

# Marine methods



## Great Barrier Reef Report Card 2016

Reef Water Quality Protection Plan



Australian Government



Queensland Government

## Marine methods

This report summarises the data and methods used for reporting progress towards the marine targets in the Great Barrier Reef Report Card 2016.

- The marine objective is to ensure that by 2020 the quality of water entering the Reef from broad-scale landuse has no detrimental impact on the health and resilience of the Great Barrier Reef.

## Marine Monitoring Program

The Australian Government's Marine Monitoring Program assesses Great Barrier Reef water quality and the long-term health and resilience of key marine ecosystems (inshore coral reefs and seagrasses). A summary of the indicators and methods used to derive Reef report card scores are outlined below.

Detailed methods are available in the annual technical reports published on The Great Barrier Reef Marine Park Authority's website: [www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/reef-rescue-marine-monitoring-program](http://www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/reef-rescue-marine-monitoring-program).

The marine monitoring program has three elements:

- inshore water quality
- seagrass condition
- coral reef condition.

### *Inshore water quality*

Monitoring of year-round water quality includes the measurement of concentrations of organic carbon, inorganic and organic nutrients (nitrogen and phosphorus), silica, coloured dissolved organic matter, chlorophyll *a*, suspended solids (water turbidity), Secchi depth, salinity and pesticides.

Techniques used to monitor water quality include satellite remote sensing, automated data loggers and collection of water samples from research vessels for laboratory analysis. Passive samplers are used to measure the concentration of pesticides in the water column which have become integrated over time (Booij et al., 2007; Shaw et al., 2009).

Monitoring is also conducted in the wet season because the majority of the annual pollutant load to the reef is delivered by flood events (Devlin et al., 2001).



### *Seagrass condition*

Monitoring temporal and spatial variation in the status of inshore seagrass meadows in relation to changes in local water quality is essential for evaluating long-term ecosystem health and resilience.

Monitoring includes an assessment of the seagrass abundance (percent cover) and reproductive effort, which provides an indication of the health of seagrass meadows and their capacity to regenerate following disturbances. Tissue nutrient composition is assessed in the laboratory as an indicator of nutrient enrichment relative to light available for growth (McKenzie et al., 2017).

**Figure 1: Monitoring seagrass on the Great Barrier Reef (Image: L. McKenzie, Seagrass-Watch HQ)**

## ***Coral reef condition***

Monitoring temporal and spatial variation in the status of inshore coral reef communities in relation to changes in local water quality is essential in evaluating long-term ecosystem health.

Monitoring covers a comprehensive set of community attributes including the assessment of hard and soft coral cover, the number of hard coral juvenile colonies (up to five centimetres in diameter), the proportion (per cent) of cover of algae that is macroalgae, the rate of change in coral cover (as an indication of the recovery potential of the reef following a disturbance) and coral community composition (Thompson et al., 2017). Comprehensive water quality measurements are also collected at many of the coral reef sites.



**Figure 2: Monitoring coral reefs on the Great Barrier Reef  
(Image: Australian Institute of Marine Science)**

## **Scoring methods**

### ***Synthesising and integrating data and information***

The Great Barrier Reef Report Card assesses and scores the condition of inshore water quality, seagrass and coral at the Great Barrier Reef-wide scale and at the regional scale for each of the six natural resource management (NRM) regions: Cape York, Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary.

A subset of indicators is used to assess and report on water quality, seagrass and coral condition. These indicators are scored on a five-point scale (very good, good, moderate, poor, very poor) and aggregated into a score that describes the overall status of each region and of the Great Barrier Reef as a whole.

An overview of the methods used to calculate the scores is provided below. Reef-wide scores are standardised by the area of each region, while regional scores are unweighted averages. Detailed information is available in the technical reports on the Marine Monitoring Program website: [www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program/marine-monitoring-program-publications](http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program/marine-monitoring-program-publications).

### ***Inshore water quality***

In 2015–16, the water quality metric was revised as an initial step towards integrating multiple streams of data to measure and report on water quality. The previous metric relied exclusively on satellite data. The new metric is underpinned by the eReefs biogeochemical model and integrates data from satellite images for improved accuracy in what is commonly referred to as data assimilation. The new metric considers all six NRM regions in calculating the Reef-wide score and is based on open coastal waters.

The regional models of eReefs include coupled hydrodynamic, sediment and biogeochemistry models for the inshore open coastal waters of the Reef. eReefs allows quantification of the impacts of rivers and atmospheric forcing on circulation patterns and biogeochemical cycles such as water clarity, nutrients, plankton and benthic plants. The skill of the model has been assessed over six years (see <http://ereefs.info>).

Data assimilation further improves the model’s skill and provides a single best estimate of the biogeochemical state of the Reef by combining both modelling and observations. Data assimilation systems quantify the difference between a modelled state and an observed state, and improve the modelled state by incorporating the observed state into the simulation.

For the Reef, only remote sensing provides the density of observations required to undertake a large-scale data assimilation (see [www.bom.gov.au/marinewaterquality](http://www.bom.gov.au/marinewaterquality)). For shallow inshore waters, using remote sensing to estimate in-water properties is challenging due to the interactions between chlorophyll, sediments, coloured dissolved organic matter and benthic communities, which all absorb and scatter light in the blue and green wavebands. Instead of using remote sensing to estimate in-water properties, the new water quality metric is based on the optical calculations of the biogeochemical model, which simulates the normalised remote-sensing reflectance. The data assimilation system uses the mismatch between observed and modelled remote-sensing reflectance to constrain the biogeochemical model. For further details on the data assimilation technique and integrity of observations, see (Robillot et al., 2017).

Measures of chlorophyll *a*, Secchi depth (derived as the inverse of  $K_d$  (490)) and total suspended solids (derived as Ecology Fine Inorganics (EFI) multiplied by 1000) were extracted from depth layer 44 of the assimilated eReefs biogeochemical model at a 4x4 kilometre spatial resolution and daily temporal resolution. Observations from each of these measures (chlorophyll *a*, Secchi depth and total suspended solids, or TSS) were partitioned into water years (October 1st through to September 30th) and into zones representing combinations of the NRM regions and cross-shelf water bodies (GBRMPA 2010). The enclosed coastal water body was excluded due to limitations associated with the 4-km model resolution near the coastline. The site-level data (4x4 km) for each of the three measures was standardised to indices on a continuous scale of zero (very poor) to 100 (very good). This was done by assessing individual values relative to the appropriate water quality guideline value according to a ‘modified amplitude indexation routine’ (fsMAMP: base 2 logarithm of the ratio of observed value to threshold).

For each zone, the daily indices for each measure were aggregated (averaged) into annual scores (Robillot et al., 2017). Scores for Secchi depth were aggregated with the chlorophyll *a* score to yield a single score for water quality per zone, which was weighted by the area of the open coastal waters. TSS was not included in the final calculation of the water quality metric due to concerns about the lack of representation of fine sediments in the eReefs biogeochemical model.

All reported scores were mapped onto a five-point (A–E) colour-coded grading scale (Table 1).

**Table 1: The colour-coded inshore water quality scoring system**

Grade	Status	Criteria	Colour
E	Very poor	0–20%	Red
D	Poor	21–40%	Orange
C	Moderate	41–60%	Yellow
B	Good	61–80%	Light green
A	Very good	81–100%	Dark green

### ***Exposure to turbidity***

Wet-season maps derived from satellite imagery (weekly composites, frequency maps and surface exposure maps) are also used to monitor water quality conditions in the Great Barrier Reef. Water types are characterised using remote-sensing imagery to assess the broadscale coastal water quality during the wet season and the composition and spatial variability of river plumes.

Coastal waters are classified into three water types:

- Primary – brownish waters with very high turbidity, low salinity (0–10 ppt), and the highest concentrations of colour dissolved organic matter (CDOM) and TSS
- Secondary – greenish waters with intermediate salinity, elevated CDOM concentrations, and reduced TSS due to sedimentation, where phytoplankton growth is prompted by the increased light (due to lower TSS) and the high nutrient availability delivered by the river plumes
- Tertiary – greenish-blue waters with low TSS concentrations, and above-ambient concentrations of chlorophyll *a* and CDOM.

For the wet season, water type maps show a well-documented inshore-to-offshore spatial pattern, with the highest frequency of the primary water type in the coastal areas, and the highest frequency of the tertiary water type in offshore areas.

Wet-season frequency maps are used to assess the frequency, on a weekly basis, with which an area was exposed to turbid waters and the three water types over the wet season. The frequency maps are categorised in five equally spaced classes to represent different levels of exposure to turbid waters. To evaluate the susceptibility of Reef communities, the frequency maps are overlaid with coral reef and seagrass meadow distributions to identify which communities are likely exposed to land-sourced contaminants. The lowest exposure categories (I and II) are characterised by low exposure frequencies of the primary and secondary water types, and the highest exposure categories (III and IV) are characterised by high exposure frequencies of primary and secondary water types. The exposure categories have yet to be validated against ecological data, so they represent relative levels of risk. In addition, the exposure information is based on surface water quality conditions, which does not necessarily represent the exposure of benthic communities.

An ocean colour-based model is used to estimate the dispersion of loads of dissolved inorganic nitrogen and TSS discharged from the rivers in the Reef catchments, and examine their exposure and influence across the Reef lagoon. The model combines in-situ data, MODIS satellite imagery and modelled annual end-of-catchment loads from all 35 Reef basins. In the model, monitored and modelled end-of-catchment wet-season (November to May) loads provide the mass of constituents delivered to the Reef, in-situ data provides the pollutant mass dispersed within river plumes, and satellite imagery provides the direction and intensity of pollutant mass dispersed throughout the Reef lagoon.

The eReefs hydrodynamic model also provides an estimate of the boundary of plume extent in the wet season (tracer maps). It also produces annual maps of average concentrations of dissolved inorganic nitrogen and TSS and loadings in the Reef waters. The difference between end-of-catchments loads for the current year and for estimated pre-development (using the same river flow) can also be mapped.

### ***Site-specific water quality***

Water quality for specific sites where the mean or median concentrations of parameters did not meet available water quality guidelines (Great Barrier Reef Marine Park Authority, 2010) is described in the Reef report card 2016. In 2015–16, the spatial and temporal frequency of site-specific water quality monitoring increased in four focus regions:

- Wet Tropics (Tully basin)
- Wet Tropics (Mulgrave-Russell basin)
- Burdekin
- Mackay Whitsunday (O'Connell basin).

A detailed analysis by Waterhouse et al. (2017) of trends in parameters (turbidity/water clarity, chlorophyll *a* and concentrations of particulate nitrogen and phosphorus) relative to the water quality guidelines is available on the Marine Monitoring Program website: [www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program](http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program).

Site-specific water quality data are not included in the water quality metric scores, but are used to cross-reference modelled outputs. This is because, while the overall trends are generally consistent, the data are collected at different spatial and temporal scales that are not directly comparable.

## Pesticides

The reference to pesticides in the Reef report card includes all herbicides, insecticides and other chemicals used to treat pests and weeds.

Pesticides are monitored using two methods (Grant et al., 2017):

- Passive samplers are deployed in both wet and dry seasons and provide an integrated assessment of pesticide concentrations over time (Booij et al., 2007; Shaw et al., 2009).
- Grab samples are collected in flood plumes during the wet season to give an indication of peak pesticide concentrations and dispersal patterns of pesticides from river mouths.

The most frequently detected pesticides in inshore waters are herbicides that act to inhibit the photosystem II (PSII) of plants: diuron, atrazine, hexazinone, simazine and tebuthiuron (Kapernick et al., 2007; Lewis et al., 2009; Packett et al., 2009; Mitchell et al., 2005; Haynes et al., 2000a). These PSII herbicides are used to control weeds in the sugarcane, horticulture, grazing and grain-cropping industries, but may also have a negative impact on non-target organisms such as algae, corals and seagrass when discharged into the Reef lagoon (Magnusson et al., 2008; Jones and Kerswell, 2003; Haynes et al., 2000b).

An index has been developed using PSII herbicide equivalent (PSII-HEq) concentrations to assess the potential combined toxicity of these herbicides relative to the guidelines. The PSII-HEq concentration incorporates the relative potency and abundance of individual PSII herbicides compared to a reference PSII herbicide—diuron. The index has five categories of ecological risk (Table 1). Concentrations detected at the lowest level (Category 5) are not expected to impact seagrass or coral, while at the highest level (Category 1) demonstrated effects on the growth and death of aquatic plants and animals exposed to the pesticide have been reported.

**Table 2: The PSII herbicide equivalent (HEq) index is used to assess ecological risk of PSII herbicides across the Reef**

Risk category	PSII-HEq concentration (ng.L <sup>-1</sup> )	Description
5	≤ 10	No published scientific papers demonstrate any effects on plants or animals based on toxicity or a reduction in photosynthesis. The upper limit of this category is also the detection limit for pesticide concentrations determined in field-collected water samples.
4	11–50	Published scientific observations of reduced photosynthesis for two diatoms.
3	51–250	Published scientific observations of reduced photosynthesis for two seagrass species and three diatoms.
2	251–900	Published scientific observations of reduced photosynthesis for three coral species.
1	> 901	Published scientific papers demonstrate effects on the growth and death of aquatic plants and animals exposed to the pesticide.

The Department of Science, Information Technology and Innovation's proposed marine diuron water quality guideline value for 99 per cent species protection (which is also applicable to the PSII-HEq concentration because diuron is the reference herbicide) is 430 ng L<sup>-1</sup>, which falls within Category 2 on the PSII-HEq index. Although categories 3 and 4 fall below this guideline, they still represent biologically relevant concentrations. However, the following points about category 3 and 4 concentrations should be noted:

- The published scientific papers indicate that the reductions in photosynthesis at these concentrations are reversible when the organism is no longer exposed to the pesticide.
- Detecting a pesticide at these concentrations does not necessarily mean that there will be an ecological effect on the plants and animals present. In particular, prolonged (i.e. chronic) exposure at these concentrations may be required to elicit an adverse effect.
- Categories 3 and 4 have been included as they indicate an additional level of stress that plants and animals may be exposed to. When combined with other stressors (e.g. sediment, temperature, salinity, pH, storm damage and elevated nutrient concentrations), the ability of these organisms to recover may be reduced.

Classifying the data into index categories provides an indication of the extent and frequency of exposure to PSII herbicides at a given site (and the potential consequences for marine organisms). The PSII-HEq concentrations used in the index are calculated from the combined toxicity of diuron, hexazinone, atrazine and its breakdown products, tebuthiuron, ametryn, prometryn, simazine, terbutryn and flumeturon, all of which are used to control weeds and other plant species in the Reef catchment and all of which are regularly detected in the Marine Park.

While the PSII-HEq index is used for assessing ecological risk in the Reef report card 2016, an alternative method is expected to be included in future reports. This method predicts the proportion of species in an ecosystem that may be adversely affected by exposure to a mixture of pesticides, known as the multisubstance potentially affected fraction, or ms-PAF (Traas et al., 2002). The recommended protection level for the Reef is ≤1% of species affected. This approach can be used to assess the combined risk from pesticides with the same toxic mode of action (as with the PSII-HEq index), and for pesticides with different modes of action. The latter allows inclusion of emerging pesticides that have been identified as alternatives to the traditional PSII herbicides, and which are increasingly being used in the Reef catchments. The ms-PAF approach is based on species sensitivity distributions, which are also used to derive water quality guidelines. The transition from evaluation of risk based on single species data to multiple species using species sensitivity distributions is underway (Grant et al., 2017), but requires further validation for the marine environment before it can be included in the Reef report card scores.

## ***Seagrass***

Abundance, reproductive effort and tissue nutrient status are used to assess and report on inshore seagrass condition (McKenzie et al., 2017).

Seagrass abundance is assessed as the average percent cover of seagrass per monitoring site according to the seagrass abundance guidelines documented by McKenzie et al. (2015) and McKenzie et al. (2003). The 80th, 50th and 20th percentiles used to define the guidelines are recommended for Queensland Water Quality Guidelines (Department of Environment and Heritage Protection, 2009) and there is no evidence to suggest that applying this approach to assess the condition and trend of Reef seagrass meadows would be inappropriate. Developing guidelines for individual sites requires 3–10 years of monitoring data with a minimum of 18 observations with no identified impacts, depending on the variability for the site. This sample size is reasonably close to the recommendation of 24 data values in the ANZECC and ARMCANZ (2000) water quality guidelines. By plotting the percentile estimates with increasing sample size, the reduction in error becomes apparent as it moves towards the true value (McKenzie et al., 2015). The seagrass abundance guidelines can then be applied to determine seagrass condition for each monitoring event. For example, if median abundance is at, or above, the 50th percentile for that site, the condition is considered 'good'.

Reproductive effort is the ratio of the average number of reproductive structures (spathe, fruits, female and male flowers) of plants on an area basis relative to the long-term average. It provides an indication of the capacity for seagrass meadows to recover following disturbances.

The nutrient status of seagrass is based on the ratio of carbon to nitrogen in leaf tissue, and reflects the level of nutrients in the surrounding waters relative to the amount of light the plant is receiving to grow.

In 2015–16, seagrass was monitored in five representative habitat types throughout the Reef: estuarine, coastal intertidal, coastal subtidal, reef intertidal and reef subtidal meadows. The additional Cape York sites (established in 2012), four subtidal sites in the Wet Tropics and Burdekin regions (established in 2008), and two intertidal sites in the Burdekin region (established in 2012) were included in the overall assessments of Reef seagrass ecosystem condition. Also included were additional sites in Cape York (Lloyd Bay), Wet Tropics (Goold Island and Missionary Bay), Burdekin (Shelley Beach), Mackay Whitsunday (Hydeaway Bay, Pioneer Bay, Tongue Bay and Newry Bay) and Burnett Mary (Burrum Heads) monitored by Seagrass-Watch and by QPWS drop-camera programs, which included monitoring the presence of foundation and other seagrass species (McKenzie et al., 2017).

## **Corals**

Five indicators are now used to assess and report on inshore coral reef condition—coral cover, coral cover change, juvenile coral density, coral community composition and proportional macroalgal cover. Further detail about the selection and scoring of these indicators is documented in Thompson et al., (2017).

Coral cover is a measure of the abundance of hard and soft corals, and indicates the capacity of coral to persist under the current environmental conditions. Coral cover also represents the availability of brood-stock required for the ongoing supply of future coral generations.

Coral change is a measure of the observed change in hard coral cover compared to modelled predictions. A healthy and resilient coral reef is expected to show an increase in coral cover during periods free from disturbances and this indicator directly assesses the rate of coral cover increase over the rolling four years of monitoring.

Juvenile density is a measure of the abundance of hard-coral juvenile colonies (up to five centimetres in diameter), standardised to the space available for coral settlement. It indicates the ongoing replacement of corals necessary to recover from disturbances or stress.

Coral community composition is a measure of changes in the relative abundance of coral species from a baseline. If the composition of communities moves beyond the standard error of their baseline condition toward a community indicative of higher concentrations of nutrients and turbidity, a score of zero is returned. Conversely, a score of one is given if the change is toward a community indicative of improved water quality conditions (Thompson et al., 2017).

Macroalgal cover is a measure of the proportion of algae cover that is classified as large, fleshy algae. A low score for macroalgae (i.e. poor or very poor) means macroalgal cover is high, which is indicative of poor water quality. Conversely, a high score for macroalgae (i.e. good or very good) means cover is low. High macroalgal cover, once established, reduces the recovery of corals by denying them space or by producing chemical deterrents that limit the recruitment and growth of coral.

Coral monitoring occurs in Wet Tropics, Burdekin, Mackay Whitsunday and Fitzroy whereas no coral monitoring occurs in the Cape York or Burnett Mary regions under the Marine Monitoring Program.

Coral scores also incorporate monitoring of inshore reefs undertaken through the [Australian Institute of Marine Science's Long-Term Monitoring Program](#).

## Qualitative confidence rankings

eReefs modelled water quality



Seagrass



Coral



A multi-criteria analysis was used to qualitatively score the confidence in each indicator used in the Reef report card, from low to high. The approach combined expert opinion and direct measures of error for program components where available.

Water quality received a three-bar confidence ranking, seagrass received a four-bar confidence ranking and coral received a four-bar confidence ranking. Note that confidence rankings for water quality apply to the open coastal area whereas rankings for seagrass and coral reflect the specific sites monitored.

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