Pesticides

Pesticide indicator scores were developed by the QLD Government's[4] GBRCLMP using the PRM. The aim of this approach is to quantify the ecological risk associated with exposure to a mixture of pesticides. Measured concentrations of up to 22 pesticides (Table 4) in a given sample are converted to a PRM that expresses risk as the percentage of aquatic species that may be adversely affected by the mixture of pesticides. In previous report cards, the PRM had been used to calculate the mixture toxicity for PSII herbicides only, which have a common MoA. From the 2019 Report Card onwards, the PRM approach has been applied to pesticides with multiple MoAs (Table 4). This was calculated using the independent action model of joint action (Plackett & Hewlett, 1952; also see Warne et al., 2020).

The pesticide mixture toxicity was calculated for all samples collected over the principal pesticide exposure period (i.e. the wet season period between 1st November and 30th April)). Where there was more than one sample per day, a daily mean concentration was calculated. The mixture toxicity data (i.e. PRM values) for all water samples collected over the wet season were then summarised as a single value. A multiple imputation technique was used to the daily average PRM for days that were not monitored during the wet season (Donders et al., 2006; Patrician, 2002; Rubin, 1996). This involved fitting a statistical distribution to the observed data for the wet season for the site. Values were then imputed to fill in the missing days in the 182-day period. The resultant data were then divided to obtain the daily PRM and ranked into five risk categories (Table 22). These categories are consistent with the ecological condition categories used in the Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters. All values were rounded to the nearest whole number.

Table 22. Grading description for the pesticides indicator in the freshwater basin assessments.

Risk Categories (% species affected)	% Species Protected	Risk Level	Pesticides Assessment	Scaling of Scores for Aggregation
≤1.0 %	≥99%	Very low risk	Very good	= 81 + ABS((19 - ((score - 0) * (19 / 1))))
>1 – <5%	>95 – <99%	Low risk	Good	= 61 + ABS((19.9 - ((score - 1.01) * (19.9 / 3.99))))
5 – <10%	>90 – 95%	Moderate risk	Moderate	= 41 + ABS((19.9 - ((score - 5.00) * (19.9 / 4.99))))
10 – <20%	>80 – 90%	High risk	Poor	= 21 + ABS((19.9 - ((score - 10.00) * (19.9 / 9.99))))
≥20.0%	≤80%	Very high risk	Very poor	= 0 + ABS((20.9 - ((score - 20.00) * (20.9 / 79.99))))

3.1.2. Habitat and Hydrology

3.1.2.1. Instream Habitat Modification

The two in-stream habitat modification indicators, impoundment length and fish barriers, were equally weighted to generate the in-stream habitat modification score for freshwater basins (only fish barriers is used in this category for estuaries). Scoring for each indicator is described below. Final impoundment length and fish barrier scores were standardised within appropriate bandwidths before an average score was generated to describe the overall condition of the in-stream habitat modification indicator.

Impoundment Length (Freshwater Basins only)

The scoring range (Table 23) was derived from work on Murray-Darling Basin rivers which involved benchmarking the ecological condition of multiple rivers in relation to several ecological indicators, one of which was the proportion of river impounded by dams and weirs. The ecological condition of streams was assessed during benchmarking and was based on existing studies and the expert opinion of a panel of experienced aquatic ecologists[3]. An assumption of status quo is implied in the scoring for impoundment length (rather than cause-and-effect with ecological function), with additional impoundments lowering subsequent report card scores.

Table 23. Grading description for the impoundment length indicator in the freshwater basin assessments.

% of Waterway Impounded	Condition Grade	Scaling of Scores for Aggregation
<1.0%	Very good	= 81 + ABS((19 - ((score - 0) * (19 / 0.99))))
1.0 - 3.99%	Good	= 61 + ABS((19.9 - ((score - 1) * (19.9 / 2.99))))
4.0 - 6.99%	Moderate	= 41 + ABS((19.9 - ((score - 4) * (19.9 / 2.99))))
7.0 - 9.99%	Poor	= 21 + ABS((19.9 - ((score - 7) * (19.9 / 2.99))))
≥10.0%	Very poor	= 0 + ABS((20.9 - ((score - 10) * (20.9 / 90))))

Fish Barriers

To score the condition of fish barriers in freshwater basins and estuaries, a scoring range and subsequent score was developed for each of the three indicators (Table 24 to Table 26). Each basin and estuary were allocated a score for each indicator based on these scoring ranges. The final aggregated fish barriers indicator score for each basin and estuary was derived by adding these three scores together (Table 27).

Table 24. Scoring range and subsequent score assigned for the barrier density indicator. Assessed on Stream Order (SO) as indicated[20].

Scoring Range (km/barrier) Freshwater Basins and Estuaries (SO ≥ 3)	Score	Condition Grade
≥16.1	5	Very good
8.1 - 16	4	Good
4.1 - 8	3	Moderate
2.1 - 4	2	Poor
0 - 2	1	Very poor

Table 25. Scoring ranges in freshwater basins and estuaries and subsequent score assigned for 'stream length to the first barrier as a proportion (%) of total stream length'. Assessed on Stream Order (SO) as indicated.

Scoring Range (%)		Score	Condition Grade
Freshwater Basins (SO ≥ 3)	Estuaries (SO ≥ 3)		
No Barriers	No Barriers	5	Very good
50% - 99.9%	80% - 99.9%	4	Good
30% - 49%	60% - 79%	3	Moderate
10% - 29.9%	40% - 59.9%	2	Poor
0% - 9.9%	0% - 39.9%	1	Very poor

Table 26. Scoring ranges in freshwater basins and estuaries and subsequent score assigned for 'stream length to the first low/no passability barrier as a proportion (%) of total stream length'. Assessed on Stream Order (SO) as indicated.

Scoring Range (%) Freshwater Basins (SO ≥ 4)	Scoring Range (%) Estuaries (SO ≥ 4)	Score	Condition Grade
≥95.1%	No low pass barriers (100%)	5	Very good
70.1% - 95%	90.1% – 99.9%	4	Good
60.1% - 70%	80.1% - 90%	3	Moderate
50.1% - 60%	60.1% - 80%	2	Poor
0% - 50%	0% - 60%	1	Very poor

Table 27. Overall fish barrier condition scoring range and fish barrier condition rating.

Scoring Range	Overall Fish Barrier Condition Rating	Scaling of Scores for Aggregation
14 - 15	Very good	= 81 + ABS((19 + ((score - 15) * (19 / 1))))
11 - 13	Good	= 61 + ABS((19.9 + ((score - 13) * (19.9 / 2))))
8 - 10	Moderate	= 41 + ABS((19.9 + ((score - 10) * (19.9 / 2))))
5 - 7	Poor	= 21 + ABS((19.9 + ((score - 7) * (19.9 / 2))))
3 - 4	Very poor	= ABS((20.9 + ((score - 4) * (20.9 / 1))))

[20] In estuaries only, barriers were assessed on waterways that intersected the Fisheries Queensland 'Estuary Extent' Layer, regardless of Stream Order.

3.1.2.2. Flow

The flow indicator scores the daily flow record for the reporting year at a given flow assessment site. There are ten measures that contribute to this score (Table 28). Each measure assesses observed flow data against the reference distribution from pre-development modelled flow for each flow assessment site. The reference distributions are selected for one of the four rainfall types (drought, dry, average or wet) to match the rainfall type of the reporting year. The ten flow measures were selected to represent key components of the natural flow regime that are required by a range of ecological assets with links to water resources that are sensitive to changed water allocation and management conditions. The key flow components and associated ecological assets are cease-to-flow (CTF) (amphibians, riffles and waterholes), low flows (some spawning fish, reptile and amphibian species, and riffles and waterholes), medium flows (riffles) and high flows (fisheries production in estuaries). Details of the flow requirements of the assets (including seasonal flow requirements), their links to the flow measures and a description of the flow measures are presented in the Report Card Flow Indicator Project report (Stewart-Koster et al., 2018)[10].

Landscape changes resulting from human activities, including vegetation clearing, removal of wetlands, levelling, modification of channel morphology and removal or addition of waterway channels, may affect the characteristics of flood waters including their duration, extent and frequency. Consequently, whilst flow volumes during flood events may be similar to pre-development levels the actual hydrological characteristics of the flood and inundation events, and hence their ecological functioning, may be altered.

Table 28. The ten flow measures used for the flow indicator, the season to which they apply and the hydrologic definition of the measure. Note, CV = coefficient of variation.

Flow Measure	Season	Hydrologic Definition
Low flow duration	July-Jan	Total duration of flows which remain equal to or below the 10th percentile threshold for the reporting period (annual).
Low flow frequency	July-Jan	Count of the number of occurrences during which the magnitude of flow falls to or below the 10th percentile threshold during the reporting period (annual).
Low flow variability (CV dry season)	July-Dec	CV (standard deviation/mean) of daily flow for dry season.
Driest six months (ratio dry/total)	July-Dec	Proportion of annual discharge contributed during the months July-December.
CTF duration	All year	Total duration of where flow ceases during the reporting period (annual).
CTF frequency	All year	Count of the number of occurrences during which flow ceases during the reporting period (annual).
Medium flow duration	All year	Total duration of flows which remain equal to or above the 50th percentile threshold for the reporting period (annual)
Medium flow frequency	All year	Count of the number of occurrences during which the magnitude of flow passes from below to equal or above the 50th percentile threshold during the reporting period (annual).
High flow duration	All year	Total duration of flows which remain equal to or above the 90th percentile threshold for the reporting period (annual)
High flow frequency	All year	Total count of flows which remain equal to or above the 90th percentile threshold for the reporting period (annual)

The scoring for each flow measure is based upon the percentile range representative of standard deviations from the mean (Table 29).

Table 29. The benchmark measures for all the flow measures expressed as standard deviations from the mean and approximate percentiles.

Score	Target Standard Deviations from Mean	Rationale	Percentile Range
5	1	Within 68.27% observed range	15.87 - 84.13
4	2	Within 95.37% observed range	2.28 - 15.87, 84.13 - 97.72
3	3	Within 99.73% observed range	0.13 - 2.28, 97.72 - 99.87
2	4	Within 99.99% observed range	0 - 0.13, 99.87 - 100
1	5	Outside the observed range	<0, >100

The flow measures score flow for the reporting year on a scale of one to five. For each flow assessment site, the 30th percentile value of all ten flow measures is used to provide a summary score. Several summary statistics were evaluated during the development of the flow indicator and the 30th percentile value was selected as the most appropriate summary statistic for representing the range of the ten flow measures. The other summary statistics were the mean, mode and minimum score. The procedures required for producing flow measure scores and summary scores were conducted using the flow indicator tool developed for the Report Card Flow Indicator Project (Stewart-Koster et al., 2018). The summary scores from the flow assessment sites were converted from the one to five scale to the standardised scale of zero to 100 for aggregation with other report card indicators. For each flow assessment site, the following steps were applied to provide a standardised score from zero to 100 from the output score of the flow assessment tool (one to five scale):

1. Determine the 30th percentile value from the ten flow measures (each scores one to five) for each flow assessment site.
2. Apply the following formula for scores of <2: (20.9 + ((30th percentile -1.9) * (23.2))).
   To provide a value of 0 to 20.9 for scores of <2 graded 'very poor'.
3. Apply the following formula for scores of 2 to <5: ((30th percentile * 20) - 19).
   To provide a value between 21 and 80 for scores 2 to <5 and are graded 'poor', 'moderate' or 'good'.
4. Apply the following formula for scores of 5: 80 + ((M_{min} – 1) * 5) where M_{min} is the lowest scoring measure (one to five) for the flow assessment site.
   To provide a value of between 80 to 100 for scores of five, using the lowest contributing flow measure score as a scale. This also prevents a flow assessment site for which a flow measure is scored one (outside of the observed distribution) from receiving a grade of 'very good'.

The 30th percentile score, standardisation formula and standardised scoring range with grade colour code are presented in Table 30.

Table 30. Standardisation formulae for 30th percentile scores of flow assessment sites.

Scoring Range 30th Percentile Score	Grade	Scaling of Scores for Aggregation
5	Very good	= 80 + ((minimum flow measure score – 1) * 5)
4 - <5	Good	= (score x 20) - 19
3 - <4	Moderate	= (score x 20) - 19
2 - <3	Poor	= (score x 20) - 19
1 - <2	Very poor	= 20.9 + ((score - 1.9) * (23.2°))

°23.2 is a scaling factor to convert the 30th percentile score to within the very poor standardised scoring range (0 - 20.9).

For basins or estuaries with more than one flow assessment site, the following steps were applied for aggregating scores:

- The total catchment area upstream of the gauged flow assessment sites were determined.

- The adjusted upstream catchment for each assessment site (stream gauge) was determined, which is the total catchment area up until the next upstream assessment site (s) if present.
- The proportion of total catchment for each assessment site was determined and multiplied by the standardised score for the assessment site.
- All contributing scores are summed to provide the final basin score.

Flow Indicator Example:

The 2019 to 2020 rainfall for the Pioneer Basin and the annual flow records for Finch Hatton Creek and Dumbleton Weir Tailwater are presented in Figure 15. Finch Hatton is located upstream in the upper catchment whilst Dumbleton Weir Tailwater (TW) is downstream, in the lower catchment of the Pioneer River. Differences in the flow records between the sites include the effect of impoundments on river flow of three weirs: Dumbleton, Marian and Mirani. A major dam, Teemburra, is also located on this watercourse. This example visually presents how assessment of flow records using the indicator differ between a site that has minimal alteration from pre-development flows (Finch Hatton) and one that has substantial alteration from flows (Dumbleton Weir TW) for the 2019-20 reporting period.

The flow at Finch Hatton Creek for 2019-20 reporting period scored a five or four (out of five) for nine of the ten flow measures, determining that much of the flow was not substantially altered from pre-development flow. The overall freshwater flow score at Finch Hatton Creek was four, calculated from the 30th percentile of the ten flow measures. The standardised report card value of this score was 61 ('good'). The flows at Dumbleton Weir TW were substantially altered from pre-development flows (i.e. a score of one out of five) for the following four measures: cease to flow duration and frequency, low flow duration, and coefficient of variation for the dry season. The flow record at Dumbleton Weir TW shows abrupt changes to flow as a result of the in-stream habitat modifications including weir impoundments and water releases for consumption purposes. The overall Dumbleton Weir TW score was one, with the standardised report card value of this score of zero ('very poor'). The example demonstrates how the flow indicator assesses the degree of change from reference for different characteristics of the flow regime.

The example includes alterations to flow that are easy to visualise from an annual flow record. However, the ten flow measures are able to assess and score aspects of the flow regime that may not be as clearly visualised from the flow record but may still be important to waterway health. The potential impacts upon waterway health attributes linked to low flows include low flow spawning fish, critical hydraulic habitat, longitudinal connectivity and water quality, those linked to medium flows include riffle habitats and macrophyte beds, and those linked to high flows include fishery productivity (Stewart-Koster et al., 2018). The results of the flow indicator for Dumbleton Weir TW identify that alteration of flows may be impacting on waterway health for the attributes linked to low flows and medium flows.

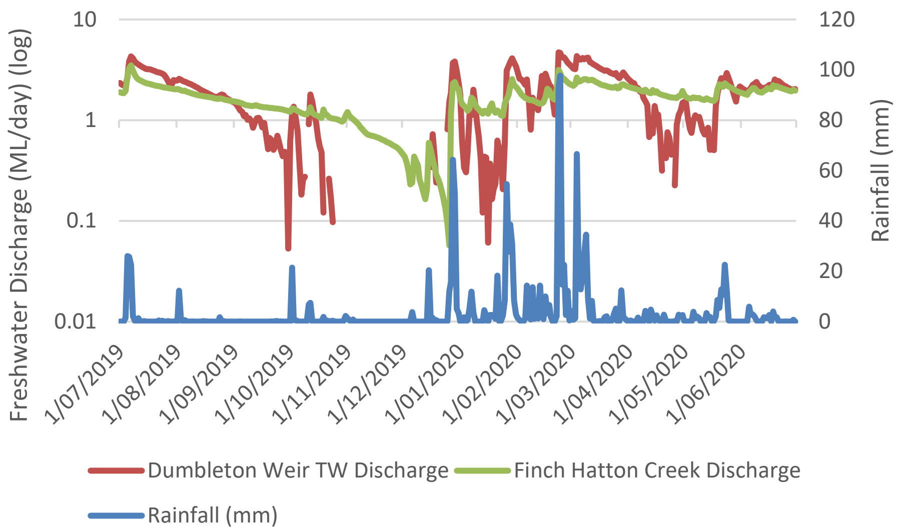


Figure 15. Observed daily discharge (ML/day) for the Dumbleton Weir Tailwater (TW) and Finch Hatton Creek sites in the Pioneer Basin, presented on a log scale. This is plotted against daily rainfall (mm) for the Pioneer Basin. Missing data represent periods of no flow at Dumbleton Weir TW.

3.1.2.3. Riparian, Wetland and Mangrove/saltmarsh Extent

The condition score for the extent of riparian, wetland and mangrove/saltmarsh extent vegetation was determined by calculating the percentage of vegetation loss since pre-clearing to 2013-14 (freshwater riparian extent) and 2016-2017 (remaining vegetation extent indicators) for each basin or estuary and assigning the result a grade (Table 31).

Table 31. Grading description for the riparian, wetland and mangrove/saltmarsh extent indicators in freshwater basin and estuary assessments.

Scoring Range	Grade	Scaling of Scores for Aggregation
≤5.0%	Very good	= 81 + ABS((19 - ((score - 0) * (19 / 4.99))))
>5.0-15.0%	Good	= 61 + ABS((19.9 - ((score - 5.01) * (19.9 / 9.99))))
>15-30.0%	Moderate	= 41 + ABS((19.9 - ((score - 15.01) * (19.9 / 14.99))))
>30-50%	Poor	= 21 + ABS((19.9 - ((score - 30.01) * (19.9 / 19.99))))
>50%	Very poor	= ABS((20.9 - ((score - 50.01) * (20.9 / 49.99))))

3.1.3. Fish (Freshwater Basins only)

A qualitative rating scheme for native species richness (PONSE) was developed (Table 32), where the 'very good' category was based on available data for the Repulse Creek sites ('minimally disturbed' site with available data) and the 'poor' was based on the 90th percentile of the results for recent times. Anything less than the 90th percentile is considered 'very poor'. The rating scheme for the pest fish model output differs slightly to that for native species richness (Table 33).

Currently, fish that are native to Queensland but not specifically to the region's waterways are included within the native richness assessment. Future assessments will consider translocated fish under the pest fish umbrella. Species distribution models are currently being developed by the QLD Government[4] to complete development of the fish assemblage indicator. This indicator is currently expected to be available in the 2021 Report Card (released in 2022).

Table 32. Rating scheme for condition of native species richness using PONSE model for freshwater fish communities.

Native Species Richness	Grade	Scaling of Scores for Aggregation
0.80 to 1	Very good	= 81 + ABS((19 + ((score - 1) * (19 / 0.2))))
0.67 to <0.80	Good	= 61 + ABS((19.9 + ((score - 0.7999) * (19.9 / 0.1329))))
0.53 to <0.67	Moderate	= 41+ ABS((19.9 + ((score - 0.6669) * (19.9 / 0.1339))))
0.40 to <0.53	Poor	= 21 + ABS((19.9 + ((score - 0.5329) * (19.9 / 0.1329))))
0 to <0.40	Very poor	= ABS((20.9 + ((score - 0.3999) * (20.9 / 0.3999))))

Table 33. Rating scheme for the modelled pest fish condition indicator for freshwater fish community.

Pest Fish	Grade	Scaling of Scores for Aggregation
0 to 0.03	Very good	= 81 + ABS((19 - ((score - 0) * (19 / 0.025))))
>0.03 to 0.05	Good	= 61 + ABS((19.9 - ((score - 0.0251) * (19.9 / 0.0249))))
>0.05 to 0.1	Moderate	= 41 + ABS((19.9 - ((score - 0.051) * (19.9 / 0.049))))
>0.1 to 0.2	Poor	= 21 + ABS((19.9 - ((score - 0.101) * (19.9 / 0.099))))
>0.20 to 1	Very poor	= ABS((20.9 - ((score - 0.201) * (20.9 / 0.799))))

3.2. Inshore and Offshore Marine Zones

3.2.1. Inshore Water Quality

3.2.1.1. Nutrients, Chlorophyll-*a* and Water Clarity

For indicators in the nutrients, chl-*a* and water clarity categories, annual medians or means were calculated (as per the guidelines of the relevant zone) for each site and condition scores were calculated using the relevant guideline value and the procedure below.

Guideline values were obtained from the relevant documents, as described below:

- Whitsunday and Central Zones - Environmental Protection (Water) Policy 2009 Proserpine River, Whitsunday Island and O'Connell River Basins Environmental Values, and the Environmental Protection (Water) Policy Pioneer River and Plane Creek Basins Environmental Values and Water Quality Objectives[21].
- Northern Zone - guidelines for Central QLD (DES, 2009; GBRMPA, 2010) were used as local guidelines are currently in draft form (Draft environmental values and water quality guidelines:

[21] https://www.legislation.qld.gov.au/LEGISLTN/SLS/2013/13SL158.pdf

Don and Haughton River Basins, Mackay-Whitsunday estuaries, and coastal/marine waters[22]).

- Southern Zone - Central QLD and Environmental Protection (Water) Policy Pioneer River and Plane Creek Basins Environmental Values and Water Quality Objectives.

Once guidelines are developed, the local guidelines will be used for scoring.

Our first two Report Cards (2014 and 2015) used only the relevant guidelines from GBRMPA (2010). The shift towards using locally relevant QLD guidelines (where available) reflects a move toward reporting on the 'interim site-specific water quality index' based on guideline values refined using site-specific long-term water quality data collected at MMP sites (Waterhouse et al., 2017), rather than GBR-wide GBRMPA (2010) guidelines. While, the MWI Report Card has not employed the same guideline values as the MMP, the adopted guideline values (scheduled guidelines noted above) are similar (see Table 34 for relevant inshore water quality guideline values used in the 2020 Report Card).

Prior to calculating annual medians or means and comparing them to the guidelines, the LOR (or limit of detection (LOD) was explored as per Table 35, and the same rules applied as described for freshwater basins and estuaries.

[22] http://www.ehp.qld.gov.au/water/policy/pdf/don-haughton-mackay-whitsunday-main-report.pdf

Table 34. Water quality guideline values for relevant water quality indicators at inshore marine monitoring sites in MWI Report Card. Also listed are the programs associated with each site, source documents for the guideline values listed, associated basin/region/water area, water type (OC = open coastal, EC = enclosed coastal) and management intent (SMD = slightly to moderately disturbed, HEV = high ecological value, MD: moderately disturbed) outlined in the source documents. Underlined values are compared to means; other single value guidelines are compared to medians. Where a range of three values are listed, the middle value is compared to medians.

Zone	Sites	Documents	Basin/region/ water area	Water Type	Management Intent	NO_x (µg/L)	PN (µg/L)	PP (µg/L)	Chl-*a* (µg/L)	TSS (mg/L)	Secchi (m)	Turb (NTU)
Northern	All sites (Abbot Point)	1 & 2	Don 121	OC	SMD	3	20	2.8	0.45	2	10	1
	WHI1 Double Cone Island (MMP)	3	SD2381	OC	HEV	0-1-2	12-13-15	1.8-2.4-2.8	0.25-0.36-0.54	0.9-1.4-2.3	10	0.7-1.1-2.1
Whitsunday	WHI4 Pine Island (MMP)	3	SD2381	OC	HEV	0-1-2	12-13-15	1.8-2.4-2.8	0.25-0.36-0.54	0.9-1.4-2.3	10	0.7-1.1-2.1
	WHI5 Seaforth Island (MMP)	3	SD2381	OC	HEV	0-1-2	12-13-15	1.8-2.4-2.8	0.25-0.36-0.54	0.9-1.4-2.3	10	0.7-1.1-2.1
	WHI6 O'Connell River mouth (MMP)	3	SD2381 (EC)	EC	HEV	2-4-10			0.8-1.3-2			
	WHI7 Repulse Is. dive mooring (MMP)	3	SD2381	OC	HEV	0-1-2	12-13-15	1.8-2.4-2.8	0.25-0.36-0.54	0.9-1.4-2.3	10	0.7-1.1-2.1
	AMB1 (Mackay & Hay Point)	4	SD2382	OC	HEV		<20	<2.8	<0.45	<2.0	>10	<1
	AMB2 (Mackay & Hay Point)	4	MD2343	OC	MD		<20	<2.8	<0.45	<2.0	>10	D = 1-2-8; W = 5-12-33
Central	AMB3B (Mackay & Hay Point)	3 & 4	OC landward of plume line	OC	SMD		<20	<2.8	<0.45	<2.0	>10	<1
	AMB5 (Mackay & Hay Point)	4	MD2341 (port open waters)	OC	MD		<20	<2.8	<0.45	<2.0	>10	D = 1-2-8; W = 5-12-33
	AMB6 (Mackay & Hay Point)	4	MD2343	OC	MD		<20	<2.8	<0.45	<2.0	>10	D = 1-2-8; W = 5-12-33
	AMB8 (Mackay & Hay Point)	3 & 4	OC landward of plume line	OC	SMD		<20	<2.8	<0.45	<2.0	>10	D = 1-2-8; W = 5-12-33
	AMB10 (Mackay & Hay Point)	3 & 4	OC landward of plume line	OC	SMD		<20	<2.8	<0.45	<2.0	>10	<1
	AMB12 (Mackay & Hay Point)	3 & 4	HEV2383	OC	HEV	0-0-1	14-18-24	1.6-2.1-3	≤0.45	1.1-1.6-2.4	10	<1
	CAM1 (Aquila Island)	2&4	SD2383	OC	HEV	3	<20	<2.8	<0.45	<2.0	>10	<1
Southern	CAM2	2& 4	SD2383	OC	HEV	3	<20	<2.8	<0.45	<2.0	>10	<1
	CAM3	2&4	SD2383	OC	HEV	3	<20	<2.8	<0.45	<2.0	>10	<1

Documents:

1. Great Barrier Reef Marine Park Authority, 2010. Water quality guidelines for the Great Barrier Reef Marine Park. Revised edition 2010, Townsville.
2. Central Queensland guidelines in Department of Environment and Science, 2009. Queensland Water Quality Guidelines 2009, Version 3.
3. Department of Environment and Science, 2009. Environmental Protection (Water) Policy Proserpine River, Whitsunday Island and O'Connell River Basins Environmental Values and Water Quality Objectives.
4. Department of Environment and Science, 2009. Environmental Protection (Water) Policy Pioneer River and Plane Creek Basins Environmental Values and Water Quality Objectives.

Table 35. Indicator LORs and LODs for different marine water quality monitoring programs used by the MWI Report Card.

Indicator Category	Indicator	LOR: SIP and NQBP (JCU)	LOD: MMP (AIMS)
Nutrients	Particulate nitrogen (PN) *(=TN-TDN)*	NA	<1.0 µg/filter
	Total nitrogen (TN)	<10 µg N/L	
	Total dissolved nitrogen (TDN)	<10 µg N/L	<0.28 µg/L
	Particulate phosphorus (PP) *(=TP-TDP)*	NA	<0.09 µg/L
	Total phosphorus (TP)	<1 µg P/L	
	Total dissolved phosphorus (TDP)	<1 µg P/L	0.62 µg/L
	Oxidised nitrogen (NO_x) *(=NO_2 + NO_3)*	NA	<0.28 µg/L (NO_x)
Chl-*a*	Chl-*a*	<0.2 µg/L	<0.004 µg/L
Water Clarity	TSS	<0.2 mg/L	<0.15mg/filter
	Secchi disk depth	NA	NA
	Turbidity	0.005 NTUe	

The following steps were used to calculate indicator scores (see Lønborg et al., 2016 and Waterhouse et al., 2017 for full details).

1. For indicators where failure to meet a guideline is defined as the annual (mean or median) concentration being *higher* than a guideline value:

   $$\text{Condition score} = \log_2 (GV/AM)$$

   For indicators where failure to meet a guideline is defined as the annual (mean or median) concentration being *lower* than a guideline value (e.g. secchi disk depth):

   $$\text{Condition score} = \log_2 (AM/GV)$$

   Where:
   AM is the annual median or mean of the measured indicator
   GV is the guideline value
2. Ratios were capped to bind the water quality index to the range of -1 to 1, to ensure all indicators were on the same scale.
3. For turbidity, where a wet and dry season score is calculated, these scores were averaged to give an annual turbidity score.
4. The nutrients indicator category score was calculated as the average of NO_x, particulate phosphorus (PP) and particulate nitrogen (PN) scores (where available and following rules for minimum information (as per Section 3, pg. 52).
5. The water clarity indicator category was calculated as the average of secchi, TSS and turbidity scores (where available and following rules for minimum information (as per Section 3, pg. 52).
6. Nutrients, water clarity and chl-*a* scores were translated to the report card five-point grading scale (Table 36).

Table 36. Inshore water quality grades, scoring ranges and scaling for aggregation.

Score Range	Condition Grade and Colour Code	Scaling of Scores for Aggregation
>0.5 to 1	Very good	= 100 - (19 - ((score - 0.51) * (19 / 0.49)))
0 to 0.5	Good	= 80.9 - (19.9 - ((score - 0.01) * (19.9 / 0.49)))
<0 to -0.33	Moderate	= 60.9 - (19.9 - ((score - (-0.33)) * (19.9 / 0.32)))
<-0.33 to -0.66	Poor	= 40.9 - (19.9 - ((score - (-0.66)) * (19.9 / 0.32)))
<-0.66 to -1	Very poor	= 20.9 - (20.9 - ((score - (-1)) * (20.9 / 0.34)))

3.2.1.2. Pesticides

Pesticides in the inshore marine zone were reported using the PRM for the third consecutive year, replacing the PSll-HEq (PSll Herbicide Equivalent Concentration) method (Grant et al., 2018) which only assessed a maximum of 13 herbicides (five in 2015 and 13 in 2016-2018). This aligns with that for freshwater basins (Section 3.1.1.2), the Reef 2050 Water Quality Improvement Plan pesticide targets, and the Australian and New Zealand Water Quality Guidelines (ANZG, 2018). The PRM approach is able to consider pesticides with different MoAs (Table 11) which exert their toxicity by different means, increasing the number of chemicals which can be incorporated to inform water quality assessments. As a result, the impacts to the marine environment through land-based run-off are captured for a greater number of pollutants.

Concentration data was converted into a single number that represents the toxicity of the mixture of pesticides in each passive sampler or water sample. This was done to express the overall risk to aquatic ecosystems in simple numeric terms (given as a percentage of species affected). The PRM for pesticides with different MoAs was calculated using the independent action model of joint action (Plackett & Hewlett, 1952). Further details on how the PRM calculations were made are provided in Warne et al. (2020).

Corresponding to the percentage of species affected calculated for each passive sampler, the percentage of species protected were allocated to given risk categories as done for freshwater basins and estuaries (Table 22). These categories are consistent with the ecological condition categories used in the Australian and New Zealand Water Quality Guidelines (ANZG, 2018)[23]. The average maximum PRM concentration recorded within the zone was used as the pesticide result. All values were rounded to the nearest whole number.

[23] https://www.waterquality.gov.au/anz-guidelines/resources/key-concepts/level-of-protection

3.2.2. Offshore Water Quality

The offshore water quality condition assessment uses the percentage of area of the Offshore Zone that exceeds the relevant water quality guideline value (mid-shelf waters that are included in the Offshore Zone are not assessed) (Table 37). These data were specifically extracted by BoM from the marine water quality dashboard[24]. Each indicator score (chl-*a* and sediment (TSS)) was calculated by determining the percentage of the area exceeding the guideline and subtracting this from 100% to provide the percentage area that met the guideline value. The score (from 0 – 100) was then directly translated to a grade using the report card grading system previously defined (Table 16). The TSS and chl-*a* results were weighted equally (Table 37), and therefore, averaged to provide the water quality indicator category result for the Offshore Zone.

Table 37. Offshore water quality indicators, guideline values and weightings.

Indicator	Measured Indicators	Guideline Value*	Weighting
Sediment	TSS	0.7 mg/L	50%
Chl-*a*	Chl-*a*	0.4 µg/L	50%

*Guideline values are based on water quality guidelines for the Great Barrier Reef Marine Park 2010 Offshore (GBRMPA, 2010).

[24] http://www.bom.gov.au/marinewaterquality/

3.2.3. Coral

Condition assessment of the coral indicators for the inshore zones followed the MMP method (Table 38):

- **Coral cover:** This indicator simply scores reefs based on the level of coral cover, with high coral cover being the desirable state for coral reefs. For each reef, the proportional cover of all genera of hard (order Scleractinia) and soft (subclass Octocorallia) corals are combined. For the first time, the 2020 Report Card includes coral cover data collected by the citizen science group, RCA, for the Whitsunday and Offshore Zones.
- **Macroalgae cover:** This indicator is the percentage cover of macroalgae as a proportion of the total cover of all algal forms (inshore regions only) as a representation of these opportunistic colonisers outcompeting corals.
- **Density of juvenile hard corals:** Counts of juvenile hard corals were converted to density per m^2 of space available for settlement.
- **Change in coral cover**: This is derived from the comparison of the observed change in coral cover between two visits and the predicted change in cover derived from multi-species, in the form of a Gompertz growth equation (Thompson et al., 2021). Due to differences in growth rates, GBR reefs were divided into eight groups based on community types. Models were developed for each group of reefs and, separately for fast growing corals of the family Acroporidae, as well as combined grouping of all other slower growing hard coral taxa. Some reefs are surveyed in alternate years. The coral change index is based on the most recent estimate of the rate of change over the interval between surveys, which for some of the reefs will include the change in cover over the two years up until the preceding year.
- **Community composition:** The basis of the indicator is the scaling of cover for constituent genera (subset of life forms for the abundant genera *Acropora* and *Porites*) by genus weightings that correspond to the distribution of each genus along a gradient of turbidity and chl-*a*. This is a new indicator for inshore coral condition reporting applied to inshore regions only.

Coral cover and density of juvenile hard coral data collected under the NQBP monitoring programs in the Central and Northern Zones were analysed using the MMP approach. This involved aggregating site-level juvenile hard coral abundance, up to the reef level mean, for 0-2 cm and 2-5 cm size classes. Consistent with MMP and the GBR Report Card, these data excluded the genus *Fungia* (mushroom/disc corals). Mean hard coral and soft coral cover for each reef are summed to produce the overall ‘coral cover’. Mean total algae cover along each transect was used to convert juvenile abundance to the indicator juvenile density. Inshore zone scores are the mean of reef-level scores for each indicator.

To combine coral cover data collected by RCA with that from the MMP, a weighted approach was used. Data from only the most recent survey was used (as done for score calculations using MMP and LTMP data). RCA coral cover data was first converted into coral cover scores as per the method used by AIMS:

$$\textit{Coral cover score} = \textit{Percentage coral cover} / 75$$

Scores were then weighted based on survey precision relative to that of the MMP, which was calculated as a function of sampling frequency. Precision was assessed using a simulation of randomly sampled point series, with known proportions and improved precision, expressed as confidence intervals around the mean. This random simulation showed that improvement in precision for each monitoring program could be determined based on sample size (number of observations). The calculation for this simulation is as follows:

Sample size = No. observations taken every metre x No. transects x transect length (m) x No. of sites sampled within the same reef

Precision estimates were then used to calculate weighting values which were then applied to the RCA coral cover data. For more detailed information on how the weighting of RCA data was conducted see Whitehead (2020). Coral indicators for the inshore and offshore zones were scored in a similar way. Observations for each indicator were scored on a continuous scale following Thompson et al. (2016) (Table 38). The approach involves selecting bounding values for each indicator based on biology. These bounds become zero ('very poor') and 1.0 ('very good') on an approximately linear scale (see Section 6 of Thompson et al. 2016). The values for the reefs in each reporting zone are then averaged and converted to a scale of zero to 100 (Table 39).

Table 38. Threshold values for the condition assessment of coral where indicators that are reported in inshore zones only are identified. CI = confidence interval.

Community Attribute	Score	Thresholds
Cover - Combined hard and soft coral cover	Continuous between 0.0 and 1.0	1 at 75% cover or greater
		0 at zero cover
Change - Rate of increase in hard coral cover (preceding four years)	1.0	Change > 2x upper 95% CI of predicted change
	Continuous between 0.6 and 0.9	Change between upper 95% CI and 2x upper 95% CI
	Continuous between 0.4 and 0.6	Change within 95% CI of the predicted change
	Continuous between 0.1 and 0.4	Change between lower 95% CI and 2x lower 95% CI
	0.0	change < 2x lower 95% CI of predicted change
Macroalgae - Proportion of algae cover classified as macroalgae (inshore only)	Continuous between 0.0 and 1.0	≤ reef specific lower bound and ≥ reef specific upper bound
Juvenile - Density of hard coral juveniles (<5 cm diameter)	1.0	> 13 juveniles per m^2 of available substrate
	Continuous between 0.4 and 1.0	4.6 to 13 juveniles per m^2 of available substrate
	Continuous between 0 and 0.4	0 to 4.6 juveniles per m^2 of available substrate
Composition - Composition of hard coral community (inshore only)	1.0	Beyond 95% CI of baseline condition in the direction of improved water quality
	0.5	Within 95% Confidence intervals of baseline composition
	0.0	Beyond 95% CI of baseline condition in the direction of declined water quality

Table 39. Scoring ranges for aggregated coral results and scaling formula to aggregate coral index with other indices to produce overall score.

Condition Grade and Colour Code	Score Range	Scaling of Scores Aggregation
Very good	> 0.8	= 'score' x 100
Good	> 0.6 – 0.8	= 'score' x 100
Moderate	> 0.4 – 0.6	= 'score' x 100
Poor	> 0.2 – 0.4	= 'score' x 100
Very poor	0 – 0.2	= 'score' x 100

3.2.4. Inshore Seagrass

3.2.4.1. Marine Monitoring Program

The MMP seagrass monitoring data are rolled up into the GBR Report Card scoring range (Table 16) (McKenzie et al., 2015). The scoring thresholds and their relation to the GBR Report Card scoring ranges are provided for the three MMP seagrass indicators in Table 40-Table 42. An overall score for each site is then calculated by averaging the three seagrass indicator scores where all indicators are equally weighted (McKenzie et al. 2015).

Table 40. Seagrass 'abundance' scoring thresholds in relation to condition grades (low = 10th or 20th percentile guideline). Source: McKenzie et al. (2015).

Category	Score	Score Range	Condition Grade
75 – 100	100	80 – 100	Very good
50 – 75	75	60 – < 80	Good
Low – 50	50	40 – < 60	Moderate
< Low	25	20 – < 40	Poor
< Low by > 20%	0	0 – <20	Very poor

Table 41. Seagrass 'reproductive effort' scoring in relation to condition grades. Source: McKenzie et al.(2015).

Reproductive Effort (monitoring period/long-term)	Ratio	Score	0-100 Score	Score Range	Condition Grade
≥ 4	4.0	4	100	80 – 100	Very good
2 to < 4	2.0	3	75	60 – < 80	Good
1 to < 2	1.0	2	50	40 – < 60	Moderate
0.5 to < 1	0.5	1	25	20 – < 40	Poor
< 0.5	0.0	0	0	0 – <20	Very poor

Table 42. Seagrass 'nutrient status' scoring in relation to condition grades. Source: McKenzie et al. (2015).

Carbon:Nitrogen Ratio Range	Value	Score	Score Range	Condition Grade
> 30	30	100	80 – 100	Very good
25 – 30	25	75	60 – < 80	Good
20 – 25	20	50	40 – < 60	Moderate
15 – 20	15	25	20 – < 40	Poor
<15		0	0 – <20	Very poor

3.2.4.2. Queensland Ports Seagrass Monitoring Program

The QPSMP uses a condition index developed for seagrass monitoring meadows based on changes in mean above-ground biomass, total meadow area and species composition relative to a baseline. The baseline is ideally calculated using a ten-year average. Seagrass meadows near Abbot Point have been monitored since 2008, and meadows near Mackay and Hay Point have been monitored since 2005 (although no surveys were conducted in 2008 or 2013). Baseline conditions were therefore calculated using all data available and will be updated annually until the full 10 years is reached.

The index provides a means of assessing current meadow condition and likely resilience to disturbance. Seagrass condition for each indicator is scored from zero to one and assigned an A - E grade (Carter et al., 2019). Scores are multiplied by 100 to align to the MMP scale.

To derive a condition score, a meadow classification system defines threshold ranges for the three indicators, in recognition that for some seagrass meadows these measures are historically stable, while in other meadows they are relatively variable. Baseline conditions for species composition were determined based on the annual percent contribution of each species to average meadow biomass of the baseline years. Meadows are classified as either single species dominated (one species comprising ≥80% of baseline species), or mixed species (all species comprise <80% of baseline species composition). Where species composition was determined to be anything less than in 'perfect' condition (i.e. a score <1), a decision tree was used to determine whether equivalent and/or more persistent species were driving this grade/score (Carter et al., 2019).

Each meadow/site score is defined as the lowest grade/score of the three indicators within that meadow. A review of the QPSMP methods in 2017 produced a slight modification from previous score aggregation. The new method still defined overall meadow condition as the lowest indicator score where this is driven by biomass or area, however, where species composition was the lowest score, it contributed to 50% of the overall meadow score, and the next lowest indicator (area or biomass) contributed the remaining 50%.

3.2.4.3. Combined Display Approach for MMP and QPSMP Seagrass Indicators

The combined display approach for seagrass indicators maintains the score calculation methods from each program. This ensures that the scores given in the regional report cards for a meadow/site remain consistent with MMP and QPSMP reporting. There is no overlap between QPSMP and MMP locations in the Whitsunday Zone, but both programs have seagrass monitoring in the Central and Northern Zones.

Scores for each monitoring site/meadow (derived by averaging across indicators at MMP sites or using the lowest indicator grade at QPSMP sites) are averaged to generate an overall score for a defined reporting zone. Final zone scores are graded based on the report card scoring ranges previously described, regardless of the program (Table 16). Final scores were calculated in this way (compared to taking an average of the overall indicator scores for each zone), due to the score calculation differences between programs. For a full description and worked example of the combined display approach refer to Carter et al. (2016).

3.2.5. Litter

3.2.5.1. Scoring Ranges

The total litter collected at each site within a reporting year is compared to the annual average for that zone collected across the four-year baseline (data from July 1st 2014 until June 30th 2018). These baseline data were used to establish a reference distribution and will be used as the permanent baseline against which data will be compared. Data are scaled from zero to one for the Report Card, with close to zero equating to "highly littered/very poor", and close to one being a "near pristine/very good" state. The reference distribution was created by:

1. Calculating the number of items collected and number of hours spent cleaning.
2. Standardising catch per unit effort (CPUE) to an approximately normal distribution:
   $$\log_e(CPUE) = \log_e(items\ collected) - ½ \log_e(hours\ cleaned)$$
3. $\log_e$(CPUE) was considered to index the individual sites within and between years.
4. Where sites were cleaned more than once in a year, $\log_e$(CPUE) was averaged over sites within a reporting year.
5. After ordering the $\log_e$(CPUE) values from smallest to largest, an empirical survivor function (ESF) was derived for the reference distribution (i.e. the probability of survival past time y which is independent of distributional assumptions.
6. The ESF was then created by plotting p (which equals [r + ½]/n), against $\log_e$(CPUE), with r the number of values greater in the sorted list, and *n* the total number of values.
7. Smoothing the ESF produced the working reference distribution and algorithm, which can be easily applied to present and future data.
8. The score corresponding to any $\log_e$(CPUE) value is then obtained using the smoothed ESF constrained to between zero and one.
9. From the smoothed ESF, the cut off (A to E) values can be determined (Figure 16).

The litter indicator scoring method was designed to show any change (increase or decrease) compared to the baseline. For example, if the mean for a financial year is lower than the mean from the four-year baseline, the indicator will be graded as an 'A' to 'C', but would be 'D' or 'E' if there was more litter than previous years (or 'the mean from the baseline period'). For more detailed methods on how the scores for the litter index were generated, refer to 'Litter Score and Grade Proposal for Townsville' (Whitehead and Venables, unpublished). The above method has been described as in Whitehead (2020).

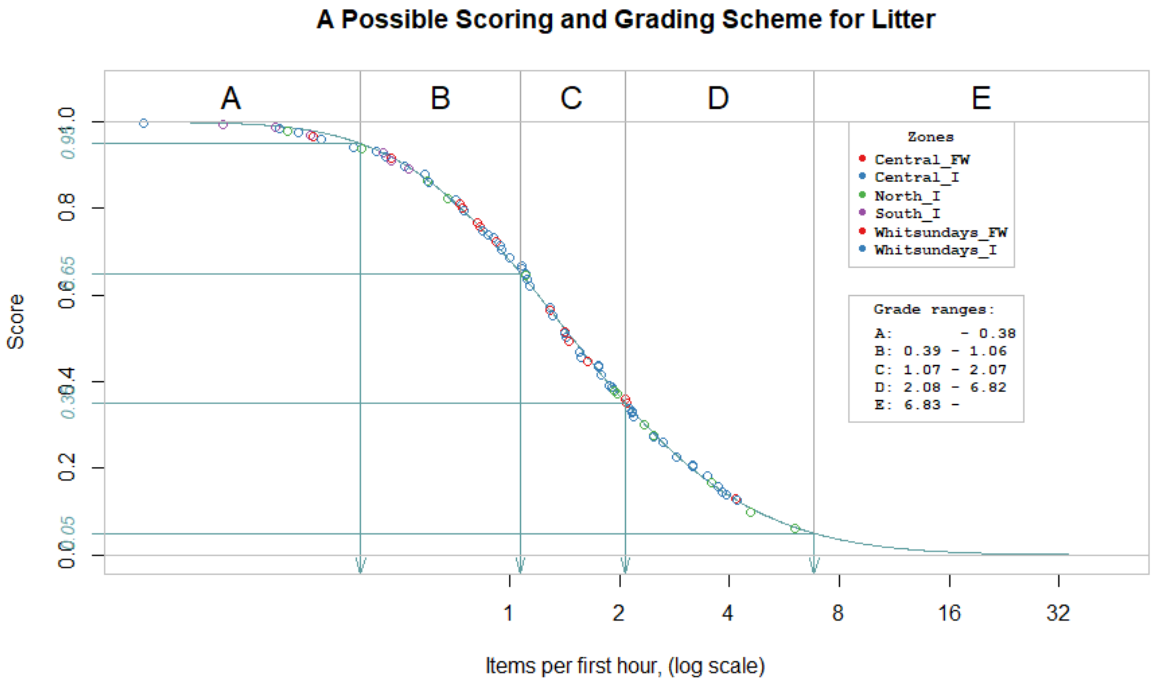


Figure 16. Transformation of standardised collection rates to scores and grades (CPUE vs scores).

4. Development of Progress to Targets Scoring Methods

To provide information on how the MWI Region is tracking toward targets set for certain aspects, progress to targets will be presented in future report cards and associated documentation. This will enable progress on a year-to-year basis to be assessed and allow comparison across years and trends to be established.

4.1. Calculating Progress to Targets

In order to provide a score on how the region is progressing toward meeting its targets, the following information will be required:

- Baseline condition (i.e. a starting point),
- Current condition, and
- Target condition.

The calculation of the results of the progress to targets in each report card will use the following equation:

$$\text{Progress to target} = ((X-Z) / (X-Y)) * 100$$

Where:
X is the baseline
Z is the current condition
Y is the target

Determining appropriate targets requires a specific body of work to identify which indicators should have targets, and what the targets (and associated timeframes) should be. Where possible, the targets established for the Report Card will align with available targets used in the GBR Report Card and other relevant programs to provide consistency.

5. Confidence, Limitations, and Recommendations

5.1. Confidence Associated with Results

The regional report cards use the 2015 GBR Report Card as the basis for communicating confidence (Australian and Queensland Governments, 2015). This is based on a multi-criteria analysis approach to qualitatively score the confidence for each key indicator used in the Report Card. The approach enables the use of expert opinion and measured data.

The multi-criteria analysis identifies the key components ("criteria") that contribute to confidence. Each criterion is then scored using a defined set of scoring attributes. The attributes are ranked from those that contribute weakly to the criteria to those that have a strong influence. If the criteria are seen to have different levels of importance for the problem being addressed, they can be weighted accordingly. The strengths of this approach are that it is repeatable, transparent and can include contributions from a range of sources. The weaknesses are that it can be subjective and open to manipulation.

The key difference in how the regional report cards use the 2015 GBR Report Card method for communicating confidence is how confidence criteria are weighted. Criteria that are seen to have more importance for the MWI Region have been given a higher weighting when determining the overall confidence.

5.1.1. Methods

Report card confidence levels are determined using the five criteria explained below (Table 43).

Maturity of Methodology

The purpose of this criterion is to show the confidence that the method/s being used are tested and accepted broadly by the scientific community. Methods must be repeatable and well-documented. Maturity of methodology is not a representation of the age of the method but the stage of development. It is expected that all methods used would be robust, repeatable and defendable. This criterion is weighted 0.36 so as not to outweigh the importance of the other criteria.

Validation

The purpose of this criterion is to show the proximity of the indicator being measured to the indicators reported. The use of proxies is scored lower than direct measures. This criterion minimises compounded errors. The score is weighted 0.71 for this criterion so as not to outweigh the importance of the representativeness criterion.

Representativeness

This criterion shows the confidence in the representativeness of monitoring/data to adequately report against relevant indicators. It takes into consideration the spatial and temporal resolution of the data as well as the sample size. This criterion is considered most important when considering confidence in the MWI Report Card, and as such is given a weighting of 2.

Directness

This criterion is similar to "validation" but instead of looking at the proximity of the indicator, it looks at the confidence in the relationship between the monitoring and respective indicators being reported against. The score is weighted 0.71 for this criterion so as not to outweigh the importance of the representativeness criterion.

Measured Error

The purpose of this criterion is to incorporate an estimate of uncertainty when an indicator is measured. This score is weighted 0.71 for this criterion so as not to outweigh the importance of the representativeness criterion.

Table 43. Scoring matrix for each criterion used to assess confidence.

Maturity of methodology (weighting 0.36)	**Validation** (weighting 0.71)	**Representativeness** (weighting 2)	**Directness** (weighting 0.71)	**Measured error** (weighting 0.71)
Score = 1 **New** or experimental methodology	**Score = 1** **Limited** Remote sensed data with no or limited ground truthing or Modelling with no ground truthing or Survey with no ground truthing	**Score = 1** **Low** 1:1,000,000 or Less than 10% of population survey data	**Score = 1** **Conceptual** Measurement of data that have conceptual relationship to reported indicator	**Score = 1** Greater than 25% error or limited to no measurement of error or error not able to be quantified
Score = 2 **Developed** peer reviewed method	**Score = 2** **Not comprehensive** Remote sensed data with regular ground truthing (not comprehensive) or Modelling with documented validation (not comprehensive) or Survey with ground-truthing (not comprehensive)	**Score = 2** **Moderate** 1:100,000 or 10%-30% of population survey data	**Score = 2** **Indirect** Measurement of data that have a quantifiable relationship to reported indicators	**Score = 2** Less than 25% error or some components do not have error quantified
Score = 3 **Established** methodology in published paper	**Score = 3** **Comprehensive** Remote sensed data with comprehensive validation program supporting (statistical error measured) or Modelling with comprehensive validation and supporting documentation or Survey with extensive on ground validation or directly measured data	**Score = 3** **High** 1:10,000 or 30-50% of population	**Score = 3** **Direct** Direct measurement of reported indicator with error	**Score = 3** 10% error and all components have errors quantified

5.1.2. Scoring

For all indicators where a condition score was reported, each criterion is scored 1 (lowest) to 3 (highest) (Table 43). The score of each criterion is weighted accordingly and the total confidence score is calculated by adding all weighted scores of the five criteria. The final score is assessed against a 1 to 5 qualitative confidence ranking (Table 44). The final scores and the associated confidence rankings have been adjusted from the previous report cards to reflect the MWI specific weightings applied to the criteria. The confidence ranking (out of five) is then presented in the Report Cards.

5.1.2.1. Scoring Confidence Criteria in the MWI Report Card

When scoring confidence for indicators in the MWI Region, confidence of an indicator was considered separately for the different reporting zones. This was because for some indicators, there were different sample sizes, programs or divergent methods contributing to the condition scores of an indicator depending on the zone.

The representativeness criterion was considered at a spatial and temporal scale. Where confidence was lower at one scale, the conservative (lowest) score was applied to this criterion for that indicator. For example, if spatial representativeness was moderate (i.e. 2), but the temporal scale representativeness was low (i.e. 1), the score used for representativeness was low (i.e. 1).

Occasionally, data from different programs were used to derive condition scores for an indicator in the same reporting zone. For example, in the Central Zone NQBP and MMP programs provided water quality data, but there was a difference in confidence in the data provided by the two programs. To score confidence in such a situation, where two or more methods/programs/datasets contribute to an overall indicator score in the same reporting zone, the following decision rule was applied:

- When data are partitioned equally between the two methods/programs/datasets, confidence is scored conservatively (i.e. the lower of two scores is applied where relevant),
- When data are not partitioned equally between the methods/programs/datasets, confidence is scored by using the score for the dominant method/program/dataset.

Based on these rules, in the Central Zone confidence is scored by considering the Ports program because it has nine sampling sites compared to the MMP's two sampling sites.

5.1.2.2. Final Confidence Scores for Presentation in the MWI Report Card

Once each criterion is scored, the appropriate weighting is applied, and these scores are added together to give a final score. An overall ranking for confidence for each indicator in each zone is applied based on the final score (Table 44). For presentation purposes, confidence scores are aggregated into a single score for freshwater basin, estuarine and inshore and offshore marine indices.

Indicator Level

- When confidence scores for an indicator are different across only two reporting zones, confidence is scored conservatively (i.e. the lowest total score of the pair is used) to determine the overall rank of the indicator,
- When confidence scores for an indicator are different across three or more zones, the median of all the total confidence scores between the reporting zones is used to apply the overall rank of the indicator.

For example, in the Don Basin, confidence in the fish barrier indicator was lower than confidence in this indicator across the other four basins because there were differences in ground truthing between the Don and the other basins. Therefore, the freshwater fish barriers indicator score used was the median of the final confidence score and associated ranking.

Indicator Category and Index Level

When confidence scores for an indicator or indicator category are different, the median of all the total confidence scores between the indicator or indicator category is used to apply the overall rank of the indicator category or index.

Table 44. Overall confidence score, associated ranking and how ranking is displayed in the Report Card.

Final Confidence Score Range	Ranking	Display in Report Card
>11.7 to 13.5	Five	VERY HIGH ●●●●●
>9.9 to 11.7	Four	HIGH ●●●●○
>8.1 to 9.9	Three	MODERATE ●●●○○
>6.3 to 8.1	Two	LOW ●●○○○
4.5 to 6.3	One	VERY LOW ●○○○○
<4.5	Zero	NO DATA ○○○○○

5.2. Limitations and Recommendations

Since the Pilot Report Card was released in 2014, considerable advances have been made in improving the quality and accuracy of report card results. However, it is important to highlight and acknowledge the limitations of our existing approach.

Multiple monitoring sites were used to inform water quality scores within the O'Connell and Plane basins. The addition of these sites, into the Report Card assessment, occurred for the first time in 2018 after previous Report Cards highlighted the low spatial representativeness of water quality monitoring data in freshwater basins. In 2016 and 2017, sites were established as part of the GBRCLMP in each of the Don and Proserpine basins, and additional sites in the O'Connell and Plane basins (now two monitoring sites in each basin).

However, limitations still exist when using data obtained from one or two discrete monitoring sites to report water quality:

- Spatial representativeness of freshwater basins is still low with only one or two sites per basin. Additional monitoring throughout all basins is a critical step to improving confidence in basin scale reporting.
- The Proserpine Basin was not given a water quality score in the 2020 Report Card, following review of the available water quality data that suggested the monitoring site was influenced by tidal action, and therefore was not fully representative of the freshwater environment. It is anticipated that this tidal action may also impact the observed concentration of nutrients (DIN and FRP). As a result, sediment and nutrient condition were not reported for the Proserpine Basin in the 2020 Report Card.

- The method produced for assessing multiple freshwater sites for the 2020 Report Card is currently being reviewed and refinements may be incorporated in the development of future report cards.
- Due to restrictions associated with the COVID-19 pandemic, monitoring in MWI estuaries was hindered from April – June 2020. As a result, the sample size for estuary monitoring in the 2020 Report Card is reduced by approximately one quarter.

Flow was incorporated into the 2020 Report Card for the third consecutive year. Considerable work has been undertaken between the 2018 and 2020 Report Card releases to explore opportunities to fill flow data gaps in basins and estuaries that were identified in the 2018 Report Card. This work is currently progressing with the BoM, with technical advice from the TWG. It was recommended at the 2020 ISP and TWG meetings that a review of the flow indicator tool be undertaken. This is still being investigated.

Low confidence in pesticide data in the estuaries has been highlighted since the 2014 Pilot Report Card. In 2017, the Partnership established and funded a supplementary pesticide monitoring program with monitoring commencing in the 2017-18 wet season. The monitoring program was scoped with the intention of improving the temporal representativeness of sampling through increasing the number of monitoring events from less than six to approximately 18 in the current assessment. The results obtained through this monitoring program were reported for the first time in the 2019 Report Card. This year's results further our understanding of pesticide concentrations in MWI estuaries.

A knowledge gap was identified in previous Report Cards for the Southern Zone. Baseline water quality, seagrass and coral monitoring was commissioned by the Partnership in 2017, and a long-term monitoring program has been established for these indicators. The 2018 Report Card saw the release of a water quality score for the Southern Zone for the first time. The 2019 Report Card reported on pesticides and coral for the first time. Seagrass scores will be released in the 2021 Report Card when five years of baseline data have been collected.

Other limitations to the Report Card include seagrass reporting, which currently does not allow for direct comparison across marine reporting zones, and limitations around the understanding of riparian, wetland and mangrove/saltmarsh habitats.

The Partnership has been working towards addressing some of these limitations:

- Improved integration of the different seagrass indicator programs is being addressed by the seagrass working group as part of the Reef Integrated Monitoring and Reporting Program (RIMReP, directed by GBRMPA),
- Working with the TWG and riparian and wetland data providers/experts to improve report card indicators for wetland and riparian extent and ensure comparability over time.

Further improvements to the Report Card that have been identified for the future are outlined in the Program Design[2]. Some of the key improvements include:

- Exploration of estuary and marine fish indicators (including the potential use of citizen science),

- Exploring the option to use eReefs modelling as part of condition assessments,
- Expansion of water quality monitoring in freshwater basins to include the upper and middle of catchments, and
- Moving towards inclusion of reporting progress-to-targets.

6. References

ANZG. (2018). *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. www.waterquality.gov.au/anz-guidelines

Australian and Queensland Governments. (2015). *Scoring system, Great Barrier Reef Report Card 2014*. http://www.reefplan.qld.gov.au/measuring-success/report-cards/2014/assets/gbrscoring-system-2014.pdf

Australian and Queensland Governments. (2018). *Paddock to Reef Integrated Monitoring, Modelling and Reporting Program: Program Design 2018-2022.*

Australian and Queensland Governments. (2019a). *Agricultural Land Management Practice Adoption Methods, Reef Water Quality Report Card 2017 and 2018, Reef 2050 Water Quality Improvement Plan*. https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0028/82918/report-card-2017-2018-methods-agricultural-mpa.pdf

Australian and Queensland Governments. (2019b). *Management Practices*. https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/management-practices

Ayling, T., Ayling, A., & Chartrand, K. (2020a). *Port of Abbot Point Ambient Coral Monitoring Surveys: 2019-2020*.

Ayling, T., Ayling, A., & Chartrand, K. (2020b). *Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2019-2020*.

Bainbridge, Z., Lewis, S., Bartley, R., Fabricius, K., Collier, C., Waterhouse, J., Garzon-Garciad, A., Robson, B., Burton, J., Wenger, A., & Brodie, J. (2018). Fine sediment and particulate organic matter: A review and case study on ridge-to-reef transport, transformations, fates, and impacts on marine ecosystems. *Marine Pollution Bulletin*, *135*, 1205–1220.

Bryant, C., Jarvis, J., York, P., & Rasheed, M. (2014). *Gladstone Healthy Harbour Partnership Pilot Report Card; ISP011: Seagrass.*

Carter, A, Jarvis, J., Bryant, C., & Rasheed, M. (2015). *Development of seagrass indicators for the Gladstone Healthy Harbour Partnership Report Card, ISP011: Seagrass*.

Carter, A, Rasheed, M., McKenzie, L., & Coles, R. (2016). *An interim approach to integrate seagrass monitoring results for NRM regional report cards. A case study using the Wet Tropics NRM region*.

Carter, AB, Chartrand, K., Wells, J., & Rasheed, M. (2019). *Gladstone Healthy Harbour Partnership 2019 Report Card, ISP011: Seagrass*.

Carter, J., Tait, J., Kapitzke, R., & Corfield, J. (2007). *Burdekin Dry Tropics NRM Region Fish Passage Study*.

DES (Department of Environment and Science). (2009). *Monitoring and Sampling Manual 2009, Version 2, July 2013*.

Donders, A., van der Heijden, G., Stijen, T., & Moons, K. (2006). Review: A gentle introduction to imputation of missing values. *Journal of Clinical Epidemiology*, *59*, 1087–1091.

Folkers, A., Rohde, K., Delaney, K., & Flett, I. (2014). *Water Quality Improvement Plan 2014-2021*

Mackay, Whitsunday, Isaac.

Gallen, C, Devlin, M., Thompson, K., Paxman, C., & Mueller, J. (2014). *Pesticide monitoring in inshore waters of the Great Barrier Reef using both time-integrated and event monitoring techniques (2013 - 2014)*.

Gallen, Christie, Thompson, K., Paxman, C., & Mueller, J. (2016). *Marine Monitoring Program. Annual Report for inshore pesticide monitoring: 2014 to 2015. Report for the Great Barrier Reef Marine Park Authority.*

GBRMPA (Great Barrier Reef Marine Park Authority). (2010). *Water quality guidelines for the Great Barrier Reef Marine Park. Revised Edition*.

Grant, S., Thompson, K., Paxman, C., Elisei, G., Gallen, C., Tracey, D., Kaserzon, S., Jiang, H., Samanipour, S., & Mueller, J. (2018). *Marine Monitoring Program: Annual report for inshore pesticide monitoring 2016-2017. Report for the Great Barrier Reef Marine Park Authority*.

Huggins, R., Wallace, R., Orr, D., Thomson, B., Smith, R., Taylor, C., King, O., Gardiner, R., Wallace, S., Ferguson, B., Preston, S., Simpson, S., Shanks, J., Warne, M. S. ., Turner, R., & Mann, R. (2017). *Total suspended solids, nutrient and pesticide loads (2015–2016) for rivers that discharge to the Great Barrier Reef – Great Barrier Reef Catchment Loads Monitoring Program*.

Jonker, M., Johns, K., & Osborne, K. (2008). *Surveys of benthic reef communities using digital photography and counts of juvenile corals*. http://www.aims.gov.au/documents/30301/23354/Long+term+Monitoring+GBR+Standard+Operational+Procedure+10/34301565-3820-4c49-9087-7f3f15f1962a

Lønborg, C., Devlin, M., Brinkman, R., Costello, P., da Silva, E., Davidson, J., Gunn, K., Logan, M., Petus, C., Schaffelke, B., Skuza, M., Tonin, H., Tracey, D., Wright, M., & Zagorskis, I. (2016). *Reef Rescue Marine Monitoring Program: Annual report of AIMS and JCU activities 2014 to 2015. Inshore water quality monitoring. Report for the Great Barrier Reef Marine Park Authority.*

McKenna, S., Rasheed, M., Reason, C., Wells, J., & LR, H. (2019). *Port of Abbot Point Long-Term Seagrass Monitoring Program-2018*.

McKenzie, L. (2009). *MTSRF Milestone report for June 2009: Seagrass indicators, distribution and thresholds of potential concern*. http://rrrc.org.au/wp-content/uploads/2014/06/113-QDPIF-McKenzie-L-2009-May-Milestone-Report.pdf

McKenzie, L., Campbell, S., & Roder, C. (2003). *Seagrass-Watch: Manual for Mapping & Monitoring Seagrass Resources by Community (citizen) volunteers*.

McKenzie, L., Collier, C., & Waycott, M. (2015). *Reef Rescue Marine Monitoring Program - Inshore Seagrass, Annual Report for the sampling period 1st June 2012 – 31st May 2013*.

McKenzie, L., Mellors, J., Waycott, M., Unsworth, R., & Collier, C. (2010). Intertidal seagrass monitoring. In RRRC Ltd (Ed.), *Reef Rescue Marine Monitoring Program: Quality Assurance/Quality Control Methods and Procedures Manual* (pp. 42–56). Reef & Rainforest Research Centre Ltd.

Moore, M. (2015a). *Mackay Whitsunday Region freshwater fish barrier prioritisation*.

Moore, M. (2015b). *Mackay Whitsunday WQIP barriers to fish migration health metrics*.

Neldner, V. J., Butler, D. W., & Guymer, G. P. (2019). *Queensland's regional ecosystems: Building a maintaining a biodiversity inventory, planning framework and information system for Queensland, Version 2.0*.

Newham, M., Moss, A., Moulton, D., Honchin, C., Thames, D., & Southwell, B. (2017). *Draft environmental values and water quality guidelines : Don and Haughton River basins , Mackay-Whitsunday estuaries , and coastal / marine waters* (Issue March).

Patrician, P. (2002). Multiple imputation for missing data, Research in Nursing and Health. *Research in Nursing and Health*, *25*(1), 76–84.

Plackett, R., & Hewlett, P. (1952). Quantal responses to mixtures of poisons. *J Roy Stat Soc B*, *14*, 141.

Rubin, D. (1996). Multiple Imputation after 18+ years. *Journal of the American Statistical Association*, *91*(434), 473–489.

Stewart-Koster, B., Bofu Yu, B., Balcombe, S., Kennard, M., & Marsh, N. (2018). *Development of regional report card flow indicators for the Mackay-Whitsunday and Wet Tropics regions*.

Storlazzi, C., Norris, B., & Rosenberger, K. (2015). The influence of grain size, grain color, and suspended-sediment concentration on light attenuation: Why fine-grained terrestrial sediment is bad for coral reef ecosystems. *Coral Reefs*, *34*, 967–975.

Thompson, A., Costello, P., Davidson, J., Logan, M., & Coleman, G. (2021). *Marine Monitoring Program: Annual report for inshore coral reef monitoring 2018-19*.

Thompson, A., Costello, P., Davidson, J., Logan, M., Coleman, G., Gunn, K., & Schaffelke, B. (2016). *Marine Monitoring Program: Annual report for inshore coral reef monitoring 2014-2015*.

Waltham, N., Buelow, C., Whinney, J., Macdonald, R., & Olsed, A. (2018). *Port of Abbot Point Ambient Marine Water Quality Monitoring Program (November 2017-July 2018)*.

Waltham, N., McKenna, S., York, P., Devlin, M., Campbell, S., Rasheed, M., Da Silva, E., Petus, C., & Ridd, P. (2015). *Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program (July 2014 to July 2015)*.

Warne, Ms., Neelamraju, C., Strauss, J., Smith, R., Turner, R., & Mann, R. (2020). *Development of a method for estimating the toxicity of pesticide mixtures and a Pesticide Risk Baseline for the Reef 2050 Water Quality Improvement Plan*.

Waterhouse, J., Lønborg, C., Logan, M., Petus, C., Tracey, D., Lewis, S., Tonin, H., Skuza, M., da Silva, E., Carreira, C., Costello, P., Davidson, J., Gunn, K., Wright, M., Zagorskis, I., Brinkman, R., & Schaffelke, B. (2017). *Marine Monitoring Program: Annual Report for inshore water quality monitoring, 2015-2016. Report for the Great Barrier Reef Marine Park Authority.*

Whitehead, T. (2020). *Methods for the Townsville Dry Tropics annual report cards*. https://img1.wsimg.com/blobby/go/801025fd-701e-4f65-8fe3-e5e652ba63c4/downloads/DTPHW_Methods_for web.pdf?ver=1615167035822

Whitehead, T., & Venables, B. (2019). Litter score and grade proposal for Townsville. *Unpublished*.

York, P., & Rasheed, M. (2019). *Annual Seagrass Monitoring in the Mackay-Hay Point Region- 2018*.

Appendix A: Data Sources

Table A1. Data sources for each index reported in the 2020 MWI Healthy Rivers to Reef Report Card.

Environment	Basin/Estuary/ Marine Zone	Index (Indicator Category)	Program	Data Source
Freshwater Basins	Don Basin Proserpine Basin O'Connell Basin Pioneer Basin Plane Basin	Water Quality (including pesticides)	GBRCLMP	Pesticide data available through the Water Quality & Investigations Pesticide Reporting Portal Current Contact: Dr Reinier Mann - Science Leader, DES (reinier.mann@des.qld.gov.au)
		Riparian Extent	Built-for-purpose	Current contact: Partnership Staff (info@healthyriverstoreef.org.au)
		Fish Barriers		
		Impoundment Length		
		Wetland Extent		
		Fish	Regional Report Card Monitoring Program	Current Contact: David Moffatt - Principal Environment Officer, DES (david.moffatt@des.qld.gov.au)
		Flow	Streamflow data - Water Monitoring Information Portal (QLD Government) Rainfall data - SILO (QLD Government) *and* BoM	Streamflow Online Database Rainfall Online Databases for SILO and BoM
Estuarine	Gregory River O'Connell River St Helens/Murray Creek Vines Creek Sandy Creek Plane Creek Rocky Dam Creek Carmila Creek	Water Quality (including pesticides)	DES Estuary Monitoring Program	Current Contact: Dr Michael Newham - Senior Scientist, DES (michael.newham@des.qld.gov.au)
		Pesticides (additional monitoring)	Regional Report Card Monitoring Program	Current contact: Partnership Staff (info@healthyriverstoreef.org.au)
		Riparian Extent	Built-for-purpose	
		Mangrove and Saltmarsh Extent		
		Fish Barriers		

Table A1. Data sources for each index reported in the 2020 MWI Healthy Rivers to Reef Report Card.

Environment	Basin/Estuary/ Marine Zone	Index (Indicator Category)	Program	Data Source
Inshore Marine	Northern	Water Quality (including pesticides)	NQBP Abbot Point Ambient Water Quality Monitoring Program	Annual Reports Current contact: Nicola Stokes - Senior Environmental Advisor, NQBP (environment@nqbp.com.au)
		Coral	NQBP Abbot Point Coral Monitoring Program	Online Database
		Seagrass	NQBP Abbot Point Seagrass Monitoring Program	Online Database
			Seagrass Watch	Online Database
	Whitsunday	Water Quality	GBR MMP for Inshore Water Quality	Annual Reports Turbidity and Chlorophyll-*a* Online Database Current contact: Dr Renee Gruber - Biological-Chemical Oceanographer, AIMS (r.gruber@aims.gov.au)
		Coral	GBR MMP for Inshore Coral Reefs	Annual Reports Online Database Current contact: Angus Thompson - Coordinator Inshore Reef Benthic Monitoring, AIMS (A.Thompson@aims.gov.au)
			RCA	Annual Reports Current contact: Jenni Calcraft - Great Barrier Reef Project Coordinator, RCA (jenni@reefcheckaustralia.com)
		Seagrass	GBR MMP for Inshore Seagrass (including Seagrass Watch)	Annual Reports Seagrass Watch Online Database

Table A1. Data sources for each index reported in the 2020 MWI Healthy Rivers to Reef Report Card.

Environment	Basin/Estuary/ Marine Zone	Index (Indicator Category)		Program	Data Source
					Current contact: Len McKenzie - Principal Research Officer, JCU (len.mckenzie@jcu.edu.au)
	Central	Water Quality	Pesticides	GBR MMP for Inshore Pesticides	Annual Reports Current Contact: Dr Reinier Mann - Science Leader, DES (reinier.mann@des.qld.gov.au)
			Nutrients, Water Clarity, Chlorophyll-*a*	GBR MMP for Inshore Water Quality	Annual Reports Turbidity and Chlorophyll-*a* Online Database Current contact: Dr Renee Gruber - Biological-Chemical Oceanographer, AIMS (r.gruber@aims.gov.au)
				NQBP Mackay and Hay Point Ambient Water Quality Monitoring Program	Annual Reports Current contact: Nicola Stokes - Senior Environmental Advisor, NQBP (environment@nqbp.com.au)
		Coral		NQBP Mackay and Hay Point Coral Monitoring Program	Online Database
		Seagrass		NQBP Mackay and Hay Point Seagrass Monitoring Program	Online Database
				GBR MMP for Inshore Seagrass (including Seagrass Watch)	Annual Reports Seagrass Watch Online Database Current contact: Len McKenzie - Principal Research Officer, JCU (len.mckenzie@jcu.edu.au)
	Southern	All indices		Partnership-funded SIP	Current contact: Partnership Staff (info@healthyriverstoreef.org.au)
		Seagrass		Seagrass Watch	Online Database

Table A1. Data sources for each index reported in the 2020 MWI Healthy Rivers to Reef Report Card.

Environment	Basin/Estuary/ Marine Zone	Index (Indicator Category)	Program	Data Source
	All inshore and urban sites	Litter	AMDI Database	Online Database
Offshore Marine	Offshore	Water Quality	BoM	Current contact: Partnership Staff (info@healthyriverstoreef.org.au)
		Coral	AIMS LTMP and GBRMPA RAP	LTMP Annual Reports and Database Current contact: Angus Thompson - Coordinator Inshore Reef Benthic Monitoring, AIMS (A.Thompson@aims.gov.au)
			RCA	Annual Reports Current contact: Jenni Calcraft - Great Barrier Reef Project Coordinator, RCA (jenni@reefcheckaustralia.com)

GBRCLMP = Great Barrier Reef Catchment Loads Monitoring Program, DES = Department of Environment and Science, NQBP = North Queensland Bulk Ports, MMP = Great Barrier Reef Marine Monitoring Program, RCA = Reef Check Australia, UQ = University of Queensland, SIP = Southern Inshore Monitoring Project, BoM = Bureau of Meteorology, AMDI = Australian Marine Debris Initiative, AIMS = Australian Institute of Marine Science, JCU = James Cook University, LTMP = AIMS Long-term Monitoring Program, Great Barrier Reef Marine Park Authority = GBRMPA, RAP = Representative Areas Program.

Appendix B: Litter Metric

Appendix B1: Filtering Methods

Document prepared and supplied by Jordan Gacutan (University of New South Wales (UNSW), Sydney)

Data filtering methods for the litter metric in regional report cards

Prepared for: Regional report card partnerships – the Dry Tropics Partnership for Healthy Waters, Partnership for Wet Tropics Waterways and MWI Healthy Rivers to Reef Partnership.

On behalf of: Tangaroa Blue Foundation and UNSW, Sydney

Summary:

The following brief provides an overview of the methods used to process the Australian Marine Debris Initiative (AMDI) Database (henceforth **'raw data'**) to a '**custom dataset'**, as in input for the model described in Whitehead and Venables (2019).

Rationale:

- Support continued monitoring of litter to detect changes due to source reduction/policy implementation within GBR catchments.
- Standardise litter reporting across regional report card partnerships, supported by the AMDI Database.
- Implementation of AMDI in reporting and decision-making.
- Support the United Nations Sustainable Development Goals [14.1.1, marine plastic pollution].

Description

This project extends the statistical model and analyses presented in the report "Litter Score and Grade Proposal for Townsville". The existing model has been implemented for the Dry Tropics Partnership for Healthy Waters reporting region. The model and required data processing, have been extended to the Wet Tropics and MWI reporting regions.

In December 2020, Tangaroa Blue Foundation and UNSW, Sydney were asked to provide a data pipeline, to process raw data from the AMDI Database for use in a statistical model. The pipeline facilitates the extraction and processing of data for future reporting needs. Tasks to be performed by UNSW are described in the '**data sharing agreement**' between Tangaroa Blue Foundation, UNSW and each Partnership.

The data pipeline involves filtering (1) data quality, (2) spatially to the reporting area, and (3) model use, described in Figure A1. Treatment of **ReefClean** data is described in Section 1.

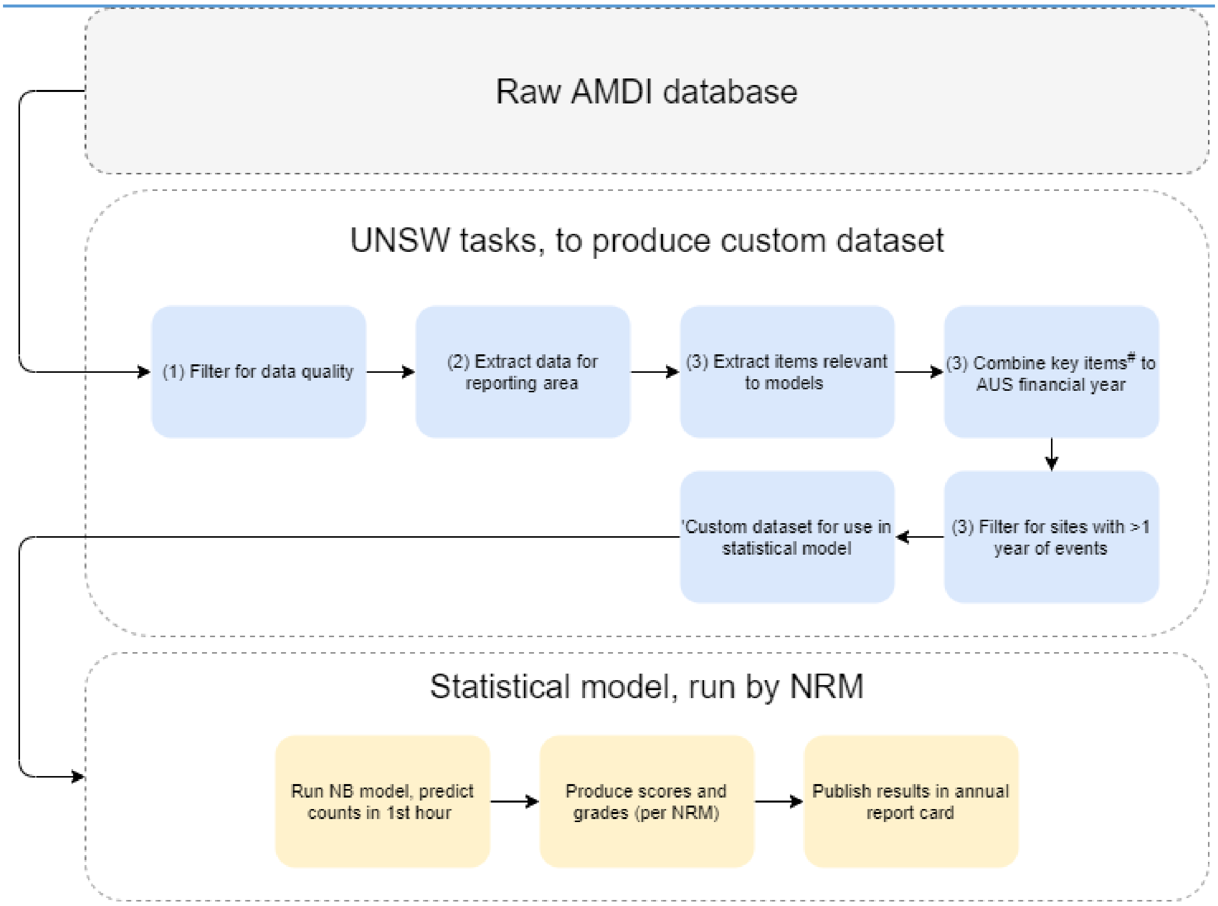


Figure B1. Data pipeline for the project, to extract key items (#) (plastic bags, plastic bottles, single-use cutlery, and cigarettes) from the Australian Marine Debris Initiative (AMDI) Database for annual use in a statistical model, for production of litter scores and grades. NRM = Natural Resource Management area pertaining to the partnership reporting region, NB = Negative binomial.

1) <u>Filter for data quality</u>

Filtering for data quality is taken from methods and related scripts of the publication, 'Continental trends in marine debris revealed by a decade of citizen science' (*in prep*). The filters used are presented in Table B1. As the work in is in preparation, scripts are currently unavailable.

ReefClean data was identified and processed separately, aggregating all transects and debris collected in surrounding areas, to align with data from community clean-ups stored within the AMDI Database. Loss of resolution was justified by model needs.

Table B1. Data quality filters used to process the Australian Marine Debris Initiative (AMDI) Database. Filters are in sequential order.

Cleaning theme	Tool used	Cleaning step	Examples / Description
Original database	DB Browser for SQL lite	Original database (Downloaded January 2021)	N/A
Limit to Australia	ArcMap 10.6	Remove foreign entries	Hawaii / Tonga / NZ / PNG / Timor Leste
	ArcMap 10.6 / Nearmap	Remove Australian external territories	Christmas island / Norfolk Island / Cocos Islands

Limit timeframe	DB Browser for SQL lite	Filter for Jan 2009 - Dec 2018	-
Clean by event entries	DB Browser for SQLite / R	Remove duplicate sites	-
		Clean-up time < 0.25 hours	Non-exhaustive clean-up.
		One volunteer, < 1 kg	A single volunteer collecting less than 1 kg indicates a non-exhaustive or informal clean-up
Clean by event entries	R / Excel	One volunteer, > 10 hours	Single volunteer cleaning more than 10 hours (indicates multiple days / weeks / months collecting)
		Not a clean-up	Daily walk / hike / Anecdotal as described in notes
		Estimated / incomplete	Stated in event notes
		Anecdotal (stated in notes)	Stated in event notes
		Clean-up over multiple days / weeks / month	Stated in notes, hours reported > 24
		Data quality poor	Number of volunteers / time / date or other details missing.
		Single item reported	Stated in event notes
		Timor Leste	Incorrectly entered as Australian site w/ incorrect coordinates
		Remove fishing line bin entries	Fishing bin Initiative hosted in the AMDI Database
Event clean (Ratios of variables used to clean database)	R	bags / volunteer > 8	Volunteers collected more than 8 bags each (accuracy of data)
		Weight / volunteer > 10 & wt /bag > 10	Volunteers collected more than 10 bags weighing 10 kg each (accuracy of data)
		Hours per volunteer > 10 (i.e. each volunteer worked + 10 hrs)	Indicates poor data quality or multiple clean-ups over a longer timeframe
Clean events by item entries	R	Single item	Single item reported at the event (not in notes)
		Components < 10	Less than 5 item categories reported
		Estimated (div 10, integers)	Entries with integers divisible by 10 (estimated item categories > 50%)

2) <u>Extract data for reporting areas:</u>

Processed data were classified according to partnership reporting areas and 'water type', as defined in Environmental Protection (Water) Policy 2009 (Qld, s. 12). Reporting areas and water types were classified by provided spatial data. Provided data and **custom dataset** were manipulated in ArcMap 10.7.

Table B2. Provided shapefiles used to classify data by each partnership's reporting needs.

Shapefile name	**Providing organisation**

Townsville boundary for Jordan.kmz	Dry Tropics Partnership for Healthy Waters
FW_report_zones_dis.shp 20160201_Wet_Tropics_Estuaries.shp Inshore_Zones_Dissolve.shp Amended_Marine_Region.shp	Partnership for Wet Tropics Waterways
HR2R_ReportingZones_v4_15March2016.shp	MWI Healthy Rivers to Reef Partnership

3) <u>Manipulate extracted data for use in model:</u>

To align with model structure, the following steps were performed:

a) Policy relevant items (plastic bags, plastic bottles, single-use items) were extracted.
b) Events were classified per financial year. Multiple events per site, per year were classified as ‘Replicates’.
c) To avoid model collapse, sites with less than one financial year were filtered from analysis.

The resulting data were then provided to each regional report card partnership.

Appendix B2: MWI Sample Sites 2014-2020 FYs

Table B3. MWI litter clean-up sites from 2014 to 2020 (financial years (FYs)) sourced from the Australian Marine Debris Initiative (AMDI) Database. Volunteer (vol) number and hours are detailed for sites that were surveyed in 2019-20. Volunteer hours are presented as the number of volunteers x the number of hours done by each volunteer. The number of times a particular site was surveyed in past FYs is represented by the corresponding number. Note, FY is displayed as per 2020 = 2019-20.

Zone	Site Type	Site	2020 Survey		Past Surveys (FYs)					
			Vol. No.	Vol. Hours	2019	2018	2017	2016	2015	2014
Northern	Inshore	**Don River Mouth, Bowen***	**24**	**6**	1					
		Queens Beach, Bowen*	**87**	**29.4**	1					
		Gloucester Island, Eastern Side	-	-		1		1		
		Gordon Beach*	-	-	1			1		
		Horseshoe Bay, Bowen	-	-				1		
Whitsunday	Urban	**Proserpine Town***	**132**	**4.5**						
		Urban Surrounds, Airlie Beach	-	-	1	1	1	1		
		Urban Surrounds, Cannonvale	-	-		1		1		
		Cannonvale Beach	-	-	1					
	Inshore	**Bluff Point North East Side, Pioneer Bay***	**27**	**18**						
		Border Island	**36**	**21**		3		1		1
		Coral Beach, Airlie Beach*	**6**	**4.5**					1	
		Dingo Beach*	**6**	**4.5**						
		Eagle Bay, Shaw Island	**36**	**21**		1				
		George Point	**36**	**21**	4			2		

Table B3. MWI litter clean-up sites from 2014 to 2020 (financial years (FYs)) sourced from the Australian Marine Debris Initiative (AMDI) Database. Volunteer (vol) number and hours are detailed for sites that were surveyed in 2019-20. Volunteer hours are presented as the number of volunteers x the number of hours done by each volunteer. The number of times a particular site was surveyed in past FYs is represented by the corresponding number. Note, FY is displayed as per 2020 = 2019-20.

Zone	Site Type	Site	2020 Survey		Past Surveys (FYs)					
			Vol. No.	Vol. Hours	2019	2018	2017	2016	2015	2014
		Hook Island, East	**66**	**42**	1					
		Luncheon Bay, Hook Island*	**24**	**6.9**						
		Mackerel Bay, Hook Island*	**6**	**18**	1			1		1
		Saba Bay, Hook Island*	**69**	**42**	3	1			3	1
		Solway Circuit, Whitsunday Island	**33**	**21**	2					
		Southeast Bay, Long Island*	**30**	**21**		1		1	1	3
		South End of Runway, Hamilton Island	**30**	**21**			2	2		
		Southern Tip, Whitsunday Island*	**36**	**21**						
		Turtle Bay, South Molle Island*	**75**	**48**	1					
		Turtle Bay, Whitsunday Island*	**33**	**39**	1	2		2		2
		Airlie Beach	-	-		1		1	2	
		Armit Island	-	-		1		1		
		Billbob Bay, Shaw Island	-	-	1	1				
		Blue Pearl Bay, Hayman Island*	-	-	2					
		Bluff Point	-	-				1		
		Coral Seas Boardwalk, Airlie Beach	-	-	1					
		Double Cone Island	-	-				1		
		Driftwood Bay, Hamilton Island	-	-					1	3
		East Neck Bay, Shaw Island	-	-						1
		Genesta Bay	-	-		1		1	1	
		Grassy Island	-	-		1		1		
		Grimstone Point, Central Beach, Western Side	-	-		1	1			
		Grimstone Point, Northern Beach, Western Side	-	-	2	1		3	1	4
		Gumbrell Island	-	-		1		1		
		Haselwood Island, Southern End	-	-	1			1	1	3
		Hook Island	-	-			1	3		
		Maher Island	-	-				1		
		Maher Island East	-	-		2				
		Neck Bay, Shaw Island	-	-		1				
		Northern Pine Bay, South Molle Island	-	-						1
		Pandanus Bay, Long Island	-	-	1				1	
		Pine Bay, South Molle Island	-	-					2	3
		Plantation Bay, Lindeman Island	-	-				1		1
		Roma Point, South Molle Island	-	-	1	2				1
		Shute Harbour	-	-		1	1	2		
		Shute Harbour, Slipway*	-	-	1					

Table B3. MWI litter clean-up sites from 2014 to 2020 (financial years (FYs)) sourced from the Australian Marine Debris Initiative (AMDI) Database. Volunteer (vol) number and hours are detailed for sites that were surveyed in 2019-20. Volunteer hours are presented as the number of volunteers x the number of hours done by each volunteer. The number of times a particular site was surveyed in past FYs is represented by the corresponding number. Note, FY is displayed as per 2020 = 2019-20.

Zone	Site Type	Site	2020 Survey		Past Surveys (FYs)					
			Vol. No.	Vol. Hours	2019	2018	2017	2016	2015	2014
		South Molle Island	-	-	1			4		
		Whitsunday Island, South of Hook Pass	-	-			5	1		
Central	Urban	**Mackay City Centre**	**24**	**24**	12	40				
		Mackay Industrial Precinct	**3**	**3**	1	1				
		Pioneer River, Glenella Connection Road North Mackay*	**135**	**47.4**	2					
		Sarina Townsite	**3**	**3**	3					
		Bucasia Beach	-	-	2	1				
		River Street Park, Mackay*	-	-	3	1				
	Inshore	**Armstrong Beach***	**6**	**4.8**						
		Conway Beach*	**45**	**30**	1					
		Half Tide Beach, Hay Point*	**138**	**45**	11	2	1			
		Harbour Beach, Mackay*	**114**	**46.5**	9	3	1	7		
		Lamberts Beach, Mackay	**69**	**3**	1	2				
		Louisa Creek Beach, Hay Point*	**60**	**15.9**						
		Town Beach, Mackay*	**93**	**12**	1	1		1		
		Wilson Beach, Conway*	**69**	**24**	1					
		Blacks Beach	-	-	3	1				
		Blacksmith Island, Whitsundays	-	-	1		1			
		Brampton Island, Multiple Sites	-	-	1	1				
		Cape Conway	-	-				1	1	1
		Dinghy Bay West, Brampton Island	-	-			1		1	1
		Eimio Beach	-	-	1	2				
		Far Beach, Mackay	-	-		1				1
		Goldsmith Island, Whitsundays	-	-	1	1	1			
		Hay Point	-	-		1	2			
		McEwens Beach	-	-		1		6		
		Sarina Beach	-	-		1		1		
Southern	Inshore	**Avoid Island, The Percy Group**	**21**	**24**		2	1			1
		Clairview Beach North*	**6**	**4.5**	1					

* ReefClean survey sites (sites were surveyed using unstandardised methodology before the ReefClean program was launched in early 2019).