WETLAND TRACKER

GREAT BARRIER REEF CATCHMENT WETLAND CONDITION MONITORING PROGRAM

TRACKING THE CONDITION OF FRESHWATER WETLANDS

WETLAND TRACKER

GREAT BARRIER REEF CATCHMENT WETLAND CONDITION MONITORING PROGRAM

PART 1: TRACKING THE CONDITION OF FRESHWATER WETLANDS

MAY 2022

The Wetland Tracker rapid method for assessing the condition of freshwater wetlands was prepared by:

The Wetland Science Team
Environmental Monitoring and Assessment Science
Science Delivery Division
Department of Environment and Science

Ecosciences Precinct
GPO Box 2454
Brisbane 4001

Citation for overall method

Vandergragt ML, Tilden JD, Johns C, Sutcliffe T, Pulman L, Ellison T and Huurdeman V, 2022, *Wetland Tracker: a rapid method for assessing the condition of freshwater wetlands in Queensland's Great Barrier Reef catchment area*. Department of Environment and Science, Brisbane, Queensland.

Citation for this document

Tilden JD and Vandergragt ML, 2022, *Great Barrier Reef catchment condition monitoring program: tracking the condition of freshwater wetlands*. Department of Environment and Science, Brisbane, Queensland.

© The State of Queensland (Department of Environment and Science)

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 3.0 Australia (CC BY) licence.

Under this licence you are free, without having to seek permission from the Department of Environment and Science, to use this publication in accordance with the licence terms.

You must keep intact the copyright notice and attribute the State of Queensland, Department of Environment and Science as the source of the publication.

For more information on this licence visit http://creativecommons.org/licenses/by/3.0/au/deed.en

Disclaimer

This document has been prepared with all due diligence and care, based on the best available information at the time of publication. The department holds no responsibility for any errors or omissions within this document. Any decisions made by other parties based on this document are solely the responsibility of those parties. Information contained in this document is from a number of sources and, as such, does not necessarily represent government or departmental policy.

If you need to access this document in a language other than English, please call the Translating and Interpreting Service (TIS National) on 131 450 and ask them to telephone Library Services on +61 7 3170 5725

Acknowledgements

This report has been prepared by the Department of Environment and Science.

We thank the following organisations and people for their contributions to the development of Wetland Tracker: the Queensland Wetlands Program (Queensland Department of Environment and Science); the Reef 2050 Water Quality Improvement Plan Paddock to Reef Monitoring, Modelling and Reporting Program (Australian and Queensland governments); the Queensland Herbarium (Queensland Department of Environment and Science), especially Tim Ryan and Chris Pennay; Queensland Department of Environment and Science, wetland science team members, former and current, for their many and various contributions; external reviewers Dr Rhonda Butcher (Water's Edge Consulting), Dr Richard Mount, and members of the Reef Water Quality Protection Plan Independent Science Panel; and statistical advisors Robert Denham (Queensland Department of Environment and Science, Dr Wayne Robinson (Charles Sturt University), Emma Lawrence (CSIRO Data61), Dr Scott Foster (CSIRO Data61) and Prof Bill Venables (University of Queensland).

Main cover image: Fenice Yoren

May 2022

Contents

Acronyms

AOI	Area of Interest
DERM	Department of Environment and Resource Management (Queensland Government)
DES	Department of Environment and Science (Queensland Government)
DPSIR	Driver Pressure State Impact Response
EHP	Department of Environment and Heritage Protection (Queensland Government)
Esri	Environmental systems research institute
FPC	Foliage Protective Cover
GIS	Geographic Information System
GBR	Great Barrier Reef
GBRCA	Great Barrier Reef Catchment Area
GRTS	Generalised Random Tessellation Stratification
PC	Pressure Class
QA/QC	Quality Assurance/Quality Control
QPWS	Queensland Parks and Wildlife Service
QWP	Queensland Wetlands Program
SKIP	Science Knowledge and Information Provision
WEV	Wetland Environmental Value
WQIP	Water Quality Improvement Plan
WT	Wetland Tracker

Introduction

The Great Barrier Reef catchment area (GBRCA) includes the river basins that flow eastwards into the Great Barrier Reef World Heritage area from the Great Dividing Range and incorporates six broad management areas – Cape York, Wet Tropics, Burdekin Dry Tropics, Mackay-Whitsunday, Fitzroy and Burnett-Mary (Figure 1). Within these management areas are 35 river basins (smaller catchments) covering an area of approximately 423,000 km² that straddles equatorial, tropical, subtropical and grassland (hot arid) climatic zones. There are approximately 312,000 ha of palustrine and lacustrine wetlands remaining within these basins.

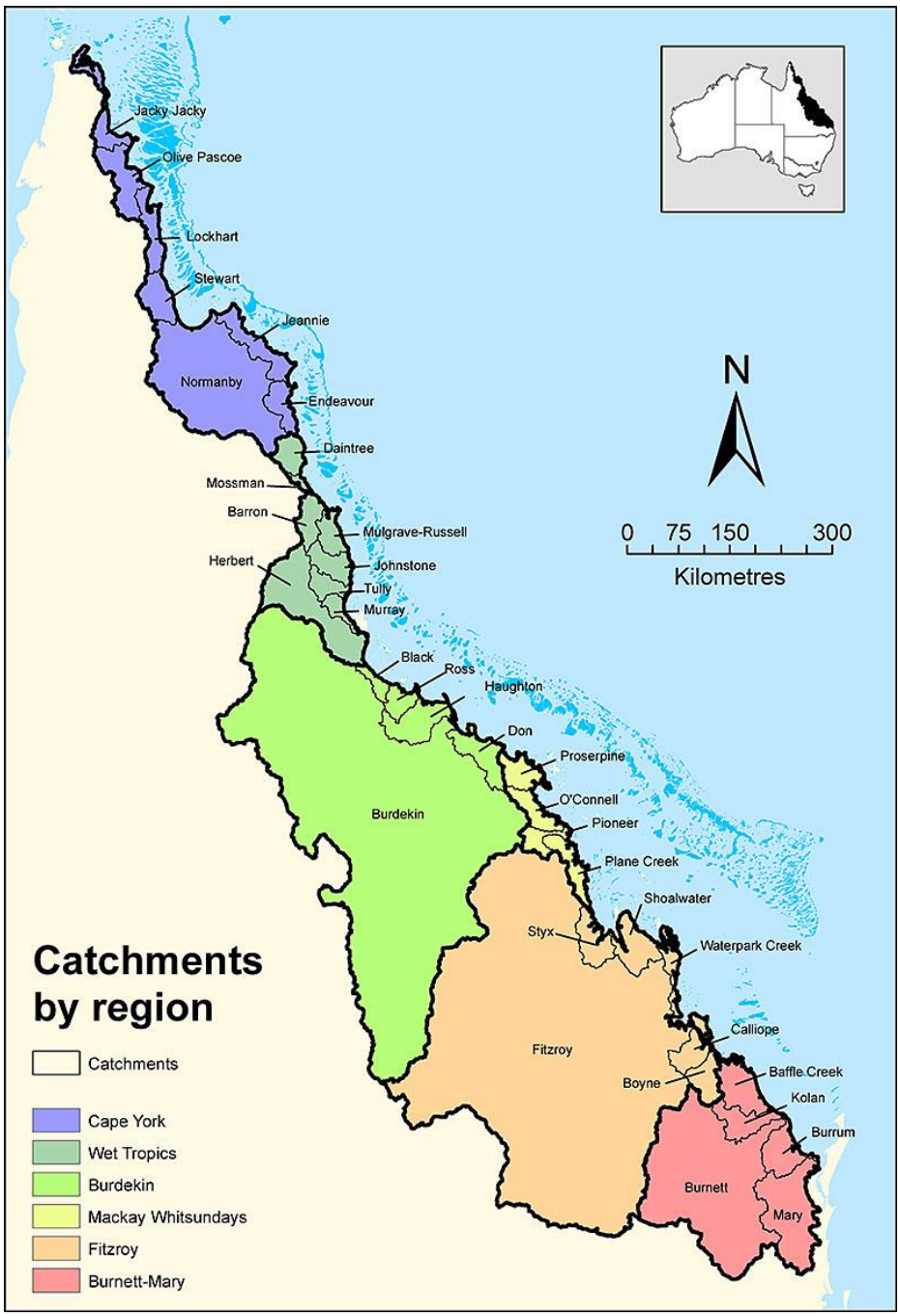

Figure 1 Great Barrier Reef Catchment Area (GBRCA): catchments by region (from Reef 2050 Water Quality Improvement Plan, State of Queensland 2018)

In 2015, the Australian and Queensland governments released the Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan), most recently updated in 2018 (Commonwealth of Australia, 2018). This plan is the overarching strategy for managing the Great Barrier Reef. It coordinates actions and guides adaptive

management to 2050. The strategy identifies seven themes – ecosystem health, biodiversity, water quality, heritage, community benefits, economic benefits and governance – under which targets have been set for managing the Great Barrier Reef World Heritage Area.

The Reef 2050 Water Quality Improvement Plan 2017–2022 (Reef 2050 WQIP) (State of Queensland, 2018) delivers the water quality theme within the Reef 2050 Plan. This joint commitment of the Australian and Queensland governments defines objectives to contribute to ecosystem health, and to social and ecosystem resilience and benefits. It sets ecosystem condition objectives and targets for improved land and catchment management, water quality and community engagement. As well, it identifies actions that will help minimise the risk to the Great Barrier Reef marine and coastal ecosystems from a decline in the quality of water entering from adjacent catchments. It builds on three previous iterations of the Reef Water Quality Protection Plan (The State of Queensland and Commonwealth of Australia 2003, The State of Queensland 2009 and 2013). The Reef 2050 WQIP specifies actions for catchment restoration, integrated within Paddock to Reef program action areas (e.g. stewardship, catchment condition). It includes management frameworks for water quality and catchment restoration activities such as wetland rehabilitation.

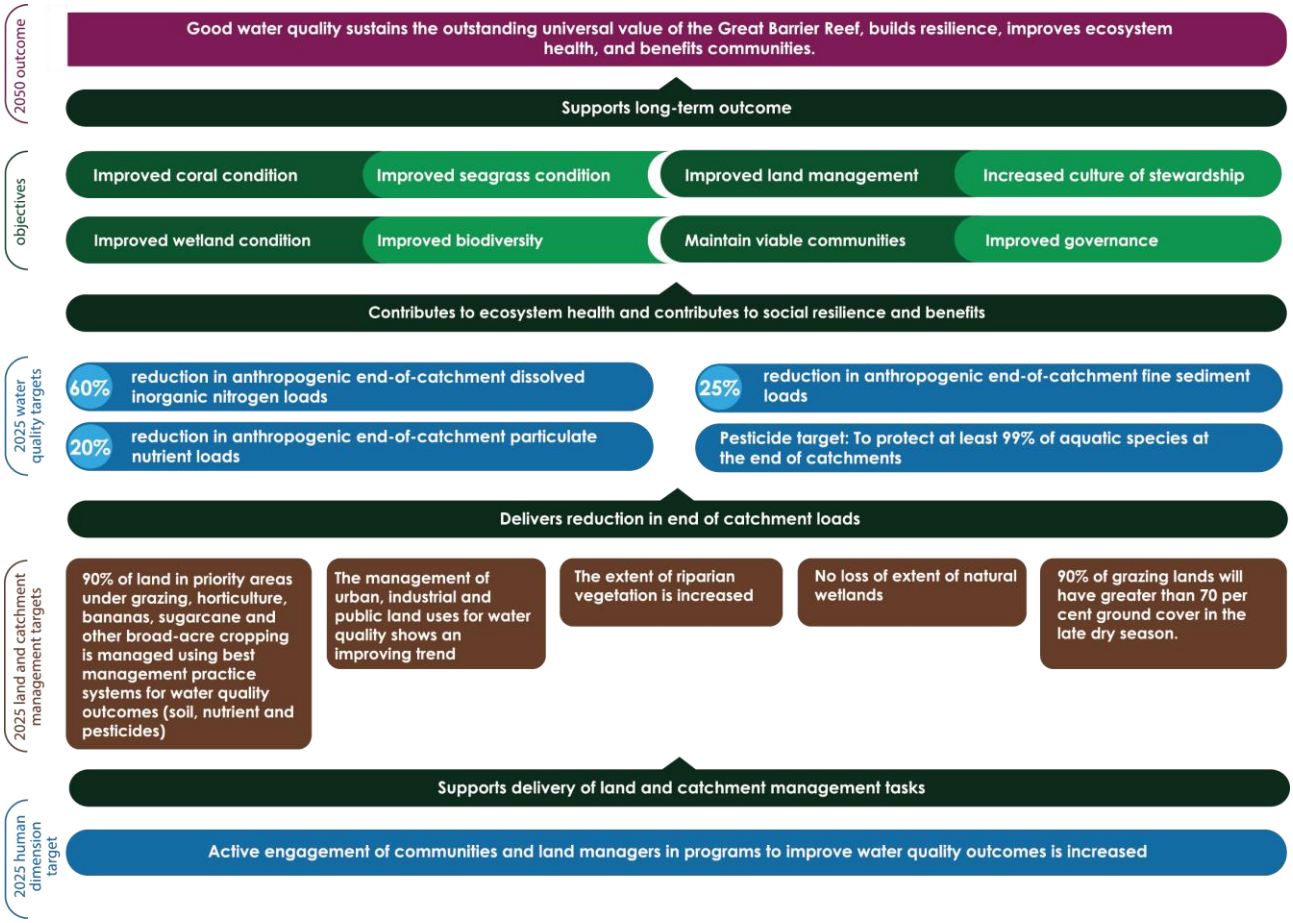

Figure 2 Reef 2050 WQIP outcomes , objectives and targets (adapted from the Queensland and Commonwealth Government 2018)

The GBRCA supports a diversity of nationally significant freshwater wetlands and wetland complexes many of which are biophysically and ecologically connected to the GBR World Heritage area. Commonly, wetlands in the GBRCA are modified in some way and continue to be exposed to a range of land use and catchment development pressures. The Reef 2050 Plan (Commonwealth of Australia 2018) and the Reef 2050 WQIP (State of Queensland 2018), have ecosystem targets and objectives for freshwater wetland condition, recognising the intrinsic importance of these ecosystems and their vital role to the GBRCA and coastal ecology (Keddy et al. 2009; Adame et al. 2019; Australian Government 2018). These targets and objectives

state that there will be no loss in the extent of natural freshwater wetlands and the condition of natural wetlands will be improved. Improving the ecological values of coastal wetlands is seen as an important step towards maintaining the health and resilience of the Great Barrier Reef (GBR) UNESCO World Heritage Area ecosystem and improving its water quality (Commonwealth of Australia 2018; State of Queensland 2018; Australian and Queensland governments 2018).

Progress towards meeting objectives and targets is detailed in the annual Great Barrier Reef Report Card, delivered by the Paddock to Reef program and contributing to the evaluation of the Reef 2050 WQIP (see for example, Reef Water Quality Report Card 2017 and 2018, Australian and Queensland Governments 2019). This progress results from government and community investment in management responses and actions. The Paddock to Reef program applies a combined monitoring and modelling approach to tracking a range of attributes (e.g. wetland condition, ground cover, water quality) across the Great Barrier Reef catchments. Attributes are assessed at a range of scales, including paddock, sub-catchment, catchment, regional and Great Barrier Reef-wide. In line with the Reef 2050 WQIP overarching framework of targets, objectives and the aimed for long-term outcome, the Paddock to Reef program evaluates management practice adoption and water quality effectiveness, catchment condition, pollutant run-off, and marine and wetland condition.

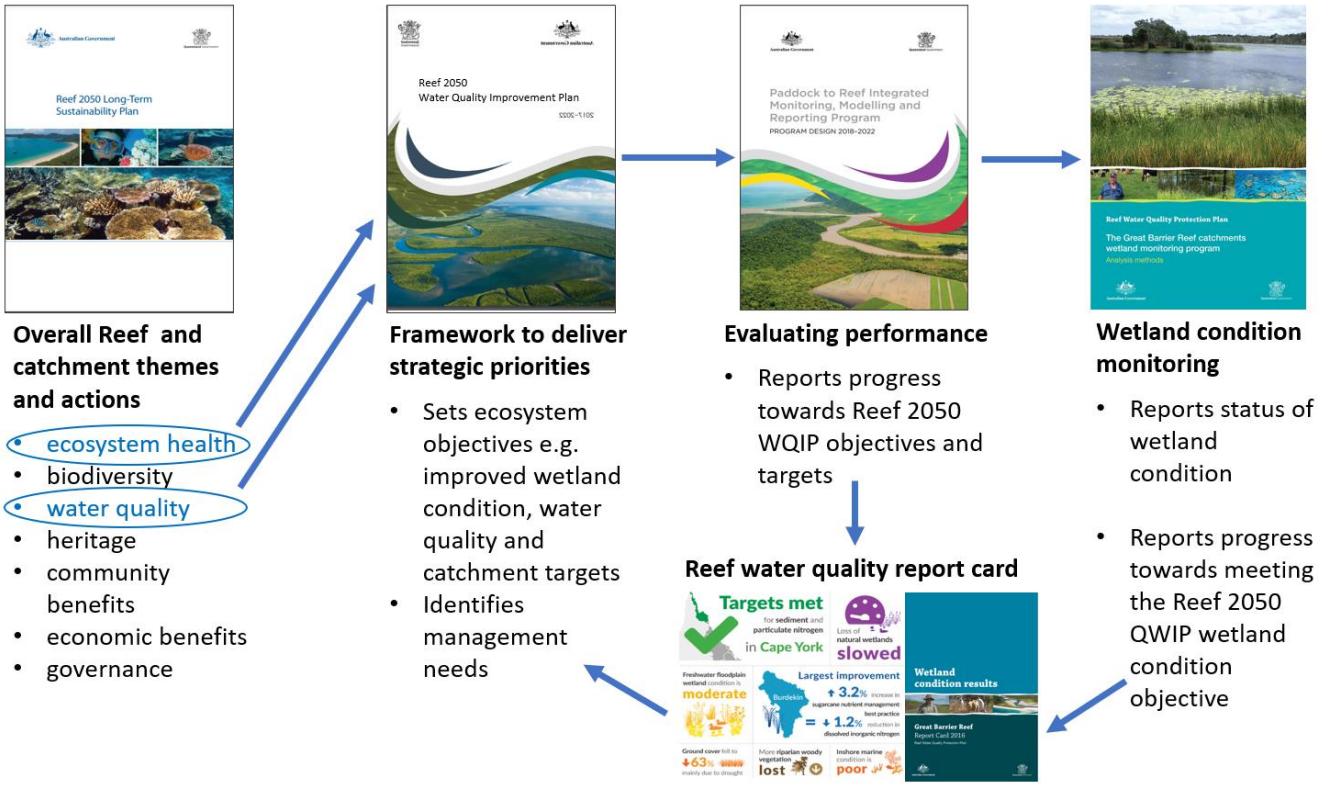

Figure 3 The overall Reef 2050 Plan hierarchy and the role of the Great Barrier Reef catchment area Wetland Condition Monitoring Program.

The GBRCA Wetland Condition Monitoring Program (the Program) was established in 2013 to track change in the condition of wetland environmental values as part of the Paddock to Reef program (Australian and Queensland governments, 2018). The baseline wetland condition report card was released in 2016 (Australian and Queensland Governments 2016). The Program is led by the Science and Technology Division of the Queensland Department of Environment Science.

Tracking GBRCA wetland condition: program design

The Program aims to provide data and evidence about wetland condition to inform the development of policy and management programs for sustaining the health and resilience of GBRCA coastal ecosystems and for the benefit of communities.

The objectives of the Program are to:

- Provide data and information on change in overall wetland condition – the pressures on and state of natural freshwater wetlands in the Great Barrier Reef catchment area from a contemporary 2016 baseline status, assessed against a pre-European reference state.
- Based on the evidence collected through the monitoring program, provide scientific and technical advice to support the development of environmental policy, planning and strategy relating to wetland ecosystems.
- Report results and communicate the Program's science, findings and research to stakeholders.

Program Framework

The Program uses a Driver–Pressure–State–Impact–Response (DPSIR) conceptual framework focussing on the Pressure and State elements. Wetland condition is the overarching term used to describe the pressures on, and the state of, wetland environmental values. Change in wetland condition is a measured reduction or increase in pressures on wetlands and/or shifts in state showing an improvement or decline in the environmental values of natural wetlands within the monitored population.

Program design

Natural wetlands are located in GBRCA catchments from the Normanby catchment in the north to the Mary River catchment in the south.

Natural freshwater wetlands covered by the Program comprise both lacustrine (lake) and palustrine (vegetated) wetlands, with the majority being palustrine. 'Natural' freshwater wetlands are those areas that existed as freshwater wetlands before European occupation in Australia and that still meet the definition of wetlands (whether modified or not) in Queensland-wide wetland mapping (Queensland Environmental Protection Agency 2005). Freshwater wetlands created by bunding natural *estuarine* wetlands to keep out salt water are not included.

The monitored population is those wetlands lying within GBRCA floodplains (land adjacent to waterways) for the reason that floodplain wetlands have clear hydrological and ecological connections with Great Barrier Reef coastal waters and ecosystems. This is consistent with the aim of the Reef 2050 WQIP program to improve GBR water quality and ecological outcomes including through actions for catchment restoration, such as wetland rehabilitation. The defined monitoring population targets the larger, denser aggregations of floodplain wetlands producing a less scattered sample that is more efficient to assess. About sixty-five percent of GBR natural freshwater floodplain wetlands are captured in these aggregations.

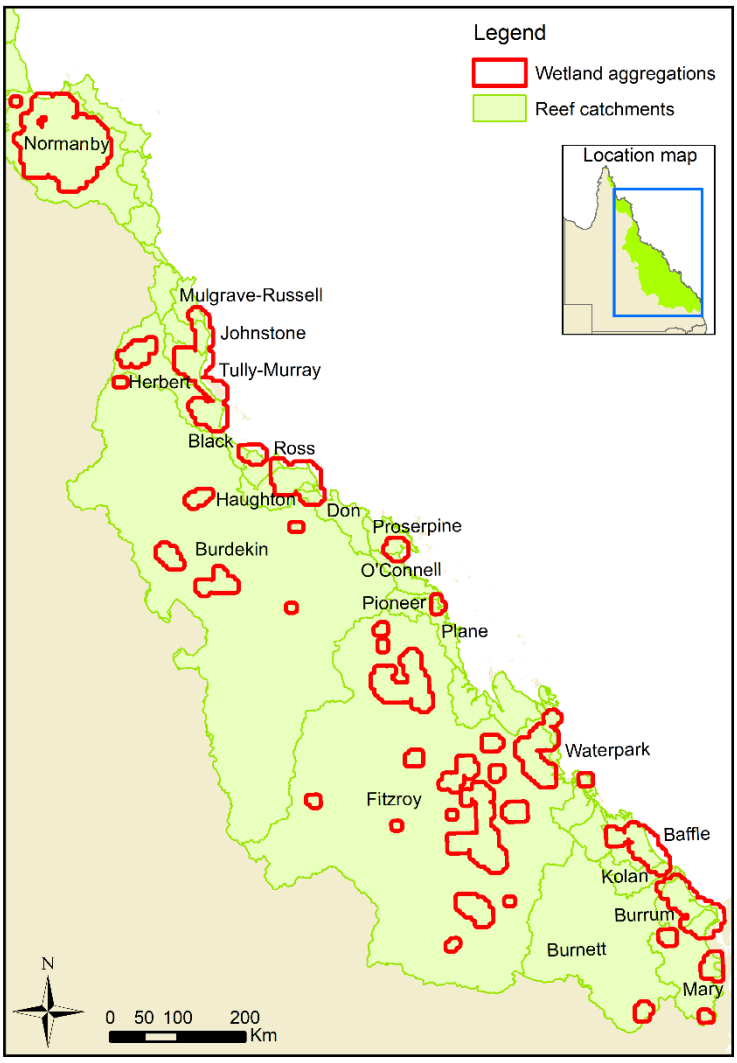

Figure 4 Outlined in red are the aggregations of wetlands that define the sub-population assessed.

Monitoring site locations and sampling strategy

The Program uses a spatially balanced random sample of wetlands for Great Barrier Reef-wide monitoring, drawn using the Generalised Random Tessellation Stratification (or 'GRTS') method to select wetlands in the high-density wetland assemblages. With GRTS sampling, easy replacement of inaccessible sites is possible. Sites can be inaccessible if land managers refuse access, or simply because there is no affordable way to get to the selected wetland. The monitored wetlands occur across a wide range of land uses including grazing, cropping, sugarcane, forestry, mining and conservation.

The Program initially focussed on GBRCA-wide monitoring and reporting, using a random sample of 100 wetlands from across the GBRCA, however it was designed to allow for rapid scaling up. Using master sample methods (Larsen et al. 2008), GRTS sampling has supported an intensified sampling program of reporting by NRM region, at acceptable precision, as resources become available (see Tilden et al., 2015). After intensification to report by region the total sample size across all regions will be ≈ 300 wetlands.

The sampling effort is optimised over time using a flexible alternating panel design. For the original GBRCA-wide sample, wetlands are assessed in five panels of 20. The design seeks to optimise detection of both status and trend of wetland condition, at the individual wetland level and, importantly, for reporting on progress towards the wetland objective across the defined Great Barrier Reef wetland (sub) population. The chosen panel design increases the number of wetlands monitored over a six-year time frame. Following an initial two-year repeat cycle, the cycle of assessments repeats every four years (see Table 1).

Table 1 The Program's augmented serially alternating panel design for allocating monitoring resources through time.

PANEL (sub-sample)	PERIOD										
	1 (2016)	2 (2017)	3 (2018)	4 (2019)	5 (2020)	6 (2021)	7 (2022)	8 (2023)	9 (2024)	10 (2025)	11 (2026)
1	20	20	20	20	20	20	20	20	20	20	20
2	20		20				20				20
3		20		20				20			
4					20				20		
5						20				20	
Year total	40	40	40	40	40	40	40	40	40	40	40
Total sample	**40**	**60**	**60**	**60**	**80**	**100**	**100**	**100**	**100**	**100**	**100**

The panel design has since been adapted to incorporate additional wetlands for regional level reporting. Fifty wetlands in five panels of 10 are assessed annually in regions with intensified monitoring. In these regions, one panel of ten wetlands is assessed every year while the remaining 4 panels of 10 are assessed in the serially alternating design. Under intensified monitoring, the total sample is stratified by region.

Wetland Tracker

Scope

Wetland Tracker (WT) was designed to measure the condition of 'natural' freshwater (palustrine and lacustrine) wetlands.

Condition of wetlands, as measured by Wetland Tracker, has two components – anthropogenic *pressure* on wetlands and the *state* of wetland environmental values (i.e. pressure and state in the DPSIR framework). Wetland Tracker measures the condition of the wetland's natural ecosystem values where the reference condition of those values is the condition before European land-use impacts.

Wetland Tracker does not identify reference or 'pristine' wetlands for direct comparison with those being assessed. Rather, each indicator has an implied reference condition in its measurement scale, generally an ordinal scale of one to five, where a score of one represents the indicator score that would have been achieved by that wetland before any impact associated with European occupation.

Wetland Tracker sub-indices and indicators

Wetland Tracker sub-indices of pressure and state derive from the DPSIR-based conceptual model of the causal relationships between different classes of anthropogenic pressure on wetlands and their impact on the state of wetlands' environmental values.

Pressure

Wetland Tracker uses four pressure sub-indices, termed Pressure classes (PCs) (Department of Science Information Technology and Innovation 2015). They are:

- PC 1 biological introduction pressures
- PC 2 habitat modification pressures
- PC 3 water regime change pressures
- PC 4 input pressures (including nutrients, sediments, pesticides etc.)

State

Overall state is characterised using a set of natural wetland environmental values derived from Queensland's Environmental Protection Regulations (State of Queensland, 2008) adapted as state sub-indices based on Wetland Environmental Values (WEVs). They are:

- WEV 1 The biological health and diversity of the wetland ecosystem (biotic integrity)
- WEV 2 The wetland's natural physical state and integrity (local physical integrity)
- WEV 3 The wetland's natural hydrological cycle (local hydrology)
- WEV 4 The natural interaction of the wetland with other ecosystems, including other wetlands (connectivity).

At the individual wetland scale, Wetland Tracker measures pressure and state using ecological indicators that can be applied rapidly to assess the level of disturbance to wetlands from local land use. The method can be used at multiple scales and across time, allowing changes in the condition of natural freshwater wetlands to be tracked.

There are three or more indicators for each of four pressure classes comprising the overall pressure index, plus two or more state indicators of each of four wetland environmental values, comprising the overall state index. Together, these indices of pressure and state make up the WT rapid assessment method for assessing the condition of freshwater wetlands in the GBRCA (see Figure 5). In all WT assesses 14 indicators of pressure and ten of state. Both pressure and state indices have a mix of desktop and field indicators. Indicators are assessed at different scales: the wetland itself along with its 200 m buffer (wetland scale), and

for spatial indicators, the area within 1 km or 5km of the wetland boundary. The next section gives more information about the choice of wetland buffer widths for WT assessments.

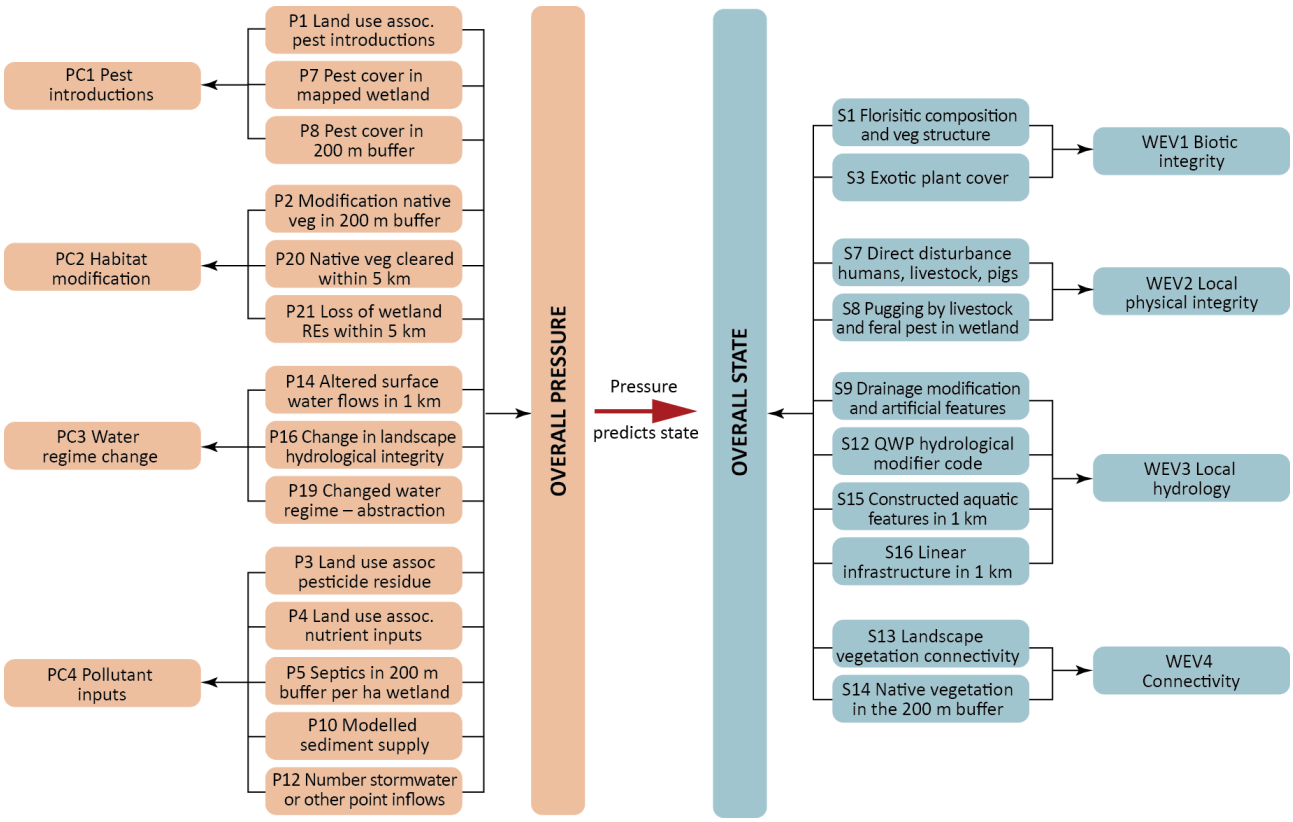

Figure 5 Structure of Wetland Tracker rapid assessment method, showing individual indicators (14 pressure, 10 state), sub-indices (4 pressure, 4 state) and overall index scores (pressure and state). Index scores are calculated independently from sub-index scores.

Since the cycle of wet and dry phases of a wetland is highly variable both within and between wetlands, Wetland Tracker assesses wetland condition without using the direct indicators of water quality or wetland fauna populations. (Direct indicators of water quality and fauna populations are used in validation research studies.) Buffer zone and wetland vegetation is assessed regardless of whether the wetland is in a wet or dry phase. The GBR wetland condition monitoring program includes a literature review (Vandergragt et al 2022, Part 4) providing the rationale for each of the individual indicators and sub-indices as valid measures of anthropogenic pressure on wetlands and the state of wetland values. The WT indicators are summarised in Table 2.

The data collection methods are detailed in the GBRCA wetland condition monitoring program Wetland Tracker Parts 2 and 3: desktop and field guides respectively (Sutcliffe and Vandergragt 2022, Johns et al 2022).

Table 2 Wetland Tracker indicators of pressure and state, by sub-index

Pressure sub-index (Pressure Class)	Wetland Tracker pressure indicators	Indicator type
PC1 Pest introductions	Land use associated with the introduction or perpetuation of pest species	Desktop
PC 1 Pest introductions	Plant pest cover in the mapped wetland	Field
PC 1 Pest introductions	Plant pest cover in the 200 m buffer	Field
PC 2 Habitat modification	Modification of native vegetation in the 200 m buffer	Desktop Field verified
PC 2 Habitat modification	Native vegetation cleared within 5 km of the wetland	Desktop
PC 2 Habitat modification	Loss of wetland regional ecosystems within 5 km of the wetland	Desktop
PC 3 Changes to water regime	Altered surface water flow due to vegetation cleared	Desktop
PC 3 Changes to water regime	Change in landscape hydrological integrity	Desktop
PC 3 Changes to water regime	Abstraction (water taken out for use) or consumption by livestock or feral animals	Field
PC 4 Inputs	Land use associated with pesticide residue inputs	Desktop
PC 4 Inputs	Land use associated with nutrient inputs	Desktop
PC 4 Inputs	Number of septic systems within 200 m of the wetland, per ha of mapped wetland	Desktop Field verified
PC 4 Input	Sediment supply (modelled, GBR)	Desktop
PC 4 Input	Number of stormwater or other point inflows per hectare of wetland	Field
State sub-index (Wetland Environmental Value)	**Wetland Tracker state indicators**	
WEV 1 Biotic integrity	Floristic composition and vegetation structure	Field
WEV 1 Biotic integrity	Exotic plant cover	Field
WEV 2 Local physical integrity	Direct disturbance by humans, livestock or feral pests physically impacting soil	Field
WEV 2 Local physical integrity	Soil surface deformation from livestock or feral pests in the mapped wetland	Field
WEV 3 Local hydrology	Drainage modifications and artificial structures altering natural surface flows	Field
WEV 3 Local hydrology	QWP hydrological modifier code for the mapped wetland	Desktop Field verified
WEV 3 Local hydrology	Modified and artificial wetlands	Desktop
WEV 3 Local hydrology	Altered surface flow due to linear transport infrastructure	Desktop
WEV 4 Connectivity	Landscape vegetation connectivity	Desktop
WEV 4 Connectivity	Native vegetation in the 200 m buffer	Desktop Field verified

Wetland Tracker buffer zones

Wetland Tracker uses three buffer zone widths to define the areas of interest (AOIs) for its indicators. These are 200 m, 1 km and 5 km. These areas are delineated in relation to mapped wetland boundaries derived from the Queensland Wetland dataset (Queensland Environment Protection Agency 2005). For example, the 200 m buffer is the area within 200 m of a wetland's mapped boundary. These buffer areas encompass but do not include the wetland itself, although for many Wetland Tracker indicators the area of interest is the mapped wetland *plus* its buffer.

The **200 m buffer** serves as a surrogate for the wetland support area (Queensland Department of Environment and Resource Management 2011), that is…

> the area adjacent to or connected to a wetland that helps to support the wetland and its associated wetland environmental values. This area does not protect the wetland from external threats. It is part of the core area on which the wetland and associated WEVs depend (p. 7).

The Queensland wetland buffer guidelines include a detailed method for delineating the wetland support area of individual wetlands, however that method is not suitable for a monitoring program based on *rapid* assessment. The 200 m buffer is an area that would encompass the wetland support area and allow for the assessment of its wetland environmental values without corresponding exactly to it. Because the 200 m buffer is delineated in relation to a feature in a well-established dataset, it is highly repeatable among assessors, whereas delineating a wetland support area involves matters of judgement, hence the result will vary among assessors.

Similarly, the **1km buffer** is a surrogate for a wetland's localised watershed. Within the GRBCA, and other geographical areas where WT could be used, exact watershed data is often not available. The 1 km buffer was chosen as an area that could encompass a wetland's water shed and allow for assessment of its environmental values without necessarily corresponding exactly to it.

The **5km** buffer recognises that the condition of wetlands can depend on ecological, hydrological and land use driven processes occurring at a broader scale than 200 m or 1 km. It forms part of the area of interest for indicators of wetland connectivity.

The relationships between the condition of buffer zones at the selected scales and the biological condition of wetlands is well established. Information supporting the use of these buffers can be found in the Wetland Tracker indicator literature review (Part 4 of Vandergragt et al 2022).

Scoring and Analysis

Scoring

Indicators are scored on ordinal scales, with scoring scales ranging from one (least pressure or least disturbed state) to five (greatest pressure or most disturbed state). The sub-indices are assessed with varying numbers of indicators per sub-index (refer to Table 2).

Aggregating indicator scores

The overall index and sub-index scores are calculated independently. This acknowledges that multiple pressures impact multiple wetland environmental values, individually or in interaction. Also, calculating index scores directly from indicators equalises the indicators' contribution on the overall index scores (overall pressure and overall state). By adding weights to indicators as a score calibration step, overall (index) scores can be adjusted, if needed, to emphasise the importance of some indicators over others.

Boosting

After average scores are calculated for indices and sub-indices, these aggregated Wetland Tracker scores are boosted, following the method established by Clayton et al. (2006) and Turpie et al. (2002), to ensure that ecologically significant outlying indicator scores are not de-emphasised in the process of averaging. To boost sub-index scores, first determine the highest-scored among the indicators for that sub-index. This represents the worst score or most disturbed condition among the indicators. This highest score is added to the *average* of all indicators for that sub-index and the result divided by two (see formulae below).

The boost for the overall index scores (overall pressure and overall state) is obtained by averaging the highest scores (most disturbed condition/worst score) from each of the four sub-indices (PCs or WEVs), adding this result to the average indicator score and dividing by two.

Formulae for calculating Wetland Tracker overall index and sub-index scores are as follows:

For **Pressure Class scores**, the boost factor is the highest or MAX score of any indicator in that PC e.g.

PC1 score = (Average of scores of all PC1 indicators) + (MAX score for a PC1 indicator)/2

PC2 score = (Average of scores of all PC2 indicators) + (MAX score for a PC2 indicator)/2

… and so on

For **Overall Pressure score**, the boost factor is the average of the boost factors for the four PCs:

$$\textit{OVERALL PRESSURE} = \frac{\textit{(Average of scores of all PRESSURE indicators)} + \textit{(}\Sigma\textit{(MAX PC scores)/4)}}{2}$$

For **Wetland Environmental Value** (WEV) scores, the boost factor is the highest or MAX score of any indicator in that WEV e.g.

WEV1 score = (Average of scores of all WEV1 indicators) + (MAX score for a WEV1 indicator)/2

WEV2 score = (Average of scores of all WEV2 indicators) + (MAX score for a WEV2 indicator)/2

… and so on

For **Overall State score**, the boost factor is the average of the boost factors for the four WEVs:

$$\textit{OVERALL STATE} = \frac{\textit{(Average of scores of all STATE indicators)} + \textit{(}\Sigma\textit{(MAX WEV scores)/4)}}{2}$$

The resulting overall index and sub-index scores all range from one to five on a pseudo-interval scale with decimal values.

At all levels (indicator, sub-index and index), Wetland Tracker scores can be used to produce individual wetland report cards or averaged across a number of wetlands in a sample to give summary statistics for that sample. The program uses decimal scores in data analyses to measure status, change and trend in wetland condition, both GBR-wide and at the regional scale. Averaged scores are converted to a scale of A to E for biennial Reef Report cards produced under the Reef 2050 Water Quality Improvement Plan.

Power to detect change

Precision criteria were set for the sensitivity of Wetland Tracker to detect change in average overall condition of wetlands, so the necessary sample size for the GBR-wide wetland condition monitoring program could be determined. This work was done using WT Version 1 scoring methods which had a 13-point ordinal scoring scale for overall pressure and overall state. To meet the criteria, a sample size was sought that would yield a power of 80 percent for a difference of one point on the 13-point scale (with alpha set at 0.05).

In the 2014 pilot study (Tilden et al. 2015), 27 wetlands in the GBR-wide freshwater wetland population were assessed once using WT Version 1. To get data from a second 'assessment', scenarios of possible changes in wetlands between two consecutive years were generated for each indicator, then basic Montecarlo methods were used to generate sets of hypothetical year-two data. For each set of differences between year one (pilot data) and year two (hypothetical data) the chosen precision criteria were used to calculate sample size (for a detectable difference of one point with alpha at 0.05 and power equal to 0.80). The most conservative estimate yielded by this method was that 39 wetlands would be needed to meet the precision criteria. Consequently, a sample size of 40 *per year* was chosen. Table 1 shows how a total of 100 randomly selected wetlands was assessed in 5 panels of 20 using an augmented serially alternating design that allowed 40 wetlands to be assessed each year.

QA/QC

Wetland Tracker assessment data go through multiple stages of quality assurance and control checks before analysis and reporting.

Desktop assessment indicator scores are allocated based on numerical analysis of data from time series spatial datasets. These datasets are sourced from Queensland Government and Australian Government and are checked at the start of each assessment year, to ensure that the most up to date version is used. Data is verified where possible by manually cross-checking against the most recent aerial imagery. Detected errors are corrected where needed. Wetland mapping boundaries are checked for accuracy before use and submitted to the Queensland Herbarium Wetland Mapping team for review and updates if needed. Python scripts automate all routine spatial analyses and associated indicator score allocation, eliminating the potential for most manual handling errors during the scoring processes. A targeted selection of scores is manually cross-checked, to ensure no errors are present in the scripts or input datasets used. For repeat assessments, scores are also checked against the previous scores, to see if they have changed between assessments. Where changes are detected, the source data are then checked to ensure these are based on real world changes (not a mapping error).

Field assessment workbooks are typically completed on an electronic tablet, with drop-down options and in-built data validation settings ensuring the indicator scores allocated by field staff are formatted consistently and within the range applicable for each indicator. If a paper workbook is used, the data are later entered electronically, then cross-checked in case of transcription errors. All scores are supported by workbook evidence notes and/or photographs recorded by the assessor and these are used in post-field checks, to ensure that indicator scores are consistent with the evidence observed and that indicator scoring criteria are being applied consistently. Each field workbook is self-checked for completeness by the field team on the day of assessment and emailed to the office for backup. Each workbook is then independently cross-checked by another experienced field assessor. Fields are provided in the electronic field workbooks for recording QA cross-check status, and details of any QA issues and follow up required. All paper workbooks are scanned and filed.

In the field, all percentage cover estimates required for indicator scoring (e.g. exotic plant cover) are averaged across assessors, with assessments conducted by a team of at least two field staff working together. Pre-assessment field calibration exercises are performed with field staff at the start of each field season, to ensure consistency in cover definitions and estimates between staff. Field staff are also rotated regularly between teams, to facilitate ongoing calibration and cross-checking of field methods between all staff during the field season.

Some field indicator scores depend on plant species identification. All staff have training and experience in plant identification. Where uncertain of species in the field, reference specimens are collected and sent to the Queensland Herbarium for identification before the indicator score is finalised.

Data management

Desktop assessment data sources, which are clipped to areas of interest and processed as described in the desktop methods guide, are stored in an Esri file geodatabase. Copies of original data sources are backed up in their original unedited state for future reference.

The field assessment data for each wetland is stored in an individual electronic field workbook (MS Excel). The original field workbooks (prior to cross-checking) are backed up and archived in read-only format, in their original unedited state, for future reference. Editable copies of these files are used for QA cross-checks and all subsequent data management steps, with any data clean-up performed on the copy, rather than the original.

Once all field and desktop indicator scores have been finalised and QAQC is complete for all wetlands assessed in the survey year, these data are aggregated from their source files electronically. For the desktop assessment data, all indicator scores, supporting evidence notes and QAQC check status information are exported from ArcGIS, into a master file in .csv format. For the field assessment data, the indicator scores, supporting evidence notes and QAQC check status information for each wetland is extracted from the individual wetland field workbook files and compiled into .csv format master files, containing data from all wetlands, by running a set of R (R Core Team 2020) data compilation scripts. Automation of these field and desktop data compilation steps has helped eliminate many opportunities for manual transcription errors. The compiled master files are checked carefully to ensure that all data sets are complete and correct. Then the contents of the master files are uploaded into the Wetland Tracker scores database (MS Access) for storage with data from previous monitoring years.

To facilitate data analysis, the Wetland Tracker scores database has in-built data validation settings, so all uploaded data are consistent in format between years. Summary statistics, graphs and statistical test results for reporting are produced by running R code scripts on score data exported from the Wetland Tracker scores database. These include standardised R scripts, used to ensure all aggregated overall pressure, overall state and individual pressure and state sub-index scores are calculated consistently.

A copy of the data set used to produce the wetland condition scores and grades for each Reef 2050 Water Quality Report Card, and the methods used to calculate them, are archived in the Paddock to Reef's Science Knowledge and Information Provision (SKIP) data archive after submission of each report. SKIP is a data management tool developed and maintained by the Department of Natural Resources, Mines and Energy to support the Paddock to Reef program.

Conclusion

The Paddock to Reef Wetland Condition Monitoring Program reports against Reef 2050 targets and objectives for *Improvement in the condition of wetlands* by tracking freshwater floodplain wetland condition and its trend in river catchments flowing into the Great Barrier Reef lagoon. Reports on wetland condition are produced every two years and results are included in the annual Reef 2050 Water Quality Reef Report cards produced by the Australian and Queensland Governments: https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card.

Wetland Tracker is a rapid assessment method, developed for the Wetland Condition Monitoring Program to measure the condition of 'natural' freshwater wetlands (palustrine and lacustrine) in the GBRCA. The diagram in Appendix 1 summarises the Wetland Tracker assessment workflow, including desktop assessment, field assessment (and post-assessment) and data processing.

References

Adame MF, Arthington, AH, Waltham N, Hasan S, Selles A and Ronan M 2019, 'Managing threats and restoring wetlands within catchments of the Great Barrier Reef, Australia', *Aquatic Conservation: Marine and Freshwater Ecosystems*, vol. 29, no. 5, pp. 829–839.

Australian and Queensland governments 2016, *Wetland condition results Reef water quality report card 2016*, accessed September 21, 2020, from <https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0025/46168/report-card-2016-wetland-condition-results.pdf>.

Australian and Queensland governments 2018, *Paddock to Reef Integrated Monitoring. Modelling and Reporting Program: Program Design 2018 – 2022*, accessed from https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0026/47249/paddock-to-reef-program-design.pdf

Australian and Queensland governments 2019, *Wetland Condition Results Reef Water Quality Report Card 2017 and 2018*, accessed from <https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0028/82909/report-card-2017-2018-results-wetland-condition.pdf>.

Australian Government 2018, 'Position statement: Coastal ecosystems (Document no. 100452)', accessed July 10, 2020, from <http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/3414/1/v0-Position-Statement-Coastal-Ecosystems.pdf>.

Clayton PD, Fielder DP, Howell S and Hill CJ 2006, *Aquatic Biodiversity Assessment and Mapping Method (AquaBAMM)*: *a conservation values assessment tool for wetlands with trial application in the Burnett River catchment*. Environmental Protection Agency, Brisbane.

Commonwealth of Australia 2018, *Reef 2050 Long-Term Sustainability Plan (revised)*, accessed from <file:///C:/Users/vanderm/Downloads/reef-2050-long-term-sustainability-plan-2018.pdf>.

Department of Environment and Resource Management 2011, *Queensland Wetland Buffer Planning Guideline*, 54 pp, Queensland Wetlands Program, Brisbane Queensland.

Department of Science, Information Technology and Innovation 2015, *A landscape hazard assessment for wetlands in the Great Barrier Reef catchment*, Brisbane, Australia, accessed from <https://wetlandinfo.des.qld.gov.au/resources/static/pdf/resources/reports/hazard-assessment-gbr-final.pdf>.

Johns C, Tilden JD, Sutcliffe T and Vandergragt ML 2022, *Wetland Tracker: Great Barrier Reef catchment condition monitoring program, Field Methods Guide and workbook*. Department of Environment and Science, Brisbane, Queensland.

Joyal LA, McCollough M and Hunter Jr. ML 2001, 'Landscape Ecology Approaches to Wetland Species Conservation: a Case Study of Two Turtle Species in Southern Maine', *Conservation Biology*, vol. 15, no. 6, pp. 1755–1762, accessed from <https://doi.org/10.1046/j.1523-1739.2001.98574.x>.

Keddy PA, Fraser LH, Solomeshch AI, Junk WJ, Campbell DR, Arroyo MTK and Alho CJR 2009, 'Wet and Wonderful: The World's Largest Wetlands Are Conservation Priorities', *BioScience*, vol. 59, no. 1, pp. 39–51.

Larsen DP, Kincaid TM, Jacobs SE and Urquhart NS 2001, 'Designs for evaluating local and regional scale trends', *BioScience*, vol. 51, no. 12, pp. 1069–1078.

Lehtinen RM, Galatowitsch SM and Tester JR 1999, *Consequences of habitat loss and fragmentation for wetland amphibian assemblages.*

Queensland Government: Environmental Protection Agency 2005, 'Wetland Mapping and Classification Methodology – Overall Framework – A Method to Provide Baseline Mapping and Classification for Wetlands in Queensland – Version 1.2', Queensland Government, Brisbane .

R Core Team (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org**/**.

Rooney RC, Bayley SE, Creed IF and Wilson MJ 2012, 'The accuracy of land cover-based wetland assessments is influenced by landscape extent', *Landscape Ecology*, vol. 27, no. 9, pp. 1321–1335.

State of Queensland 2008, 'Environmental Protection Regulation 2008', accessed September 16, 2020, from <https://www.legislation.qld.gov.au/view/pdf/inforce/2017-07-01/sl-2008-0370>.

State of Queensland 2018, *Reef 2050 Water Quality Improvement Plan 2017–2022*, accessed from <https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0017/46115/reef-2050-water-quality-improvement-plan-2017-22.pdf>.

Steen DA, Gibbs JP, Buhlmann KA, Carr JL, Compton BW, Congdon JD, Doody JS, Godwin JC, Holcomb KL, Jackson DR, Janzen FJ, Johnso, G, Jones MT, Lamer JT, Langen TA, Plummer MV, Rowe JW, Saumure RA, Tucker JK and Wilson DS 2012, 'Terrestrial habitat requirements of nesting freshwater turtles', *Biological Conservation*, vol. 150, no. 1, pp. 121–128, accessed from <http://www.sciencedirect.com/science/article/pii/S0006320712001553>.

Stevens DL and Olsen AR 2004, 'Spatially balanced sampling of natural resources', *Journal of the American Statistical Association*, vol. 99, pp. 262–278.

Sutcliffe T and Vandergragt ML 2022, *Wetland Tracker: Great Barrier Reef catchment condition monitoring program, Desktop Methods Guide*. Department of Environment and Science, Brisbane, Queensland.

The State of Queensland and Commonwealth of Australia 2003, *Reef Water Quality Protection Plan; for catchments adjacent to the Great Barrier Reef World Heritage Area*, Queensland Department of Premier and Cabinet, Brisbane.

The State of Queensland (Department of the Premier and Cabinet) 2009, Reef Water Quality Protection Plan Secretariat, September 2009, 100 George Street, Brisbane Qld, 4000.

The State of Queensland 2013, *Reef Water Quality Protection Plan 2013. Securing the health and resilience of Great Barrier Reef World Heritage Area and adjacent catchments*. Brisbane (QLD), Australia: Reef Water Quality Protection Plan Secretariat, the State of Queensland.

Tilden J and Vandergragt M 2017, *The Great Barrier Reef wetland monitoring program Analysis methods*, Queensland Department of Science, Innovation Technology and Innovation, Brisbane.

Tilden J, Borschmann G, Walsh C, Mayger B and Vandergragt M 2015, *Great Barrier Reef catchments wetland monitoring pilot study: Assessment methods and monitoring design*, Department of Science Information Technology and Innovation, Queensland. Brisbane

Turpie JK, Adams JB, Joubert A, Harrison TD, Colloty BM, Maree RC, Whitfield AK, Wooldridge TH, Lamberth SJ, Taljaard S and Van Niekerk L 2002, 'Assessment of the conservation priority status of South African estuaries for use in management and water allocation', *Water SA*, vol. 28, no. 2, pp. 191–206.

Vandergragt ML, Tilden JD, Johns C, Sutcliffe T, Pulman L, Ellison, T and Huurdeman V, 2022, *Wetland Tracker: a rapid method for assessing the condition of freshwater wetlands in Queensland's Great Barrier Reef catchment area*. Department of Environment and Science, Brisbane, Queensland.

Glossary

Alpha	The probability of rejecting a null hypothesis when that null hypothesis is true
Anthropogenic	Caused by human activity
Attribute	In an ecosystem context, an attribute is a biological, physical or chemical characteristic or feature inherent to an ecosystem. Attributes are aspects of ecosystems that can be evaluated, such as water quality and ground cover.
Baseline	Starting point used for comparisons between assessments to detect a change or trend in wetland condition over time
Catchment	A drainage basin. An area of land from which runoff collects to a specific zone, usually defined by a wet area such as a wetland, river, lagoon or bay.
Desktop	Desktop assessment methods use maps, aerial images and remotely sensed geographical information to assess the condition of wetlands without going into the field
Exotic plant	For Wetland Tracker assessments, exotic plants include any plants not indigenous to the area of interest, including cultivated crop and pasture species originating elsewhere, plus any plants listed in the current Census of the Queensland flora as: (a) Naturalised in QLD or (b) Naturalised for the pastoral district encompassing the area of interest.
Floodplain	Land adjacent to a waterway that is naturally subject to occasional or periodic flooding. Floodplains can be narrow, or wide and flat with steeper sides at the edges.
Geodatabase	A collection of geographic datasets of various types held in a common file system folder
GRTS	Generalised Random Tessellation Stratification. A method for generating a spatially balanced random sampling of geographically defined areas, lines or points.
Index	A compound measure that aggregates multiple indicators. Also sub-index.
Indicator	A measurable entity or process whose existence in an area is strongly correlated with specific environmental conditions that are desired to be measured
Integrity	The ability of a system to maintain its organisation in the face of changing environmental conditions
Lacustrine	Lake-like; referring to large, open, water-dominated systems
Palustrine	Swamp-like; primarily vegetated, non-channel environments
Pest plant	A weed; an exotic plant, including any plant not indigenous to the area of interest, that reduces the overall quality and function of a natural wetland ecosystem. Pest plants can include cultivated crop and pasture species.
Pressure	Human activities directly affecting the environment
Pseudo-interval	A pseudo-interval scale is a scale of lineally ordered decimal values for which the relationships between values are not uniform or consistent compared with a true interval scale but which carry more information than an ordinal scale.

Rapid assessment	An assessment giving a broad view of a subject at a particular time. A rapid assessment is conducted in the shortest time frame that will produce reliable and valid results for its intended purpose.
State	The actual condition of an ecosystem and its components established in a certain area at a specific time that can be quantitatively-qualitatively described based on physical, biological and chemical characteristics
Wetland buffer zone	The transition zone between the wetland and the surrounding land use. Well-managed buffers support the functions and values of wetlands (Department of Environment and Resource Management 2011).
Wetland condition	Ecosystem condition is the overall quality of an ecosystem asset (United Nations et al., 2012). Wetland Tracker assesses two aspects of wetland quality within a Driver–Pressure–State–Impact–Response conceptual framework – the amount of anthropogenic pressure on a wetland and the state of its environmental values.
Wetland Environmental Values	Wetland Environmental Values (WEVs) are based on the physical and biological characteristics associated with a particular wetland. WEVs *support* the wetland's ecological processes and *underpin* its ecological, social and economic benefits. These benefits are sometimes referred to as ecosystem goods and services.

Appendix 1

Wetland Tracker assessment workflow

Desktop indicators → Field indicators → Post-assessment

DESKTOP ASSESSMENT (OFFICE)

ArcGIS ArcMap 10.3 esri

GBR-wide spatial data: (wetland mapping, land use, clearing, historical imagery, floodplain hydrology, modelled sediment erosion rates, etc)

Individual wetland-scale mapping, data analysis and generation, and tabulation of indicator scores. (Score confidence ratings also assigned based on spatial data quality.)

Final QA/QC checks – desktop scores

Scores now finalised – all desktop indicators

upload

Upload to Scores database

FIELD ASSESSMENT (ONSITE)

Tablet data entry

Excel datasheet workbooks for field-scored (and ground-truthed desktop) indicators

Raw data checked then emailed to office as back up

Ground-truth desktop scores and mapping (for selected wetland-scale indicators)

Potential pest and exotic plant specimens collected for scoring some indicators

POST-FIELD ASSESSMENT (OFFICE)

Original raw data archived

COPY

Final QA/QC checks – field scores

Scores finalised for plant-based indicators

Plant ID completed

Scores now finalised for all field indicators

Run code to extract and collate all field score data from individual wetland files

Upload to Scores database

upload

DATA PROCESSING

upload

Scores database

Query and export data

Run code to generate outputs for reporting:
- Aggregated pressure and state scores
- Graphs and summary statistics

Data analysis

Reporting

Report data archived