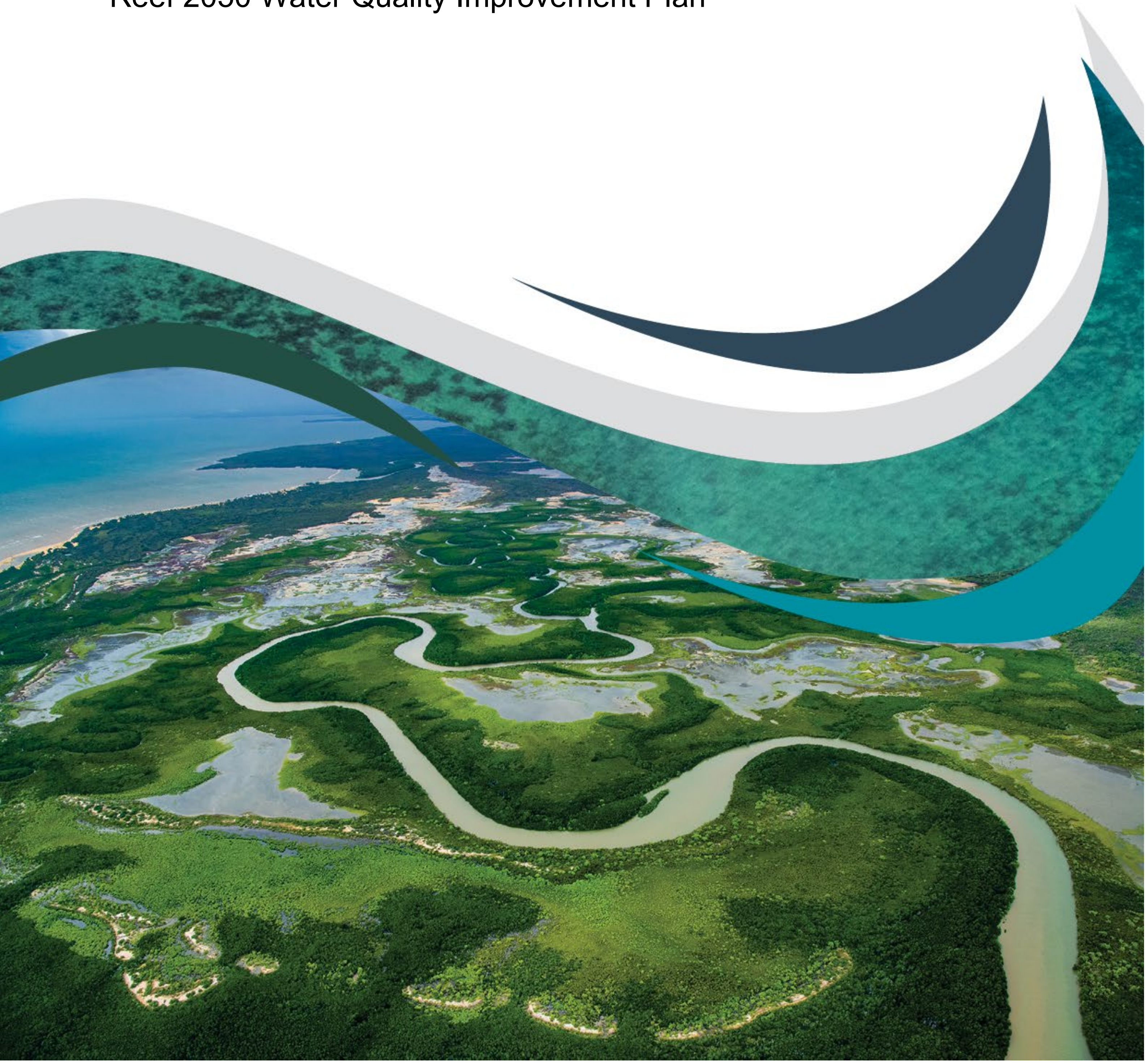
Australian Government

Queensland Government

Wetland Condition Methods

Reef Water Quality Report Card 2021 and 2022

Reef 2050 Water Quality Improvement Plan



Citation

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CONTENTS

Catchment Condition: Wetland condition monitoring methods

This report describes methods used to produce the Reef Water Quality Report Card 2021 and 2022 wetland condition results. Within the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program, the Wetland Condition Monitoring Program (the Program) tracks progress towards the improved wetland condition objective of the Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP).

The Program's initial design is described in Tilden et al. (2015) and the Program's analysis methods up to 2020 inclusive are outlined in Tilden and Vandergragt (2017).

Baseline data for pressure on wetland values and the state of wetland values were reported in 2016. Wetland condition (anthropogenic pressure on wetlands and state of environmental values) was reported for 2018, along with an analysis of change between 2016 and 2018, including power to detect change between the two years. Change in wetland condition between 2018 and 2020 and between the 2016 baseline study and 2020 were reported in 2020 along with differences between panel 1 and panel 4 data gathered in 2020. Panels are groups of wetlands with the same schedule of repeat assessments across years.

Since 2020, sampling effort has intensified to enable reporting by Natural Resource Management (NRM) region, done for the first time in 2022, replacing the previous reporting by land use type (conservation area vs non-conservation area). To date, 'sampling-effort intensification' (i.e. increasing the number of wetlands sampled) has commenced in the Wet Tropics, Burdekin, Fitzroy and Burnett Mary NRM regions.

The Program's data analysis methods have also been updated since the last report, to state of the art methods that can deal with nonresponse (see below) and enable reporting on change over time (trend) in wetland condition. Trend is reported on for the first time in the 2022 report card, replacing tests of change between reporting years. The methods used in 2022 are described in more detail below.

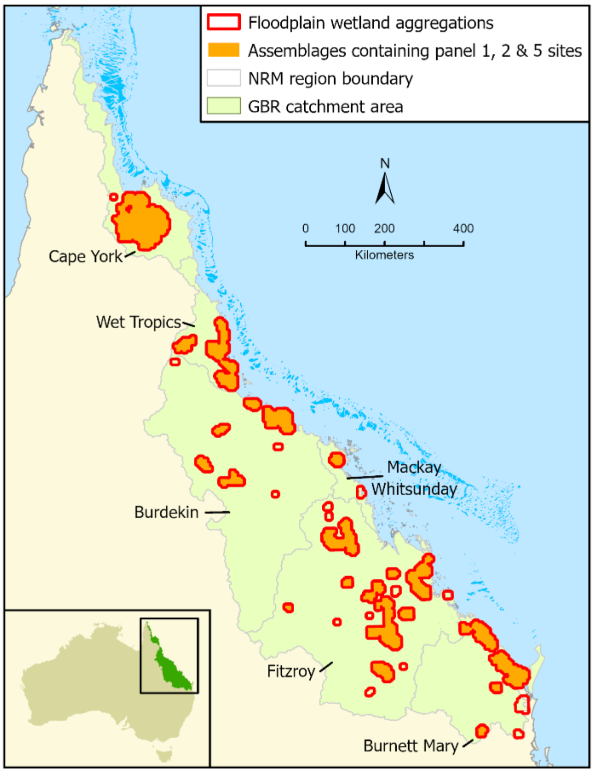

Figure 1. High density wetland aggregations and the wetlands assessed since last reported.

Program design and data analysis

Progress with the monitoring design

The Program focuses on the subpopulation of natural, freshwater floodplain wetlands in high density aggregations in the Great Barrier Reef catchment area (GBRCA) (Figure 1). A spatially balanced random sample of wetlands from the subpopulation, selected using the Generalised Randomised Tessellation Stratified (GRTS) method, is surveyed according to an augmented serially alternating panel design that repeats every four years (Table 1).

Initially, one panel of 20 wetlands was assessed every year and four panels of 20 were assessed in alternate years. In 2020, the number of wetlands sampled in each NRM region started to increase (as part of the 'sampling-effort intensification') to enable reporting at the NRM region scale, in addition to GBRCA-wide reporting. By the end of 2025, when sampling-effort intensification for the Wet Tropics, Burdekin, Fitzroy and Burnett Mary NRM regions is complete, the total sample size for the Program will be ~240 wetlands.

Table 1. Panel design for the Great Barrier Reef catchments wetland monitoring program.*

Panel	Year									
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
1	20	20	20	20	28	36	50	50	50	50
2	20		20				44			
3		20		20				49		
4					27				49	
5						32				46
Year total	40	40	40	40	55	68	94	99	99	96
Total sample	**40**	**60**	**60**	**60**	**96**	**136**	**174**	**203**	**225**	**239**

*Some wetland sample sizes per panel differ slightly from the planned size due to factors such as attrition and replacement. For example, panel 1 originally comprised 21 wetlands, but only 19 of these have been assessed repeatedly; two have dropped out and been replaced. Since 2020, more wetlands have been added to panels as part of the NRM-region sampling-effort intensification process.

Data collection

Wetland assessment data are collected in two ways:

- Desk top analysis based on imagery and spatial data using a range of data sets for 15 indicators primarily related to pressure
- Field-based data collection methods for nine indicators primarily related to state.

Data gathered from wetlands in all six NRM regions (Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy, Burnett Mary) contribute to reporting on the status of and trend in wetland condition at the GBRCA-wide scale. The 2022 GBRCA-wide assessment of status focuses on 2022 data from wetlands across all six NRM regions (Table 1). The 2022 GBRCA-wide assessment of change over time (trend) is based on data gathered annually since 2016 from all six NRM regions.

The 2022 assessments of status in NRM-regions focus on 2022 data from wetlands in individual NRM regions. Status at the NRM region scale is only reported for the four NRM regions in which sampling-effort intensification has commenced: the Wet Tropics, Burdekin, Fitzroy and Burnett Mary. Sampling-effort intensification has not occurred in Mackay Whitsunday or Cape York NRM regions, hence why they do not have NRM region-scale status assessments yet. The Mackay Whitsunday region is small, and this has constrained the ability to increase the number of wetlands sampled there. Cape York is logistically challenging to sample, which constrains the ability to increase the number of wetlands sampled there[1].

Trend is not reported at the NRM region scale, because there are three or fewer years only of sampling-effort intensification data available to date, which is insufficient for trend detection (Starcevich et al. 2018a; White 2019).

Wetland Tracker indices

For each wetland, the condition assessment tool, Wetland Tracker (WT), produces overall scores for anthropogenic **pressure** on wetlands and the **state** of wetland environmental values, plus scores for

[1] Note also that in 2020 and 2021, field assessments could not be conducted in the Cape York NRM region due to COVID19 restrictions. Scores for Cape York field indicators in 2020 and 2021 were imputed based on data from previous years.

four 'pressure class' (PC) subindices of pressure, and four 'wetland environmental value' (WEV) subindices of state:

- PC1: pest introductions (e.g. plant pests and animals changing a wetland)
- PC2: habitat modification (e.g. loss of natural vegetation around a wetland)
- PC3: change to water regime (e.g. natural wetland water levels being altered by a dam or levee)
- PC4: pollutant inputs (e.g. land use associated with the likelihood of sediment and nutrients going into a wetland)
- WEV1: biotic integrity (the biological health and diversity of a wetland)
- WEV2: local physical integrity (a wetland's natural physical state and integrity)
- WEV3: local hydrology (a wetland's natural hydrological cycle)
- WEV4: connectivity (the natural interaction of a wetland with other ecosystems, including other wetlands).

Each subindex comprises two or more individual indicators.

Scoring scales for individual wetland and GBRCA-wide assessments

Generating the wetland condition scores for sampled wetlands, for each of the **pressure** and **state** subindices and overall indices, is a four step process, as follows:

Step 1. Scores per indicator: Individual indicators of pressure and state are assessed on ordinal scales with integer scores ranging from one to five**:**

Condition	**Very low pressure/Very good state**	**Low pressure/ Good state**	**Moderate pressure/ Moderate state**	**High pressure/ Poor state**	**Very high pressure/ Very poor state**
Indicator scores (individual wetlands)	1	2	3	4	5

Step 2. Aggregation of indicator scores into subindex scores: The indicator scores are aggregated into numeric subindex scores between one to five, inclusive, for each of the eight subindices per wetland.

Independently, the indicator scores are aggregated to generate an overall numeric pressure and overall numeric state score per wetland, which can take on values between one to five, inclusive.

Step 3. GBRCA wide and NRM region scores: Generating scores at the GBRCA-wide and NRM region scales follows a new process that uses model-assisted methods to account for non-response bias and frame error (see below) and assess change over time (trend) in wetland condtion. GBRCA-wide scale scores are no longer generated by averageing the values from individual wetlands, because this does not adequately account for nonresponse bias (see below).

The resulting GBRCA-wide and NRM-region scale numeric scores for the eight subindices and overall state and pressure indices range in value from one to five, inclusive.

Step 4. Report card grades: All subindex and index scores are reported as decimal values ranging from one to five. Breakpoints (cutoffs) for report card grades are as follows:

Index and subindex cutoffs	<1.50	≥1.50 to <2.50	≥2.50 to <3.50	≥3.50 to <4.50	≥4.50
Report Card grade	A	B	C	D	E

Non-response bias

The 2016 Reef wetland condition report established that there was non-response bias in the Program's wetland assessment data.

Most wetlands that are approached for inclusion in the Program can be sampled and these are known as 'responding' wetlands. 'Nonresponse' occurs when a wetland cannot be sampled for some reason. Reasons for nonresponse are recorded annually and include: site inaccessibility (e.g., due to geography); absence of landholder contact information; landholder declining to grant access for sampling; landholder postponement of access for sampling; no reply from landholder. When this occurs, the nonresponding wetland is replaced from the randomly generated sample list by the next wetland in the list from the same NRM region that *can* be sampled (making the replacement wetland a responding wetland). As a result, the sample of wetlands on which data are collected represents the subpopulation of responding wetlands rather than wetlands from the entire target subpopulation. This represents a potential source of what is known as nonresponse bias.

To account for the non-response bias, a state-of-the-art multiple imputation method (Little and Rubin 2019) is used to impute subindex and overall index scores for non-responding wetlands, NRM region by NRM region. This is because analysis performed on data gathered to date indicates that NRM region is the best predictor of whether a wetland will be nonresponding or responding (logistic regression analysis using the corrected Akaike Information Criterion of Burnham and Anderson 2002 and with statistical significance, alpha, set at 0.05).

Nonresponding wetlands that are inaccessible due to geography or have no contact information are treated as missing at random (MAR) and those for which landowners decline or postpone participation or do not reply, are treated as missing not at random (MNAR). Wetland condition is assumed to be related to MNAR but not MAR nonresponse, so MNAR and MAR scores are imputed differently. For each index within each NRM region, score means and variances for MAR wetlands are considered similar to those of responding wetlands, under the quasi-randomisation assumption (Oh and Scheuren 1983). So, for each NRM region, forty imputations are drawn for each MAR wetland and index from the truncated normal distribution, within the bounds of the 95% confidence interval for the responding wetland mean (Rodwell et al. 2014). For MNAR cases, scores for each index within each NRM region are assumed to be no lower than the average score observed for responding wetlands. So, for each NRM region, forty imputations are drawn for each MNAR wetland and index from the truncated half-normal distribution (Rodwell et al. 2014), within the bounds of the responding wetland mean up to the maximum score of 5.

The imputed scores for nonresponding wetlands are analysed together with scores from responding wetlands to produce estimates of status and trend in wetland condition. Analyses are conducted in R, a language and environment for statistical computing (R Core Team 2022), using the Program's GBRCATrend package (Starcevich 2022).

Frame error

Another source of bias in the data is frame error, which results when some wetlands in the list of those approached for inclusion do not actually belong to the target subpopulation of natural, freshwater floodplain wetlands in major aggregations (e.g. they might have been converted from estuarine to fresh water). Results of analysis performed on data gathered to date indicate that frame error, i.e. whether or not a wetland is a member of the target subpopulation, is best predicted by NRM region (logistic regression analysis using the corrected Akaike Information Criterion and with statistical significance, alpha, set at 0.05).

So, to account for frame error, design weights are applied within NRM regions that sum to the total number of target-subpopulation wetlands in each relevant NRM region. This ensures that the sample of wetlands in an NRM region will represent the target subpopulation of wetlands in that NRM region. Specifically, the weight for a wetland in any one NRM region and year is the inverse of the probability of its inclusion in the sample for that NRM region and year, as per the Horvitz-Thompson estimator (Horvitz and Thompson 1952; Cordy 1993).

Status of wetland condition

GBRCA-wide and NRM-region scale reporting

Annual design-based estimates of status in wetland condition for the GBRCA-wide, Wet Tropics, Burdekin, Fitzroy and Burnett Mary NRM regions were computed for each subindex and the overall pressure and state indices (Table 2).

Table 2. Pressure and state score estimates for 2022, with 95% confidence intervals in parentheses, at the GBRCA-wide and NRM-region scales. Note, all six NRM regions contribute to the GBRCA-wide results, but only four regions are reported on at the NRM-region scale.

Measure	GBRCA-wide	Wet Tropics	Burdekin	Fitzroy	Burnett Mary
State of wetlands	2.46 (2.41 – 2.52)	3.18 (3.13 – 3.23)	3.09 (3.02 – 3.15)	3.11 (3.01 – 3.22)	2.61 (2.54 – 2.68)
Biotic integrity	2.45 (2.36 – 2.53)	3.18 (3.09 – 3.27)	3.35 (3.27 – 3.43)	3.38 3.26 – 3.49)	2.50 (2.36 – 2.64)
Local physical integrity	2.91 (2.76 – 3.06)	2.79 (2.69 – 2.88)	2.98 (2.86 – 3.09)	2.96 (2.78 – 3.14)	2.07 (1.96 – 2.17)
Local hydrology	2.14 (2.07 – 2.21)	3.29 (3.21 – 3.37)	3.11 (2.97 – 3.25)	2.55 (2.35 – 2.76)	2.84 (2.71 – 2.96)
Connectivity	2.62 (2.57 – 2.66)	3.69 (3.59 – 3.80)	3.17 (3.05 – 3.29)	4.00 (3.86 – 4.13)	3.13 (3.00 – 3.25)
Pressure on wetlands	2.86 (2.81 – 2.91)	3.70 (3.66 – 3.75)	3.49 (3.43 – 3.56)	3.60 (3.53 – 3.68)	2.98 (2.89 – 3.06)
Pest introductions	3.49 (3.43 – 3.54)	4.00 (3.94 – 4.06)	4.18 (4.13 – 4.23)	4.10 (4.02 – 4.19)	3.60 (3.51 – 3.69)
Habitat modification	2.87 (2.77 – 2.98)	4.04 (3.95 – 4.12)	3.19 (3.09 – 3.28)	4.07 (3.95 – 4.20)	3.35 (3.24 – 3.45)
Water regime change	2.96 (2.92 – 3.01)	3.35 (3.30 – 3.40)	3.51 (3.44 – 3.57)	3.49 (3.35 – 3.63)	2.84 (2.71 – 2.97)
Pollutant inputs	2.34 (2.26 – 2.42)	3.63 (3.58 – 3.69)	3.29 (3.21 – 3.37)	3.09 (3.02 – 3.16)	2.37 (2.24 – 2.50)

To produce the estimates, datasets containing both the imputed-nonresponding and the observed-responding wetland scores were analysed using weighted linear regression for design-based estimates (WLRDB; Starcevich et al. 2018b), the ‘cont_analysis’ function in the spsurvey package (Dumelle et al. 2022) and the neighbourhood variance estimator (Stevens and Olsen 2003, 2004). The online Reef Water Quality Report Card 2021 and 2022 reports the status estimates only; the 95% confidence intervals for those estimates are reported in this Methods report card (Table 2).

Backcasting data to maintain comparability across seven years of monitoring

Any comparisons made in the Reef Water Quality Report Card 2021 and 2022 between scores from 2022 and previous years, and all assessments of trend, are based on scores calculated using the new methods. As such, scores provided in the online Reef Water Quality Report Card 2021 and 2022 (for 2022 and previous years) are calculated using the new analysis methods. This is made possible by backcasting scores for previous years using the new methods.

In most cases, there has been no change in previous years’ grades as a result of backcasting. The few cases where a change has occurred involve scores lying very close to the breakpoint between B and C grades. The greatest difference in score for these grade changes was 0.34, which is much smaller than 0.99, the range between the lowest and highest score possible within either a B or C grade.

The backcast scores also indicate there has been minimal change between 2020 and 2022 in the grades for pressure and state indices. Although the Pest introductions pressure subindex received a backcast 2020 grade of D, and a 2022 grade of C, the 2022 score is only 0.01 points below the D-C breakpoint. Likewise, the overall state index received a backcast 2020 grade of C, and a 2022 grade of B, but 2022 score is only 0.04 points below the C-B breakpoint.

Change over time (trend)

GBRCA-wide scale reporting

Change over time, as the annual improvement, decline or no change, in wetland condition since 2016, along with 95% confidence intervals, is estimated using a trend modelling approach. For each overall index and each subindex, trend estimates and variances are combined across imputations so that the additional variation from multiple imputation is reflected in the variance of the trend estimate.

The linear mixed effects trend model of Piepho and Ogutu (PO; Piepho and Ogutu 2002), which can include random intercept and slope effects (e.g. for NRM regions and/or wetlands), is used to provide inference and perform diagnostic checks on residuals. PO models are fitted using the 'glmmTMB' package (Brooks et al. 2017). The 'lmerTest' package (Kuznetsova et al. 2017) is used to construct 95% confidence intervals and perform Wald t-tests for trend testing.

The probability-weighted iterative generalized least squares (PWIGLS) model of Starcevich et al. (2018b), which can incorporate design weights to account for frame error, is then used to provide inference on annual trend. Using both the PO and PWGLS methods enables the effect of weighting and random effects on trend inference to be evaluated.

Statistical significance of trends is set at alpha = 0.05.

Power to detect trends using the new methods is being investigated and will increase over time as more years of data become available.

The online Reef Water Quality Report Card 2021 and 2022 reports the results of PWIGLS models only and does not report 95% confidence intervals (CI), which are reported here instead.

Since 2016, there has been no annual trend in the overall pressure on or state of freshwater floodplain wetlands in the GBRCA overall. However, an annual score increase of 0.06 (CI: 0.02 – 0.09) has been detected in the pressures associated with water regime change (PWIGLS model). There has also been an overall decline in the biotic integrity of wetlands, represented by an annual score increase of 0.08 (CI: 0.04 – 0.12) since 2016 (PWIGLS model). There has been an improvement in the local physical integrity of wetlands, represented by an annual score decrease of 0.10 (CI: 0.04 – 0.16; PWIGLS model).

Note that no trends were detected using PO models that included random effects. However, when random effects were removed, an increase in pressures associated with water regime change and a decline in the biotic integrity of wetlands was detected. These findings align with results of the PWIGLS models (that do not include random effects but do include design weights to account for frame error) for these two subindices. The trends detected using the PWIGLS and PO models should be re-evaluated as more data become available in coming years.

Data confidence

A multi-criteria analysis is used to qualitatively score the confidence in each index used in the Reef Water Quality Report Card 2021 and 2022, from low to high (Australian and Queensland Governments 2017). The approach combines expert opinion and direct measures of error for program components where available.

Wetland condition received a two-bar confidence ranking, out of 5 bars, in previous Reef Report Card wetland condition results reports. This year data confidence can be raised to three bars.

Maturity of methods (weighting = 0.5)

Score 3 out of 3

The Wetland Tracker assessment tool (current Version 2.0, used since 2019) has been independently reviewed and published. We are now also using peer-reviewed, state of the art, model-assisted analytical methods (see above) to account for frame error and nonresponse bias and to estimate status of and trend in wetland condition.

Validation (weighting = 1)

Score 2 out of 3

The assessment uses a combination of remotely sensed, ground-validated (score 2) and directly measured field survey data (score 3).

Representativeness (weighting = 1)

Score 3 out of 3

The annual sample of ≈40 wetlands has been bolstered to ≈100 wetlands since the last report, as a result of an intensification process that has increased sample sizes in the NRM reporting regions. This is an 150% increase in the annual GBRCA-wide representative sample of wetlands contributing to GBRCA-wide analysis and reporting. The increase has also enabled reporting on wetland condition at the NRM-region scale as well at the GBRCA-wide scale. Power to detect trend in condition will continue to increase over time.

Directness (weighting = 1)

Score 2 out of 3

The Wetland Tracker assessment tool (Version 2.0) uses updated indicators and simplified scoring scales that have improved the directness of reporting.

Measurement error (weighting = 1)

Score 2 out of 3

The issue described in 2018, regarding loss of data precision due to overly complex scoring scales has since been addressed through the simplification of report card scoring and grading scales in the wetland assessment tool (Version 2.0).

While it is still not possible to quantify the variance attributable to different sources of error in the data, a repeatability study was conducted in 2017 to identify sources of inter-operator variance, and versions of the assessment tool used from 2018 onward have focused on minimising this source of error variance.

Data confidence score

The average of the above scores, taking into account their individual weightings, is 2.1 out of 3. This equates to 3.5 bars on a 5-bar scale of data confidence.

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Glossary

Aggregated wetland assessment scores of state of and pressures on wetland condition: The wetland assessment method uses scores at three levels – **state** *indicators* are aggregated into four **state** *subindices* based on wetland environmental values (WEVs), and **pressure** indicators are aggregated into four **pressure class** subindices. State and pressure indicators are each aggregated into an **overall state** and an **overall pressure** index, respectively.

Augmented serially alternating design: A monitoring design consisting of a number of panels of sites (wetlands), where one panel is assessed every year (the augmented component of the design) and the remaining panels are assessed in different years on a regular and repeating schedule.

Baseline: A baseline is the initial collection of data used for comparison with data acquired subsequently. In the case of the wetland condition monitoring component of the Reef Report, baseline data were collected in 2015 and 2016 and reported in the Reef Water Quality Report Card 2016.

DPSIR framework: A causal framework for describing the interaction between society and the environment. Driver, Pressure, State, Impact, Response.

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.

Lacustrine: Lake-like; referring to large, open, water-dominated systems.

Natural, freshwater wetlands: Natural freshwater wetlands covered by the Great Barrier Reef Wetland Condition Monitoring Program comprise both lacustrine (lake) and palustrine (vegetated) wetlands. '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.

Nonresponse bias: A nonresponse bias occurs when randomly selected experimental units (wetlands) cannot be involved in a study (wetland assessment), not at random, but in ways that are meaningful to the phenomenon under study (wetland condition).

Palustrine: Swamp-like; primarily vegetated, non-channel environments.

Panel: A panel is a group of wetlands with the same schedule of repeat assessments across years.

Power (to detect a change): In statistical testing, Power = $(1 - \beta)$, where β is the probability of making a Type II error, that is, failing to detect an effect when it is present.

Pressure: Under the DPSIR framework, pressure refers to human activities directly affecting the environment.

Spatially balanced random sample: A random sample whose sample sites are more or less evenly dispersed over the extent of the population being studied.

State: Under the DPSIR framework, characteristics, at a particular time, of ecosystem processes and the organisms and habitats that define, support and/or adversely affect ecosystem environmental values.

Index/indices/subindex/subindices: The Great Barrier Reef Wetland Condition Monitoring Program assesses two indices of wetland condition, overall anthropogenic **pressure** on and overall **state** of wetland condition. Subindices of pressure are classes of pressure on wetlands (PCs), defined as: pest introductions, habitat modification, changes to water regime and pollutant input pressures. State subindices are wetland environmental values (WEVs), defined as: biotic integrity, local physical integrity, local hydrology and connectivity.

Wetland condition: Under the Great Barrier reef Wetland Condition Monitoring Program, wetland condition refers to the pressure on the natural environmental values of wetlands and the state of those values under a DPSIR conceptual framework.