Reef Water Quality Protection Plan

The Great Barrier Reef catchments wetland monitoring pilot study

Assessment methods and monitoring design

Australian Government

Queensland Government

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Main cover image: Maria Vandergragt

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1 Executive summary

The Great Barrier Reef (GBR) wetland monitoring pilot study established the foundation for a monitoring program to assess progress towards the Reef Water Quality Protection Plan (2013) target that:

> *There is no net loss of the extent, and an improvement in the ecological processes and environmental values, of natural wetlands.*

The pilot study tested the Wetland Field Assessment Tool for Monitoring (WFAT–M) and established a monitoring design for assessing progress towards the target.

The WFAT–M was confirmed as a valid index of disturbance to wetland environmental values although more work is needed to refine the tool. Baseline data gathered in 2015 and 2016 will answer outstanding questions about validity and reliability and inform further calibration of the WFAT–M if needed.

The monitoring program design covering wetlands in catchments from the Mary River in the south to the Normanby in the north was formulated. It comprises:

1. an estimated sample size to allow change in wetland values to be detected at the required level of precision. This will be confirmed or adjusted after the first round of baseline data collection;
2. a focus on a sub-population of all GBR natural freshwater floodplain wetlands in defined density 'hotspots';
3. a selected random, spatially balanced sample; and
4. a sampling design comprising panels of wetlands visited on different time schedules to maximise trend detection while also allowing for the measurement of wetland status across the sub-population.

The program is designed to allow for rapid scaling up to report for wetlands across the Great Barrier Reef catchments and by region, should resources be available in the near future.

The program is being partially implemented as a continuing pilot project under the Paddock to Reef Program. Further resources are needed for full implementation.

Image: Maria Vandergragt

2 Introduction

Wetlands play an important ecological and hydrological role in landscape function and water quality. They provide a natural filtration system and destruction of wetlands can result in increased sediment and nutrients flowing to the Great Barrier Reef.

The Reef Water Quality Protection Plan sets targets for improved water quality and land management practices and identifies actions to improve the quality of water entering the reef. Progress against these targets is detailed in the annual Great Barrier Reef Report Card. The Reef Water Quality Protection Plan 2013 wetland target is:

There is no net loss of the extent, and an improvement in the ecological processes and environmental values, of natural wetlands.

Changes in wetland extent have been included in previous report cards. The Great Barrier Reef wetland monitoring program aims to report on changes in wetland environmental values and processes of natural freshwater wetlands.

A pilot study was carried out during 2014 to establish a program for monitoring wetland values using the Wetland Field Assessment Tool for Monitoring (WFAT–M), a rapid assessment method measuring disturbance to the values of individual wetlands on a gradient from natural to highly disturbed. The aims of the pilot study were to:

1. test the operational aspects of the WFAT–M
2. trial a delivery model collaborating with natural resource management (NRM) regional groups
3. test and evaluate WFAT–M indicators
4. test the performance of the index as a whole in discriminating across the range of disturbance in GBR wetlands
5. improve the design of the ongoing monitoring program for GBR wetlands.

This report focuses on the findings about the ability of the assessment tool to discriminate across the range of disturbance and on the wetland monitoring program design.

Image: Geoff Borschmann

3 The wetland assessment tool

The GBR wetland monitoring program uses a Driver–Pressure–State–Impact–Response conceptual framework that can be applied at three levels of assessment: 1) landscape scale studies, 2) rapid wetland-specific assessments and 3) detailed research projects. Based on the Wetland Field Assessment Tool (WFAT) (Environment and Heritage Protection, unpublished), the WFAT–M has been developed for rapid wetland-specific assessments of the pressure, state and impacts on environmental values as outlined in Figure1.

The WFAT–M measures pressures on wetland environmental values (WEVs) with indicators of input pressures (e.g. toxicants), exploitation and harvesting, biological introductions (e.g. pests), changes to water regime, and habitat disturbance and alteration. The state of WEVs is gauged with indicators related to wetland components and processes. The WFAT–M combines desktop spatial and image-based indicators with field-based indicators of disturbance to wetland components and processes.

The WFAT–M comprises two indices (one for pressure and one for state) that are derived by rolling up

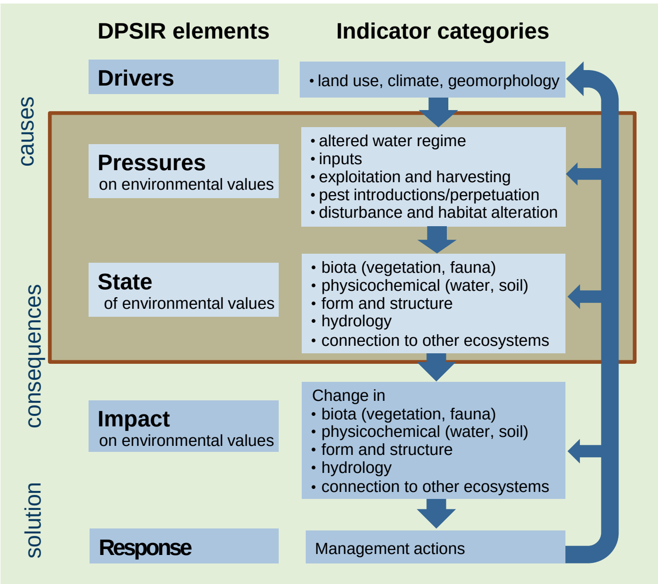


Figure 1 Conceptual framework for wetland monitoring program. The WFAT–M directly assesses pressure and state (outlined) and can assess impact over time.

indicator scores measured on Likert-like ordinal scales. For individual indicators, scores typically range from 1 to 5 where 1 is the closest-to-natural and 5 the most disturbed. There are four sub-indices for pressure and for state, based on wetland environmental values:

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

For pressure and for state, index scores of 3, 6, 9, 12 and 13 are equivalent to grades of A, B, C, D and F, respectively, with A to D having plus and minus scores as well – yielding an ordinal scale of 13 points for pressure and state.

The WFAT–M pressure and state scores are calculated separately to produce two overall scores for each wetland (see the software section below for more information about WFAT reports). These individual wetland scores are rolled up for reporting at regional and Great Barrier Reef-wide scales.

3.1 WFAT–M proformas and operational design

The WFAT–M has three components. These are Section 1 The Desktop Workbook, for reproducing a standard set of maps and other information to be used in the field, Section 2 Desktop assessment methods guide and proforma, for conducting the desktop component of the assessment and recording results, and the Section 3 Field methods guide (part a) and proforma (part b), for conducting the field assessment and recording results. Sections 1 and 3 are required in the field.

For each wetland, a number of sample sites are chosen according to rules set out in the proformas.

The desktop assessment, using maps and aerial photographs, gives whole-of-wetland scores for its indicators. The field assessment has two components – indicators scored for the whole-of-wetland while conducting a traverse (according to rules set out in proformas) and indicators scored at each sampling site. A typical wetland would have eight sampling sites, including sites at the inlet and outlet of the wetland, sites at hydrological modifiers, sites in the most undisturbed part of the wetland and sites in the 200m buffer, close to the wetland. Larger wetlands require more sampling sites to be assessed.

Rules for recording the location of sites ensure that the same sampling sites are assessed at each repeat visit to the wetland. This is to maximise trend detection.

One objective of the pilot phase was testing the WFAT–M, both on the desktop and in the field.

3.2 WFAT–M software

For each wetland, the WFAT–M pressure software produces a standard report with rolled up scores for overall pressure as well as rolled up scores for each WEV and individual pressure indicator scores. The scales for individual indicators and for WEVs range from one to five, while the overall scores range from one to thirteen as described above.

The state software yields similar results for sampling sites. An extra software step is involved to roll up site scores into an overall score for the wetland and scores for WEV sub-indices.

3.3 Methods

Wetland assessments using all three sections of the WFAT–M were completed for 27 wetlands in GBR catchments from the Burnett Mary region to the Wet Tropics. The wetlands comprise examples of lacustrine (lake) and palustrine (vegetated swamp) and a range of hydro-modifications from not modified (H1) to estuaries converted to fresh (H2M3), identified in the Queensland Wetland Mapping (EPA 2005). The characteristics of these wetlands are summarised in Table 1.

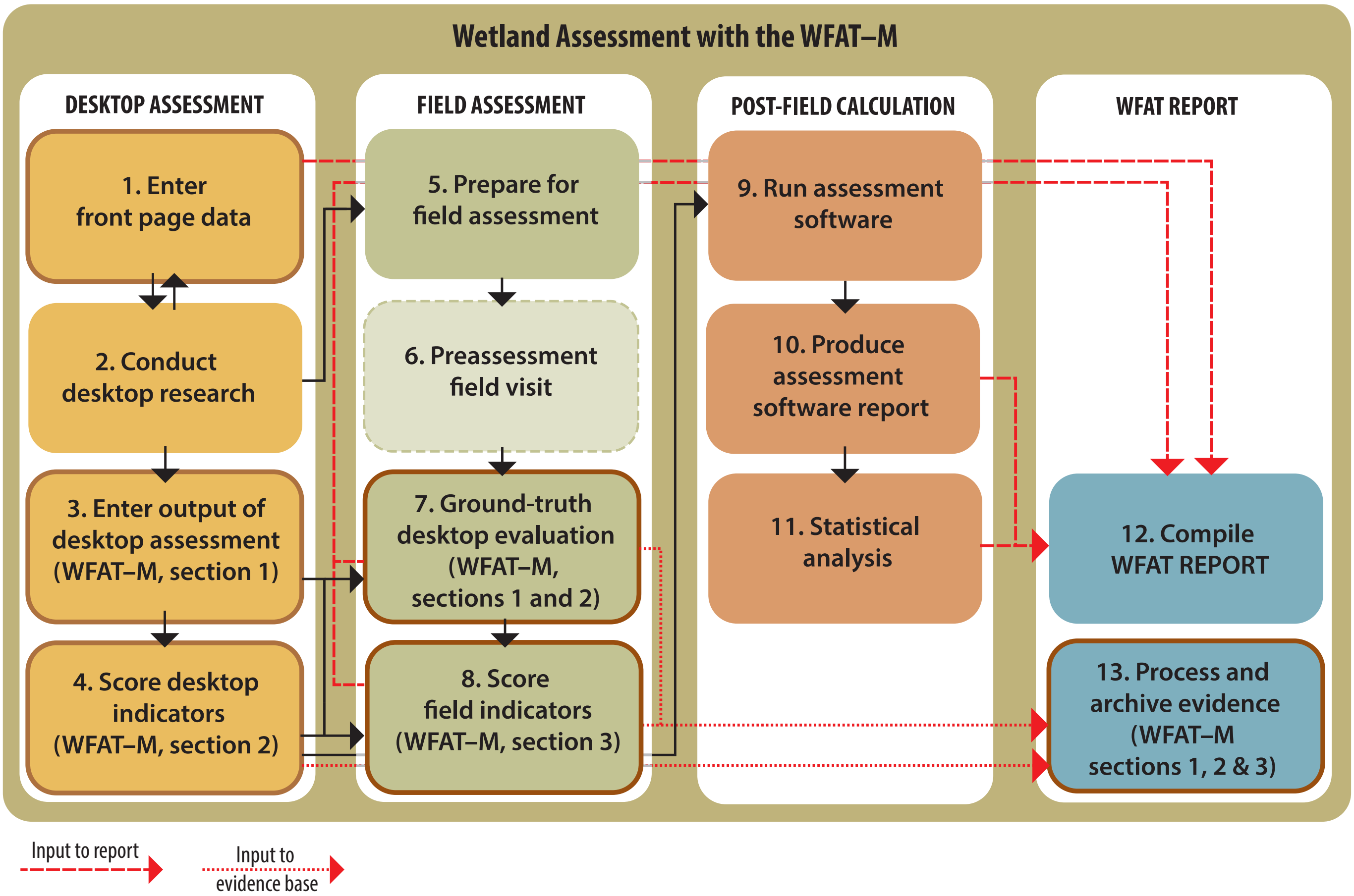


Figure 2 Wetland assessment using the WFAT–M

The sample was chosen by the regional natural resource management (NRM) groups and was not a representative sample but rather, a purposive sample of wetlands across the full disturbance gradient from those in near-natural condition (e.g. Dismal Swamp in the Fitzroy region) to wetlands whose natural components and processes are severely disturbed (e.g. Mon Repos typha wetland in the Burnett–Mary Region).

All wetland assessments were processed using the WFAT–M software and the results were analysed with a range of summary statistics to evaluate the performance of the WFAT–M instrument.

3.4 Results

As illustrated in Figure 3, both the pressure and the state scales (as a whole) discriminated across the full range of wetland disturbance levels. Pressure scores were generally higher than state scores and there was greater variability among the state scores than among the pressure scores.

Figure 4 shows that for individual wetlands, there was a strong relationship between overall pressure and overall state, with pressure being generally higher than state.

Dismal Swamp located in the Shoalwater Bay Training Area and the Mon Repos typha wetland located behind the Mon Repos turtle nesting beach, represent the extremes of the range of disturbance across the wetlands assessed (see Figure 5).

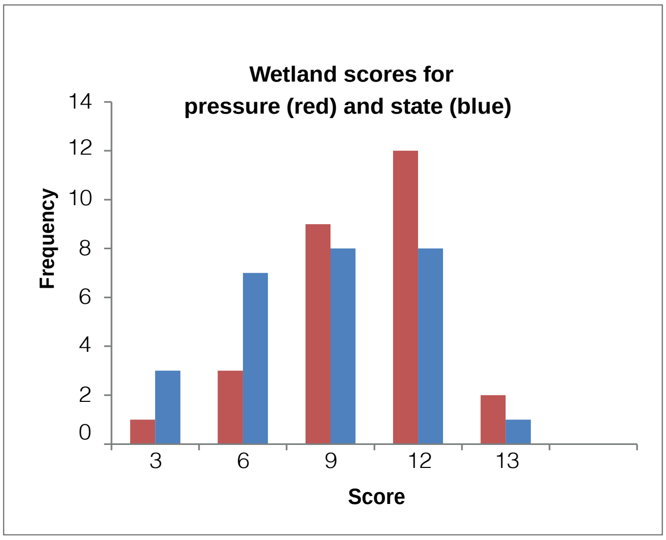


Figure 3 Score range for pressure and state

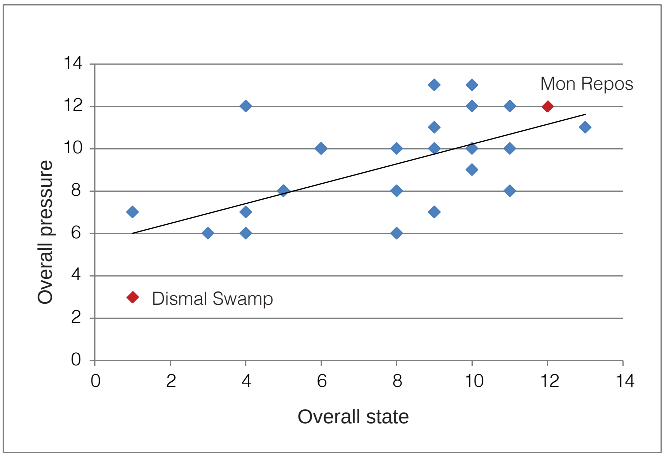


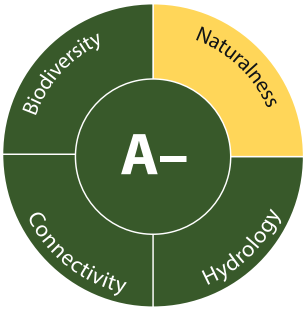
Figure 4 Relationship between pressure and state for individual wetlands

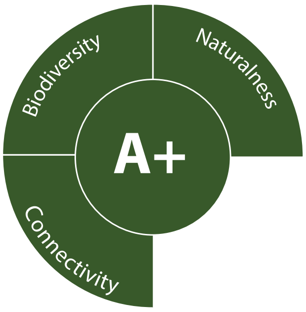
Table 1 Characteristics of wetlands in the pilot study

Floodplain wetlands (N=15)					
	H1	H2M2	H2M3	Other	
Lacustrine		1			**1**
Palustrine	11	1	2		**14**
Non-floodplain wetlands (N=12)					
	H1	H2M2	H2M3	Other	
Lacustrine	1			1	**2**
Palustrine	5	1	4		**10**
	17	**3**	**6**	**1**	**N = 27**

Image: Jan Tilden

Dismal Swamp





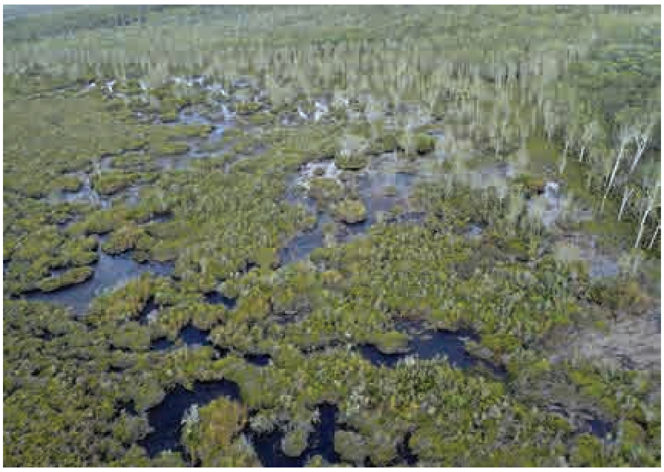
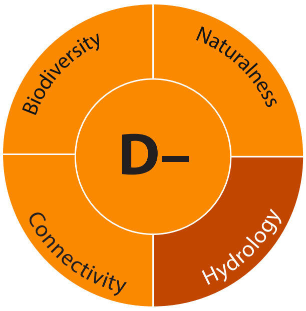
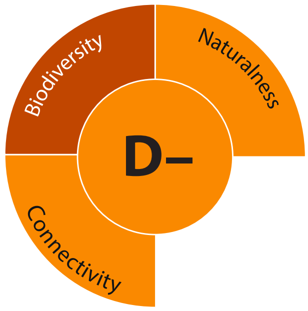


Image: Geoff Borschmann

Image: Geoff Borschmann

Mon Repos typha





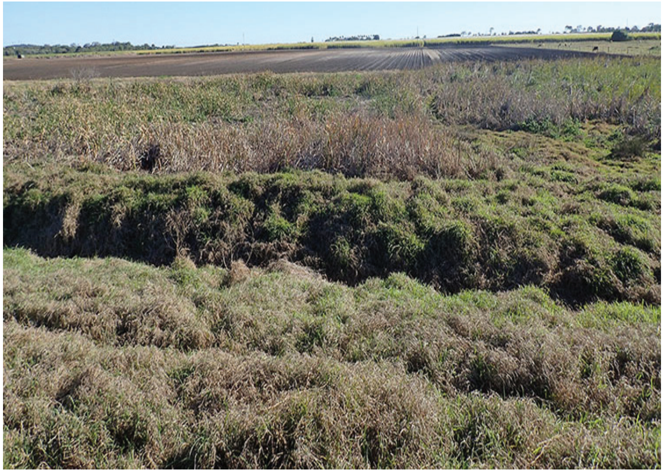


Image: Maria Vandergragt

Image: Geoff Borschmann

Pressure scoring system

A	B	C	D	F
very low	low	moderate	high	very high

State scoring system

A	B	C	D	F
very good	good	moderate	poor	very poor

Figure 5 Examples of wetlands with very low (Dismal Swamp on the left) and very high (Mon Repos, right) levels of disturbance as measured using the pilot version of the WFAT–M. Each circle shows the overall pressure or state of the wetland (inner circle) along with a set of scores for the wetland environmental values (the four quarters of the outer circle). In the pilot version of the instrument, there were no state indicators for hydrology. The photographs below the circles show typical sections of each wetland.

Most of the WEV sub-indices also discriminated across the full range of disturbance. The exception was WEV 2 for pressure on wetlands, which discriminated poorly. All but three of the 27 wetlands achieved a score of 4 (high pressure) on the WEV. Dismal swamp scored 3 (moderate pressure) and two wetlands scored 5 (very high pressure) (see Figure 6).

Looking at the relationships among scores on the sub-indices and the overall state score, it was pressure on the hydrology value that had the highest correlation with the overall state of the wetland ($r = 0.63$).

A preliminary validity check was performed using data from a Level 1 (Desktop) landscape hazard assessment (DSITI 2015). In this study, catchments across the GBR were assessed for their level of land-use hazard to wetlands. Aquatic Conservation Assessment (ACA) sub-catchments (see e.g. Clayton et al, 2006) were used in these hazard assessments with each of these sub-catchments getting an overall land-use hazard score (on an ordinal scale of one to six).

Conceptually, land-use hazard to wetlands should be correlated with pressure on wetlands, as the pressure classes used to develop WFAT–M indicators were derived from the land-use hazard assessment. Assuming that land-use pressure on wetlands is largely unmitigated, a correlation is also expected between land-use hazard score and the state of wetland values.

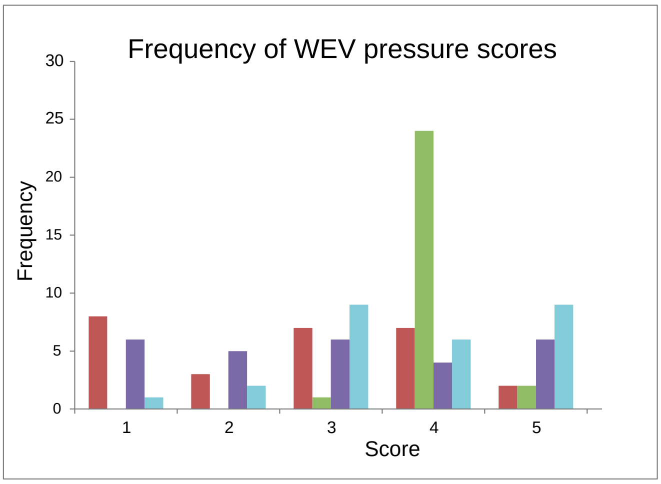


Figure 6: Among the 27 wetlands in the pilot study, there was a high concentration of wetlands at score point 4 for WEV 2 (green bars). The other WEVs discriminated among wetlands, yielding scores across the full range of 1 to 5.

For the wetlands assessed, the landscape hazard scores for their surrounding ACA sub-catchments were found to be highly correlated (Spearman's Rho) with both pressure on wetland values ($\rho = 0.64$, $p < 0.01$) and state of wetland values ($\rho = 0.64$, $p < 0.01$) as measured by the WFAT–M. In other words, the state of the wetland values co-varies with land-use hazard in the catchment surrounding a wetland, at least for those wetlands assessed in the pilot study.

3.5 Discussion

While the WFAT–M generally performed as intended, the pilot study highlighted some issues for attention or further consideration.

3.5.1 Relationship between pressure and state scores

The links between pressure on a wetland's values and state of the wetland are complex. Lags in a system between the application of pressure and the response of the wetland, non-linear components including ecological tipping points (thresholds) and differences in vulnerability to pressure of different wetland types are some of the factors contributing to the link between pressure and state and its associated variability.

There are several possible explanations for the finding that, while pressure and state were correlated, wetlands in the pilot sample generally had higher scores for pressure on values than for state of values. The fact that the most pristine wetland in the sample, Dismal Swamp, is almost an outlier to the line of best fit suggests a potential explanation. We may not have captured a good sample of the range of pressures on GBR wetlands. In other words, wetlands under less pressure are poorly represented. If this is the case, including wetlands from less disturbed areas such as Cape York in the monitoring sample could be expected to increase the slope of the line of best fit, as they would likely be subject to pressures lower than most wetlands in the pilot sample but higher than dismal swamp. This may be confirmed once data have been gathered in the baseline phase of the monitoring program.

3.5.2 Non-discriminating sub-index (WEV 2)

The previous version of the WFAT included a number of sub-indices – the wetland environmental values

Table 2 Comparison between sub-indices of the WFAT–M and three other wetland rapid assessment tools

WFAT–M (new) WEVs	CRAM ‘attribute’ alignments	IWC ‘subindex’ alignments	FARWH ‘key components’ alignments
Biological health and diversity of wetland’s ecosystems	Biotic structure	Biota	Biota
Wetland’s natural physical state and integrity	Physical structure	Physical form	Physical form
Wetland’s natural hydrological cycle	Hydrology	Hydrology	Hydrological disturbance
Natural interaction of wetland with other ecosystems	Buffer and landscape context	Wetland catchment	Fringing zone, catchment disturbance
		Soils	Water quality and soils
		Water properties	

CRAM = California Rapid Assessment Method; IWC = Index of Wetland Condition (Victoria); FARWH = Framework for the Assessment of Wetland and River Health

Table 3 Changes to WFAT–M sub-indices (WEVs) 1 and 2*.

Original WEVs with their associated indicatorS		New WEVs with their associated indicators	
WEV 1 The health and biodiversity of the wetland’s ecosystems	WEV 2 The wetland’s natural state and biological integrity	WEV 1 The biological health and diversity of the wetland’s ecosystem	WEV 2 The wetland’s natural physical state and integrity
Pressure indicators			
P1 Number of stormwater or other point inflows per hectare of wetland	P5 Exposure of the mapped wetland to pugging by livestock and feral pests	P1 Land use associated with the introduction or perpetuation of pest species	P10 Sediment supply (modelled)
P2 Number of septic systems per hectare of wetland within 200m of the wetland	P6 Land use associated with sediment runoff on slopes of 3% or greater	P2 Modification of vegetation in the 200m buffer	P12 Number of stormwater or other point inflows per hectare of wetland
P3 Recreational use	P8 Land use associated with pesticide residue inputs	P3 Land use associated with pesticide residue inputs	P13 Recreational use
P4 Fishing (or other fauna taking) within the wetland	P9 Rubbish items per square metre averaged across sample sites	P4 Land use associated with nutrient inputs	
	P10 Modification of vegetation in the 200m buffer	P5 Number of septic systems per hectare of wetland within 200m of the wetland	
	P11 Land use associated with the introduction or perpetuation of pest species	P7 Plant pest cover in the mapped wetland	
	P12 Evidence of plant pests in the mapped wetland area	P8 Plant pest cover in the 200m buffer zone	
	P13 Evidence of plant pests in the 200m buffer zone	P9 Fishing (or other fauna taking) within the mapped wetland	
State indicators			
S1 Naturalness of landform within the sample site	S3 Disturbance to native plant cover by people plant or animal pests or livestock	S1 Floristic composition and vegetation structure	S5 Integrity and stability of the upper waterbody margin
S2 Floristic composition and vegetation structure	S4 Exotic plant cover	S2 Disturbance to native plant cover by people plant or animal pests or livestock	S6 Naturalness of landform
	S5 Integrity and stability of the upper waterbody margin	S3 Exotic plant cover	S7 Direct disturbance by humans, livestock or pigs physically impacting soil
	S6 Direct disturbance by humans, livestock or pigs physically impacting soil		S8: Pugging by livestock and feral pests in the mapped wetland

*The original wording of sub-indices (WEVs) 3 and 4 was retained.

(WEVs) – that were not exclusive. This conceptual issue was highlighted by the poor discrimination of the original WEV 2 on the pressure index. There was conceptual overlap between WEV 2 ‘The wetland’s natural state and biological integrity’ and each of the other WEVs, but particularly with WEV 1 ‘The health and biodiversity of the wetland’s ecosystems’.

In comparison, the sub-indices of similar wetland rapid assessment tools do fall into exclusive conceptual categories – see table 2 which shows the alignments among sub-indices of three rapid wetland assessment tools. A small but significant change to the wording of the original WEVs gave the WFAT–M a new set of sub-indices that aligned more closely with those of the comparable rapid assessment tools as well as being more conceptually sound. This new set of WEVs is also included in Table 2.[1]

Table 3 illustrates this point further by listing the original WEV 1 and WEV 2 indicators for both pressure and state in columns one and two with the realigned indicators in columns three and four.

Because the pilot study version of WFAT–M is now different to the version that will be used for baseline and ongoing assessments, it remains to be seen whether the new WEV 2 pressure sub-index will discriminate better than the original one; however an experiment with a limited set of pilot study data (i.e. those data to which the new instrument could be applied) suggests that the new WEV 2 will discriminate better.

The WEVs listed in the introduction to this paper are the new WEVs.

3.5.3 Changes to indictors

Another change to the instrument as a result of the pilot study has been the addition of a set of hydrology ‘state’ indicators.[2] A wetland’s hydrology is considered to be the primary driver of its state (see for example Mitsch and Gosselink, 2015, Boulton and Brock,1999) so the absence of such indicators was seen as a weakness of the pilot instrument. This was emphasised by the pilot study finding that, of all the pressures on wetlands, it was pressure on hydrology that had the strongest relationship with the overall state of the wetlands.

As well as changes to the WEVs, the pilot study also highlighted the need for changes to some individual indicators such as:

- amendment and addition of indicators mostly related to hydrology, including adding hydrological state indicators (as described above)
- adding a field verification component to some indicators
- changes to some indicator methods
- edits to clarify indicator operating procedures.

3.5.4 Validity of the WFAT–M

Ideally, rapid assessment instruments of the type represented by the WFAT–M are validated using detailed studies of wetland components and processes (level 3 studies). However, some indication of the validity of the overall instrument for assessing the range of disturbance to wetlands can be gained from its relationship to independently derived level 1 data of the range of disturbances, such as those provided by the landscape hazard assessment described earlier. While the independence of these data from the WFAT–M *pressure* index is questionable, a strong case can be made for the independence of the WFAT–M *state* index and the landscape hazard assessment scores for land use.

For this reason, the strong correlation between land-use hazard score and WFAT–M state score for the wetlands tested in the pilot study is very encouraging. If this relationship holds for the next phase of the GBR wetland monitoring program, it will help to validate the instrument as a method for rapidly assessing the amount of disturbance to wetland environmental values.

[1] Two of the comparison indices also include sub-indices for assessing soil properties and water quality. These were not included in the WFAT–M, as they were not part of the original WFAT index from which the WFAT–M was derived. The California Rapid Assessment Method (CRAM) also conducts rapid assessments of wetlands without the benefit of soil and water chemistry indicators.

[2] After earlier attempts to come up with ‘one visit’ hydrology indicators, this was abandoned on the advice of hydrology experts, so the pilot study went ahead without state indicators for hydrology. Renewed efforts have since been made to develop hydrology state indicators and several are now included in the instrument.

4 Monitoring program design

As well as testing the WFAT–M and its application in the field, the pilot study also aimed to inform three main aspects of the GBR wetland monitoring design:

1. the sample size needed for reporting at a chosen level of precision
2. the allocation of sampling effort in space
3. the allocation of sampling effort in time.

4.1 Determining sample size

A sample size was estimated that would yield sufficient statistical precision to report on the Reef Plan target within the life of the current project.

4.1.1 Methods

Because the primary objective is to detect trend with limited resources, the same wetlands will be measured over time. Therefore the test to determine the minimum sample size for an ambient monitoring program is a test on the sample variance between two times.

The pilot data gives us information for 27 wetlands for one time point. Scenarios of likely and possible change between two times were generated from this data. This exercise revealed that, for individual wetlands, incremental improvements or deteriorations were possible within the proposed assessment cycle[3] (± 1 or 2 points on the instrument's 13 point scale), as were larger deteriorations (up to +4 points on the 13 point scale) due to 'catastrophic' events (e.g. weather events, land clearing, development, conversion of wetlands). Large improvements were not likely to occur in such a short time. Averaging across all wetlands in a GBR-wide sample, a likely result for GBR wetlands within one assessment cycle is no detectable change.

The desired level of precision for measurement of change from one monitoring period (notionally, one year) to the next is ± 1 point on the 13 point scale.

One reason for choosing this level of precision for the WFAT–M instrument is this: it is important to be able to say, when no change is detected, that there really is no change and not just imprecise measurement. In other words, it is important that we avoid type II errors (i.e. no change reported when negative change is actually occurring) in a GBR wetland values improvement and conservation context.

4.1.2 Results and discussion

We estimate (based on variance calculations using the pilot study data) that a probability sample of about 40 wetlands will give the required precision for reporting on change in the state of GBR wetlands, using the WFAT–M.[4] (Difference between WFAT–M scores of ±1 between two times, power = 0.8, $\alpha = 0.05$).

For a monitoring design that stratifies by region in order to report change at the regional level, a sample of 40 wetlands would be required for each region.

This sample size estimate was made using conservative assumptions at every step, so it is likely that a higher power will be achieved from a probability sample of 40 wetlands, that is, the likelihood of failing to detect a change when there is one will be less than 20%.[5]

4.2 Allocation of sampling effort in space

Experience gained from the pilot study informed two important spatial aspects of the monitoring design, the choice of monitoring population and the method of sampling that population.

4.2.1 Choosing the population

Methods

Nominally, the monitoring population for the pilot study consisted of all 'natural' freshwater wetlands in the GBR catchments with 'natural' being defined as wetlands in hydro-modifier classes H1, H2M2, H2M3 and H2M8 (EPA, 2005). From this population, a purposive sample was drawn that met certain criteria. The sample:

[3] That is, by the end of 2018 – see table 5 for an explanation of this time frame.

[4] This assumes that the WFAT–M is a valid instrument for assessing degree of disturbance to wetland values. Evidence for validity of the instrument is discussed in the previous section.

[5] If power = 0.8, the probability of making a type II error is 0.2, or 20%, all other things being equal.

- included wetlands from across the spectrum of disturbance for GBR wetlands
- included wetlands with a range of attributes that would challenge the WFAT–M instrument (e.g. very large as well as small wetlands, lacustrine as well as palustrine wetlands)
- consisted of wetlands that were relatively easy to access, to optimise the number that could be assessed in the time available.

Based on these criteria, five or six wetlands were assessed from among those chosen by each of the NRM groups that collaborated in the pilot project. This yielded a convenience sample approximately stratified by region.

Results and discussion

As noted earlier, the sample provided the necessary information about the performance of the WFAT–M instrument and was used to calculate a sample size for the monitoring program (with conservative assumptions to allow for non-randomness). However, the pilot highlighted some issues with the population as defined, the sample drawn from it and the method used to draw that sample.

Wetlands attributed with the hydro-modifier class H2M3 presented an assessment challenge. The water body of these wetlands has been changed from estuarine or marine to freshwater, generally becoming ponded pastures. While many such wetlands are considered to have high biodiversity values for wetland birds, they do not meet the criterion of ‘natural’. Restoring these wetlands to their natural state would involve removing bunds and returning them to estuarine or marine condition. Under such management, they would no longer meet the population criterion of ‘freshwater wetland’. For this reason, it was recommended not to include H2M3 wetlands in the population.

Another question that arose in the course of the pilot was the relevance of the population, given the primary aim of the Paddock to Reef Program is to improve GBR water quality. A further recommendation, in the light of this concern was to focus on the wetland environmental values of floodplain wetlands only, as these have a clear hydrological connection with the waters of the Reef.

Finally, the geographic scatter of the wetland sample that would result from a random draw on all natural freshwater wetlands presented some challenges, both logistical and in terms of relevance to management. A method was sought to narrow the population to dense aggregations of floodplain wetlands, which would have more impact on reef water quality and be of more interest to wetland managers. Such a population would also produce a less scattered sample that would be more efficient to assess.

To achieve a more targeted population, a series of wetland density classes were created for the GBR freshwater wetlands, using the point density tool in ARC GIS (Figure 7). Density classes with a threshold >0.0595/km2 (a density of >1 wetland per 16.8km2), were used to focus the population on the more dense aggregations of wetlands (hotspots, see Figure 8). These also provided a good overlap with (a) aggregations of

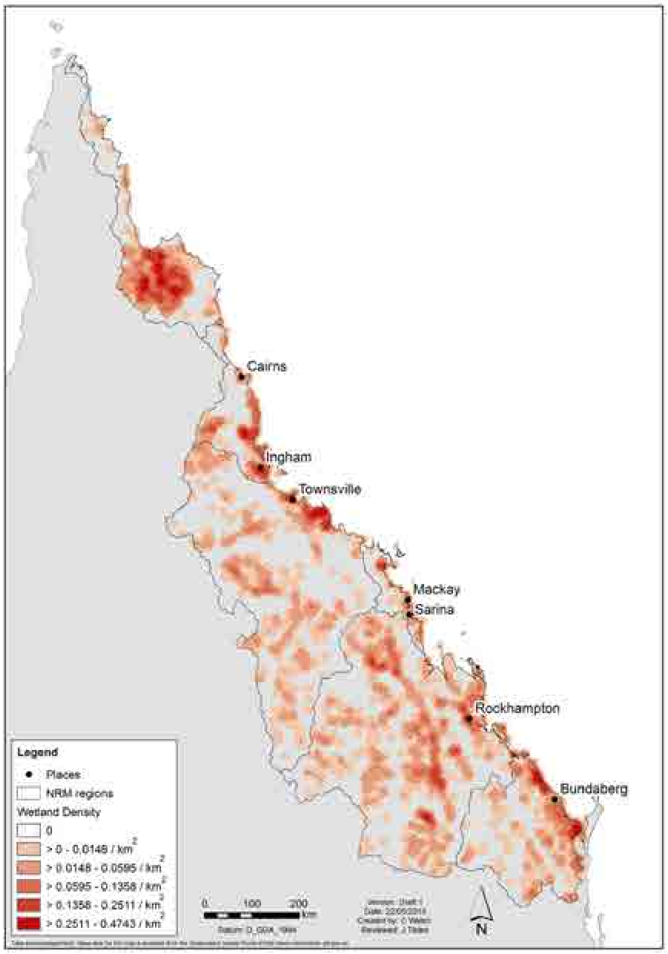


Figure 7 Wetland density classes at GBR catchments

high and very high conservation wetlands, as assessed by the Aquatic Conservation Assessment process (see Clayton et al, 2006), and (b) major source areas of fine sediments, pesticides and nutrients for GBR receiving waters (Brodie et al, 2013, Waters et al, 2014). Sixty percent of GBR natural freshwater floodplain wetlands were captured by these classes and hence fell within the more restricted (sub)population of wetlands that was used to draw the monitoring sample.

4.2.2 Sample structure

Another issue highlighted during the pilot study was the impact of stratifying by GBR natural resource management (NRM) region, in other words, sampling the same number, or roughly the same number, of wetlands in each region. This method was used in the pilot study for two reasons, first because the regions were equally resourced to contribute to the pilot project and second, because providing results by region is standard for Reef Plan reporting.

Table 4 shows the numbers of floodplain and non-floodplain wetlands by NRM region. Stratifying by region greatly over-represents some regions, especially Mackay–Whitsunday, while under-representing others, for example the Fitzroy, which has the largest and one of the more diverse populations of floodplain wetlands among the regions.

In deciding whether to abandon regional stratification, a further consideration was resourcing for the current phase of the GBR wetland monitoring program. If it were possible to report by region at the precision needed to make a meaningful statement about whether or not wetland environmental values have changed, there would be more justification for stratifying by region. Under conservative assumptions about the number of wetlands needed to reach the desired level of precision, this means sampling 40 wetlands in each region.

The decision was made to focus on assessing, in each monitoring period (notionally, each year), 40 natural freshwater floodplain wetlands in high density aggregations, randomly drawn from across the whole GBR. This will allow reporting across the GBR at the required precision within the current funding period. The 40 wetlands are divided into two panels of 20 with one panel being assessed every monitoring period, while the other is assessed and replaced on a schedule set out in the next section on allocating sampling effort in time (Table 5).

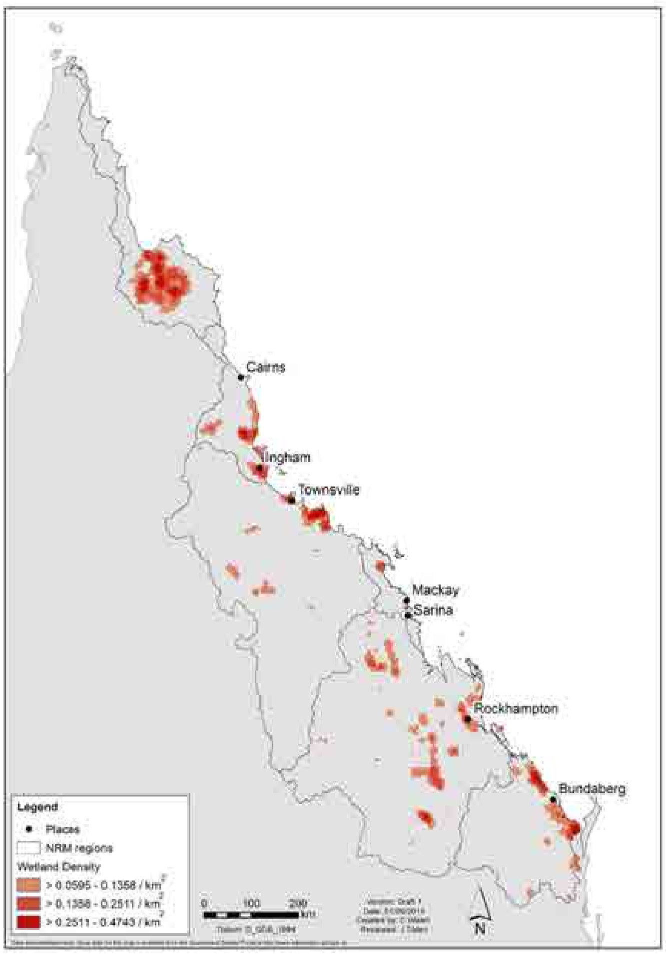


Figure 8 Density 'hotspots' defined by the >.0595 wetlands/km^2 density classes

Table 4 Wetland numbers by NRM region

	Floodplain wetlands	Non-floodplain wetlands	Total number wetlands
Cape York*	2042	1324	3366
Wet Tropics	808	980	1788
Burdekin	1513	937	2450
Mackay WS	161	121	282
Fitzroy	2570	690	3260
Burnett Mary	1430	801	2231

Bearing in mind that eventually we want to able to report by region at an acceptable level of precision, a sampling method was chosen that kept as many options open as possible. This method is described in the next section.

4.2.3 Sampling method

Because the monitoring program aims to use a small sample to make inferences about the (sub)population of all GBR natural freshwater floodplain wetlands in dense aggregations, a probability sampling method was needed.

The Generalised Random Tessellation Stratification (GRTS) method has certain advantages when sampling for an ecological monitoring program (see for example, Dobbie et al, 2008, Olsen et al, 2012). These are:

- GRTS is a random sampling method, supporting inferences about the chosen population (or sub-population).
- GRTS is a spatially balanced sampling method. This is important when the sample size is small relative to the size of the population. It ensures that the sample is a good spatial representation of the population.
- GRTS is flexible – an important feature in the real world of ecological monitoring. For example, by using an oversample, GRTS allows easy replacement of non-responsive sites within a sample. Sites could be non-responsive if owners refuse access, or simply because there is no affordable way to get to them.
- Using the master sample techniques described by Larsen et al (2008), GRTS sampling will support scaling up of the program, for example to report by region at acceptable precision if more resources become available.
- An initial selection of a large master sample of all natural freshwater wetlands in GBR catchments will also enable coordination and integration of future monitoring and research in GBR wetlands. A master sample can be held as a resource to be tapped by other researchers or wetland assessors. The result would be an integrated body of wetland research, making the most of scarce resources.

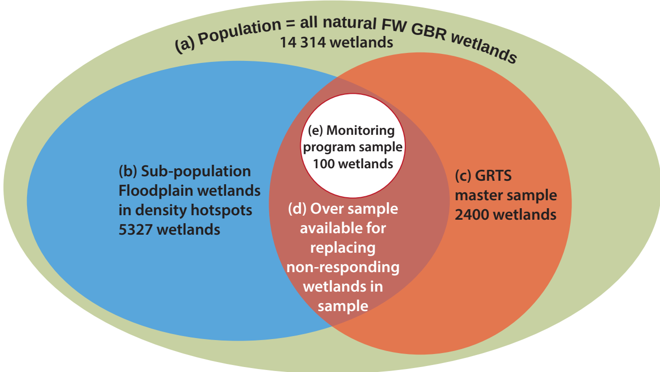


Figure 9 GBR wetland monitoring program population, sub-population and samples

From a GRTS master sample (n=2400) of all natural freshwater GBR wetlands, an initial monitoring sample was selected of GBR natural freshwater floodplain wetlands in density hotspots from the Normanby to the Mary river catchments. Choosing this density hotspot monitoring design does not preclude later studies on the broader GBR wetland population from which the master sample was drawn.

Figure 9 shows the relationships among (a) the original population ‘all natural freshwater GBR wetlands’ (14,314 wetlands), (b) the sub-population consisting of floodplain wetlands in density hotspots (5327 wetlands), and (c) the GRTS master sample which was drawn from the original population then sorted to exclude first the non-floodplain wetlands and then wetlands outside density hotspots. Eight hundred and eighty nine wetlands remained after these exclusions – the red area (d) of overlap in the diagram. According to GRTS sampling rules, the first 100 of these wetlands comprise the monitoring program sample (e) while the remainder are available as an oversample to replace any non-responding wetlands among the first 100.

In this panel design:

- 20 wetlands in panel 1 are assessed in every monitoring period (notionally every year)
- panels 2 and 3 are assessed in alternating years
- by the end of 2017 panel 2 will have been assessed twice and it will be possible to report on change across the GBR
- at the end of 2018, panels 2 and 3 are rested for 4 years. This helps to deal with the problem of management biasing the sample.
- in 2019, depending on whether extra new funding is forthcoming, we can either add a new panel of 20 or a panel of 90 (balanced across the regions) this would be panel 4
- the next year, panel 5 is added (20 or 90)
- these two new panels (4 and 5) are assessed for 2 years in rotation then 'rested'
- in 2023, either panel 2 is assessed again or a new panel of 90 is added (depending on financial circumstances) … and so on.

Table 5 Flexible panel design for two funding scenarios

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Panel 1	20	20	20	20	20	20	20	20	20	20	20	20
Panel 2	20		20						20		20	
Panel 3		20		20						20		20
Panel 4					20 90		20 90					
Panel 5						20 90		20 90				
Panel 6									20		90	
Panel 7										90		90
Panel 8												
Total per year	40	40	40	40	40 or 110	40 or 110	40 or 110	40 or 110	40 or 110	40 or 110	40 or 110	40 or 110
Total in sample (cumulative)	40	60	60	60	80 or 150	100 or 240	100 or 240	100 or 240	100 or 330	100 or 420	100 or 420	100 or 420
Timeline		Baseline for minimal design completed end 2016.	Analysis needed by end 2017. Estimated minimum to achieve desired precision = 40	Report by 2018. End of funding period	New funding period, possible funding increase	Inferences about status of region can be reported at this point	Inferences about change in regions can be reported at this point					

4.3 Allocation of sampling effort in time

Panel designs for ecological monitoring optimise the use of resources over time, with different numbers of panels and different revisit schedules favouring the power to detect either trend or status (see e.g. McDonald, 2003, US National Park Service, 2010). In general, assessing the same sites every visit (pure panel design) optimises the detection of trend while replacing the sites with independent new samples for each sampling round optimises the detection of status. Split or rotating panel designs balance the two objectives – measuring status and trend – in terms of statistical power.

4.3.1 Methods

While detecting trend is the primary objective of the GBR wetlands program, there are other reasons for introducing new panels during the course of the program, rather than continuing to monitor the same wetlands over and over. These include:

- Frequent monitoring of the same sites in the same wetlands can have a detrimental physical impact on those sites (e.g. trampling, weed introductions, changes to wildlife behaviour).
- If the same assessors visit the same wetlands over and over, as is intended, they may lose the ability to look with fresh eyes each visit and therefore may miss important changes.
- There may be very little change between monitoring periods, making such frequent monitoring a waste of resources.
- Visiting new sites decreases the likelihood that the monitored wetlands will be preferentially managed, rendering the sample no longer representative of the population.

Furthermore, as long as newly added panels are eventually revisited, they also contribute to power for detecting trend.

Another consideration in the panel design was the schedule of reporting. The aim is to complete panels and analyse results so findings can be reported in a timely manner.

4.3.2 Results and discussion

The chosen monitoring design seeks to optimise detection of both status and trend of wetlands, both at the individual wetland level and, importantly for reporting on the target, across the defined GBR wetland (sub)population. The panel design chosen increases the number of wetlands sampled (over a fixed panel design), thus improving precision of status assessment, while favouring trend detection. A further benefit of the chosen design is that it allows us to test for different sources of variability and uncertainty in the data.

Finally, this design allows the program to be scaled up, should more resources become available.

Image: Jan Tilden

5 Conclusion

The Great Barrier Reef wetland monitoring pilot study resulted in refinements to the Wetland Field Assessment Tool for Monitoring (WFAT–M) including:

- the realignment of indicators with a set of wetland environmental values that were more closely aligned with the conceptual categories used in instruments similar to the WFAT–M and potentially, more discriminating as sub-indices
- renewed efforts to find a set of ‘one visit’ indicators of the state of wetland hydrology
- changes to individual indicators to improve and clarify their methods.

High correlations of the WFAT–M pressure and state scores with an independently derived landscape-scale score of land-use hazard to wetlands help to demonstrate that the WFAT–M is a valid index of disturbance to wetland environmental values; however more work is needed both to validate and calibrate the WFAT–M. Baseline data gathered in 2015 and 2016 from a probability sample of GBR wetlands will answer outstanding questions about validity and reliability and inform further refinements to the instrument, if needed.

Based on the outcome of the pilot study, the following decisions were made about the GBR wetland monitoring program design:

- Subject to confirmation or adjustment after the first round of baseline data collection, a sample size of 40 wetlands was estimated to allow change in wetland values to be detected at the required level of precision. The level of precision was chosen to allow meaningful GBR-wide reporting within the time frame of the current project.
- A sub-population of all GBR natural freshwater floodplain wetlands in defined density ‘hotspots’ was chosen for reporting on the Reef Plan target: improvement of wetland environmental values and ecological processes.
- The Generalised Random Tessellation Stratification (GRTS) method was chosen to draw a large master sample of all GBR natural freshwater wetlands. This master sample will give maximum flexibility with future program research design.
- From this master sample, an oversample of wetlands was chosen according to GRTS rules for preserving randomness and spatial balance. These wetlands will represent the sub-population for reporting on the Reef Plan target.
- A panel design was chosen for the monitoring program to maximise trend detection while also allowing for the measurement of wetland status across the sub-population. A decision was made to focus on GBR-wide reporting for the current phase of the project (including catchments from the Mary River in the south to the Normanby in the north); however the program was designed to allow for rapid scaling up to report by region, should resources be available in the near future.

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