The Current Pesticide Risk Condition (2019/2020) of Waterways that Discharge to the Great Barrier Reef

Reef 2050 Water Quality Improvement Plan

Queensland Government

Prepared by: Water Quality and Investigations Unit, Environmental Monitoring and Science Group, Department of Environment and Science

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Glossary

Term	Definition
Baseline Condition	An estimate of the risk posed by pesticides in the Pesticide Risk Baseline that covers the years 2015/2016 to 2017/2018.
Basin	An area of land that contains one or more catchments. Examples of basins on the east coast of Queensland include the Mulgrave-Russell basin that includes the Mulgrave River catchment and the Russell River catchment; the Johnstone basin that includes the North Johnstone River catchment and South Johnstone River catchment; the Haughton basin that includes the Haughton River catchment and Barratta Creek catchment. There are 35 basins that drain into the Great Barrier Reef lagoon.
Catchment	An area of land where all surface water drains to a single point of discharge to marine waters.
Current Condition	An estimate of the risk posed by pesticides in a particular year following the establishment of the most recent Pesticide Risk Baseline. For example, the Current Condition referred to in this report is for the year 2019/2020. In the Reef Water Quality Report Card the term Pesticide Current Condition was replaced by Pesticide Risk Condition as this was felt to be more meaningful to the target audience.
GBR	Great Barrier Reef
Great Barrier Reef Catchment Area (GBRCA)	All the land where the surface water is discharged to the marine waters of the Great Barrier Reef World Heritage Area. There is a spatial hierarchy used in this report. The GBRCA contains 6 Natural Resource Management (NRM) regions. The 6 NRM regions contain 35 basins. Each basin may contain one or more catchments.
Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP)	A program conducted by the Queensland Department of Environment and Science. It monitors total suspended solids, nine forms of nutrients and a suite of pesticides in selected creeks and rivers that discharge to the Great Barrier Reef. Further information can be obtained from: https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/modelling-and-monitoring#story-map
Insecticides	This is a group of pesticides designed to kill or inhibit insects. Examples include: aldicarb, chlorpyrifos, DDT, imidacloprid and permethrin.
Insecticide toxicity	The toxicity exerted by insecticides included in the Pesticide Risk Metric (i.e., chlorpyrifos, fipronil and imidacloprid) that are present in water samples.
Multi-substance potentially affected fraction (msPAF) approach	An approach for estimating the toxicity of mixtures of chemicals. It uses species sensitivity distributions to convert the concentration of individual chemicals to toxic units, then applies a model for mixture toxicity (either concentration addition or response addition) and calculates the fraction of species that are estimated will experience adverse effects (toxicity).
Natural Resource Management Region (NRM	Areas of land and water that have been designated by state and territory governments and are recognised by the Australian Government. Within each NRM region is an organisation responsible for managing the natural resources of the

Term	Definition
region)	region. There are six NRM regions that contain waterways that discharge to the Great Barrier Reef; these are Cape York, Wet Tropics, Burdekin, Mackay Whitsundays, Fitzroy and the Burnett Mary.
Other Herbicides	A term used to denote all herbicides other than PSII herbicides that are included in the Pesticide Risk Metric. These are: haloxyfop, imazapic, metsulfuron-methyl, pendimethalin, s-metolachlor, metolachlor, 2,4-D, MCPA, fluroxypyr, triclopyr, isoxaflutole.
Other Herbicides toxicity	The toxicity exerted by all Other Herbicides included in the Pesticide Risk Metric that are present in a water sample.
Pesticide Risk Baseline (PRB)	An estimate of the risk that Total Pesticides, PSII Herbicides, Other Herbicides and Insecticides pose to aquatic ecosystems at the mouth of rivers, basins, regions and the entire Great Barrier Reef Catchment Area for the period 2015/2016 to 2017/2018.
Pesticide Risk Condition	In the Reef Water Quality Report Card the term Pesticide Current Condition was replaced by Pesticide Risk Condition as this was felt to be more meaningful to the target audience. The Pesticide Risk Condition is an estimate of the risk posed by pesticides in a particular year (2019/2020 in the current report) following the establishment of the most recent Pesticide Risk Baseline.
Pesticide Risk Metric (PRM)	The group of methods used, in part, to calculate the Pesticide Risk Baseline. The components of the metric are: the multi-substance potentially affected fraction (msPAF) approach, multiple imputation and response addition to calculate the average per cent of species protected during the wet season. Details of the metric are provided in Warne et al. (2020a).
PSII Herbicides	These are herbicides that inhibit the photosystem II component of the photosynthetic process. Specifically, they bind to the plastoquinone B (QB) protein binding site on the D1 protein in PSII which prevents the synthesis of adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH) and therefore prevents the conversion of CO_2 to carbohydrates. PSII herbicides included in this report are: ametryn, atrazine, diuron, hexazinone, metribuzin, prometryn, simazine, tebuthiuron and terbuthylazine.
PSII Herbicide toxicity	The toxicity exerted by PSII herbicides included in the Pesticide Risk Metric (i.e., ametryn, atrazine, diuron, hexazinone, metribuzin, prometryn, simazine, terbuthylazine and tebuthiuron) that are present in water samples.
Reef Report Card	A report card that reports on progress made to meeting the catchment and water quality targets set out in the Reef 2050 Water Quality Improvement Plan.
Reef 2050 Water Quality Improvement Plan (WQIP)	A plan jointly developed by the Australian and Queensland governments that sets out to improve the quality of water entering and in the Great Barrier Reef lagoon. It has an overall goal and catchment and water quality targets that are to be achieved and help drive improvement.
Total Pesticide Toxicity	An estimate of the toxicity of up to 22 pesticides that are included in the Pesticide Risk Metric (Warne et al., 2020a). The 22 pesticides are: 2,4-D, ametryn, atrazine, chlorpyrifos, diuron, fipronil, fluroxypyr, haloxyfop, hexazinone, imazapic,

Term	Definition
	imidacloprid, isoxaflutole, MCPA, metribuzin, metolachlor, metsulfuron-methyl, pendimethalin, prometryn, simazine, tebuthiuron, terbuthylazine and triclopyr.

Executive Summary

The Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) (Australian and Queensland governments, 2018a) sets catchment management and water quality targets to reach the desired outcome of 'Good water quality sustains the Outstanding Universal Value of the Great Barrier Reef, builds resilience, improves ecosystem health and benefits communities.' The Reef Water Quality report cards report progress towards meeting those targets. The initial water quality target for pesticides was to reduce the annual load (mass) of pesticides in waterways that discharge to the Great Barrier Reef lagoon. However, the harmful effects of pesticides are not related to mass but rather to concentration and the duration of the exposure. Therefore, the pesticide target was changed to a reduction of the risk posed by pesticides to aquatic organisms (Australian and Queensland governments, 2018a). The 2025 target for pesticides is to 'protect at least 99% of aquatic species at the end-of-catchments' that drain to the GBR lagoon (Australian and Queensland governments, 2018a). When reporting progress to this target in the Reef Water Quality report cards, progress is measured at the basin (referred to as 'catchment' in the report cards), regional and whole Great Barrier Reef scales.

In order to report on progress towards a target, a starting position (baseline) needs to be determined. The baseline risk that pesticides posed to aquatic organisms compared to the pesticide target was determined in the Pesticide Risk Baseline project (Warne et al., 2020a). The Pesticide Risk Baseline was determined using pesticide monitoring data for 2015/2016 to 2017/2018, and was reported in the Reef Water Quality Report Card 2017 and 2018 (https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card).

A method for measuring the risk posed by pesticide condition on an annual basis was developed (Warne et al., 2020b) and included in the Reef Water Quality Report Card 2019. The method relies on pesticide monitoring data from the long-term Great Barrier Reef Catchment Loads Monitoring Program to adjust the Pesticide Risk Baseline values for each reporting period. The method calculates the risk posed by pesticides in the reporting year. In the previous report (Warne et al. 2020b) this was termed the Current Pesticide Condition; however, in reporting the values from Warne et al. (2020b), the annual Reef Water Quality Report Card adopted the term Pesticide Risk Condition as this was considered more meaningful to the target audience. It is desirable for the terminology to be consistent; however, the complexity of the calculations require that this and future reports use the term Current Pesticide Risk Condition.

The approach, as described here and in the previous report (Warne et al. 2020b), is a similar approach to other indicators in the report card that rely on monitoring data to assess against targets and objectives, such as Wetland Condition, Marine Inshore Condition, Ground Cover, Riparian extent and Wetland extent. While the method is based on the Pesticide Risk Metric that reduces the influence of year-to-year climate variations on the results, some influence is likely to remain. Therefore, Current Pesticide Risk Condition reporting is not used to determine 'progress' towards the pesticide target from the pesticide risk baseline, as is reported for the sediment and nutrient water quality.

There are 35 basins that drain into the Great Barrier Reef lagoon. The Pesticide Risk Baseline estimated that 17 basins met the pesticide target (i.e., protected at least 99% of aquatic species) and therefore there was no need to determine a Current Pesticide Risk Condition estimate for 2019/2020, rather the Current Pesticide Risk Condition was stated as being >99% species protected and having met the pesticide target. Aquatic organisms in those basins faced a very low risk from pesticides. Pesticide monitoring in two basins (the Calliope and Mossman) stopped in 2018/2019 so their Current Pesticide Risk Condition could not be

calculated. The method was used to determine the Current Pesticide Risk Condition (in terms of the percentage of species protected and risk class) for the remaining 16 basins, as well as the 6 Natural Resource Management Regions and the Great Barrier Reef Catchment Area (the definitions of these terms are presented in the Glossary).

Of the 16 basins, it was estimated that 7 faced a low risk, 4 faced a moderate risk, 3 faced a high risk and only 2 basins faced a very high risk from pesticides. The Current Pesticide Risk Condition values ranged from 74.7% to 100.0% of aquatic species being protected at the basin level. The Current Pesticide Risk Condition values for NRM regions ranged from 82.3% species protection for the Mackay Whitsunday region to >99% species protection for the Cape York region[1]. The Current Pesticide Risk Condition for the GBR Catchment Area was estimated to be 96.7% species protection. The Wet Tropics, Burdekin, Mackay Whitsundays, Fitzroy and Burnett Mary NRM regions and the Great Barrier Reef Catchment Area were all estimated to protect less than 99% of aquatic species in 2019/2020. The median relative contributions of PSII Herbicides, Other Herbicides and Insecticides to the Total Pesticide toxicity (refer to Glossary for definitions) in 2019/2020 for the 16 basins with Current Pesticide Risk Condition estimates for 2019/2020 that did not meet the pesticide target, were 57.0%, 34.5% and 7.0%, respectively. The corresponding relative contribution values for pesticide groups in the Pesticide Risk Baseline were 47%, 32% and 17%, respectively (Warne et al., 2020a).

[1] The Current Condition values for all basins in the Cape York region were adopted from the Pesticide Risk Baseline as being > 99% species protected.

Background

In response to deteriorating water quality that adversely affects the health and resilience of the Great Barrier Reef (GBR), the Australian and Queensland governments developed the Reef Water Quality Protection Plan (Australian and Queensland governments, 2003, 2009, 2013), which was revised in 2017 as the Reef 2050 Water Quality Improvement Plan 2017–2022 (Reef 2050 WQIP) (Australian and Queensland governments, 2018a). The Reef 2050 WQIP sets catchment management and water quality targets to reach the desired outcome of 'Good water quality sustains the Outstanding Universal Value of the Great Barrier Reef, builds resilience, improves ecosystem health and benefits communities' (Australian and Queensland governments, 2018a). The water quality targets address fine sediment, nutrients (various forms of nitrogen and phosphorus) and pesticides. Until 2017 the pesticide target was to reduce the annual load (mass) of pesticides in waterways that discharge to the Great Barrier Reef lagoon by 50% (Australian and Queensland governments, 2009) and 60% (Australian and Queensland governments, 2013). However, the harmful effects of pesticides are not dependent on load but rather by the concentration (mass per volume) and the length of time organisms are exposed to the pesticides. Another limitation of the original pesticide target was that the load of each pesticide was treated as being of equal importance, whereas the concentrations at which different pesticides cause harmful effects can vary over several orders of magnitude. Therefore, focussing on reducing the pesticide load could misdirect efforts to improve water quality. For instance, the pesticide with the largest load may be relatively non-toxic whereas a pesticide with a smaller load might be far more toxic. It would be logical, in order to meet the target of reducing the pesticide load, to focus on the pesticide with the largest load, but from a toxicological and ecological point of view it is more important to focus on the most toxic pesticides (the pesticides that cause toxic effects at the lowest concentrations). For these reasons Smith et al. (2017a, b) proposed the pesticide target be changed from loads to risk.

Brodie et al. (2018) subsequently developed a series of basin-specific targets for suspended solids, nutrients and pesticides. The target for pesticides is a risk-based target (as opposed to the load-based target for nutrients and fine sediments) with the aim to protect at least 99% of aquatic species from the harmful effects of all pesticides at the end of catchments that drain to the Great Barrier Reef (GBR) lagoon (Brodie et al., 2018; Australian and Queensland governments, 2018a). The targets developed by Brodie et al. (2018) were adopted into the Reef 2050 Water Quality Improvement Plan (Australian and Queensland governments, 2018a). With the Pesticide Target now being expressed in terms of protecting a certain percentage of aquatic organisms it became necessary to develop a new pesticide risk baseline (starting point) expressed using the same units.

The Pesticide Risk Baseline was developed by Warne et al. (2020a) and reported in the Reef Water Quality Report Card 2017 and 2018 (https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card/2017-2018). It used pesticide concentration data measured by the Great Barrier Reef Catchment Loads Monitoring Program (GBRCLMP) over three years (July 1 2015 to June 30 2018), species sensitivity distributions, the Independent Action model of joint action and a multiple imputation method to estimate the total toxicity of up to 22 pesticides present in water samples. Relationships were then developed between pesticide mixture toxicity and land use, climatic and/or site-specific data. These relationships were used to predict the pesticide mixture toxicity at the 35 basins, 6 NRM regions and the GBR catchment area (GBRCA) that are reported on in the Reef report card.

In order to assess the risk that the 22 pesticides included in the pesticide risk metric (Total Pesticide mixture toxicity) currently pose relative to the pesticide target at each spatial scale, a new method using

monitoring data was developed by Warne et al. (2020b). The current report presents the Current Pesticide Risk Condition values for the 2019/2020 monitoring year that will be included in the 2020 Reef Water Quality Report Card.

Methods

The methods used in the current report were the same as those used in Warne et al. (2020b) to develop Current Pesticide Risk Condition values for the 2019 Reef Report Card. For brevity all the Current Pesticide Risk Condition values for basins, regions and the GBRCA will henceforth be referred to as Current Condition values. Nonetheless, the methods are repeated here so the report can be read without reference to Warne et al. (2020b). The below methods for calculating the Current Condition and the relative contribution of pesticide groups were not used for those basins[2] that had met the pesticide target in the Pesticide Risk Baseline report (Warne et al., 2020a), except for the Daintree, Black, Burdekin and Don. In addition, pesticide monitoring was discontinued in the Mossman and Calliope basins after 2018/2019 and so Current Condition values could not be calculated using the below methods, rather the estimates of percent species protected that were generated in the Pesticide Risk Baseline report (Warne et al., 2020a) are included for reference. As in the 2018/2019 estimates of Current Condition (Warne et al., 2020b) the calculations for the Murray basin use a modelled Baseline Catchment Condition value generated using the pesticide mixture toxicity – land use relationships from the Pesticide Risk Baseline report (Warne et al., 2020a). The confidence in the Current Condition calculation method was re-assessed for the current report as some relevant factors had changed in the intervening period.

Calculating Current Condition

In the following equations the various estimates of Condition use acronyms that consist of two terms. The first term refers to the time that the Condition estimate applies to — either the period covered by the Pesticide Risk Baseline (B) i.e., 2015/2016 to 2017/2018 or to the Current reporting year (C) — in this case 2019/2020. The second term refers to the spatial scale that the Condition estimate applies to — Catchment (Ca), Basin (Ba), region (R) or the Great Barrier Reef Catchment Area (G). Thus, for example, BR is the Baseline Region Condition and CBa is the Current Basin Condition.

Equations 1 to 4 were used to calculate the Current Basin Condition (CBa) values in Table 3, equations 5 to 7 were used to calculate the Current Region Condition (CR) in Table 4, and the equations 8 to 10 were used to calculate the GBRCA Condition (CG) in Table 4. The various estimates of Current Condition were all calculated using Total Pesticide toxicity data (the toxicity of all 22 pesticides included in the Pesticide Risk Metric calculations, Warne et al., 2020a) unless stated otherwise.

Where only a single catchment was monitored in a basin, the Current Basin Condition (CBa) was calculated using

$$\mathrm{CBa} = \mathrm{BBa} \times \left[1 - \left(\frac{\mathrm{BCa} - \mathrm{CCa}}{\mathrm{BCa}} \right) \right] \quad (1)$$

[2] These basins are (from north to south) the Jacky Jacky, Olive Pascoe, Lockhart, Stewart, Normanby, Jeannie, Endeavour, Barron, Black, Burdekin, Don, Styx, Shoalwater, Waterpark, Boyne and Baffle. Where 2019/2020 monitoring occurred in basins that met the Pesticide Risk Baseline target (e.g., Daintree, Black, Burdekin and Don), a Current Condition value was calculated. These values are presented in the report for additional information but will not be reported in the Reef Report Card. Basins that met the target in the Pesticide Risk Baseline (Warne et al., 2020a) are characterised as having land use profiles indicative of a low pesticide risk. Therefore, the risk from pesticides is not expected to change markedly from one year to the next. Pesticide risk will be reassessed for all basins and regions that met the target in 2017 and 2018 with the next update of the Pesticide Risk Baseline or earlier if significant land use changes occur that could increase pesticide runoff.

where BBa is the Baseline Basin Condition, CCa is the Current Catchment Condition (the Condition in 2019/2020) and BCa is the Baseline Catchment Condition (the Condition of the catchment in the Pesticide Risk Baseline – Warne et al., 2020).

Where there are multiple monitored catchments in a basin the Current Basin Condition (CBa) was calculated using Equation 2, which is a modification of equation 1.

$$\mathrm{CBa} = \mathrm{BBa} \times \left[1 - \left(\frac{\boldsymbol{BCa - CCa}}{\mathrm{BCa}}\right)\right. \quad (2)$$

where $\boldsymbol{CCa}$ and $\boldsymbol{BCa}$ are the surface area–corrected averages of the Current Catchment Condition and the Baseline Catchment Condition, respectively. These two terms were calculated using

$$\boldsymbol{CCa} = \left(\frac{\mathrm{CCa_1 \times SACa_1}}{\mathrm{SAB}}\right) + \left(\frac{\mathrm{CCa_2 \times SACa_2}}{\mathrm{SAB}}\right) \ldots \quad (3)$$

$$\boldsymbol{BCa} = \left(\frac{\mathrm{BCa_1 \times SACa_1}}{\mathrm{SAB}}\right) + \left(\frac{\mathrm{BCa_2 \times SACa_2}}{\mathrm{SAB}}\right) \ldots \quad (4)$$

where the numerical subscripts indicate the catchment, SACa is the surface area of a catchment and SAB is the surface area of the basin the catchment is located in (surface area values are provided in Warne et al., 2020a). Equations 3 and 4 adjust the contribution of each catchment according to their contribution to the surface area of the basin they are located in. Thus, the larger the percentage of the basin that a catchment occupies, the greater its influence on the Current Basin Condition (CBa) and the Baseline Basin Condition (BBa).

The corresponding equations used to calculate the Current Region Condition (CR) were

$$\mathrm{CR} = \mathrm{BR} \times \left(\frac{\boldsymbol{CBa}}{\boldsymbol{BBa}}\right) \quad (5)$$

where BR is the Baseline Region Condition, $\boldsymbol{CBa}$ and $\boldsymbol{BBa}$ are the surface area-corrected averages of the Current Basin Condition and the Baseline Basin Condition, respectively. Equation 5 is equivalent to equation 2. There is no equivalent to equation 1 at the region scale as there are always more than one basin in a Region. The latter two terms in equation 5 were calculated using

$$\boldsymbol{CBa} = \left(\frac{\mathrm{CBa_1 \times SABa_1}}{\mathrm{SAR}}\right) + \left(\frac{\mathrm{CBa_2 \times SABA_2}}{\mathrm{SAR}}\right) + \ldots \quad (6)$$

$$\boldsymbol{BBa} = \left(\frac{\mathrm{BBa_1 \times SABa_1}}{\mathrm{SAR}}\right) + \left(\frac{\mathrm{BBa_2 \times SABa_2}}{\mathrm{SAR}}\right) + \ldots \quad (7)$$

where the numerical subscripts indicate the basin, SAB is the surface area of a basin and SAR is the surface area of the region the basin is located in.

The corresponding equations used to calculate the Current Great Barrier Reef Catchment Area Condition (CG) are

$$\mathrm{CG} = \mathrm{BG} \times \left(\frac{\boldsymbol{CR}}{\boldsymbol{BR}}\right) \quad (8)$$

where BG is the Baseline Great Barrier Reef Catchment Area Condition, $\boldsymbol{CR}$ and $\boldsymbol{BR}$ are the surface area-corrected averages of the Current Region Condition and the Baseline Region Condition, respectively. The latter two terms were calculated using

$$\boldsymbol{CR} = \left(\frac{\mathrm{CR_1 \times SAR_1}}{\mathrm{SAG}}\right) + \left(\frac{\mathrm{CR_2 \times SAR_2}}{\mathrm{SAG}}\right) + \ldots \quad (9)$$

$$\boldsymbol{BR} = \left(\frac{BR_1 \times SAR_1}{SAG}\right) + \left(\frac{BR_2 \times SAR_2}{SAG}\right) + \ldots \quad (10)$$

where the numerical subscripts indicate the region, SAR is the surface area of a region and SAG is the surface area of the GBRCA. Equations 9 and 10 were used in equation 8 as there are multiple regions within the GBRCA.

Calculating the Relative Contribution of Each Group of Pesticides

In the Pesticide Risk Baseline (Warne et al., 2020a), four estimates of pesticide mixture toxicity were calculated. These were the toxicity of photosystem II inhibiting herbicide mixtures (PSII Herbicides); other herbicide mixtures (Other Herbicides); insecticide mixtures (Insecticides) and the total toxicity of pesticides (Total Pesticides — the PSII Herbicides, Other Herbicides and Insecticides combined). Understanding which chemical groups contribute to risk in a waterway is important to inform policy and make improvements to land management practices. Therefore, the Pesticide Risk Baseline determined the relative contribution of each pesticide group and this was included in the Reef Water Quality Report Card 2017 and 2018 (Pesticide Risk Baseline), the Reef Water Quality Report Card 2019 (Current Condition), and is calculated herein for the Reef Water Quality Report Card 2020 (Current Condition) (https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card). The relative contributions of individual pesticides for 2016/2017 to 2018/2019 are diagrammatically provided in the Great Barrier Reef annual Catchment Loads Monitoring Program story maps (https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/modelling-and-monitoring#story-map).

The method used to calculate the relative contribution of each pesticide group had two stages. First, the Current Basin Condition values were calculated for each group of pesticides. Second, the relative contribution to the Total Pesticide Toxicity (from all 22 chemicals) was calculated. The equations used to determine the Total Pesticide Toxicity for basins (equations 1 to 4) were used except that all Condition values for Total Pesticides were replaced by the corresponding values for PSII Herbicides, then for Other Herbicides and finally for Insecticides.

Once the Current Basin Condition values were obtained for PSII Herbicides, Other Herbicides and Insecticides, they were converted from % species protected to % species affected (i.e., 100% - % species protected). The Current Basin Condition (% affected) values for PSII Herbicides, Other Herbicides and Insecticides were summed. The relative contribution for PSII Herbicides was calculated for each basin using equation 11.

$$\text{Relative contribution (PSII)} = 100 \times \left(\frac{\%\ \text{affected}_{PSIIs}}{\sum \%\ \text{affected all groups}}\right) \quad (11)$$

where % affected$_{PSII}$ is the estimated % of species affected by PSII Herbicides for a basin and Σ % affected all groups is the estimated sum of the % species affected by PSII Herbicides, Other Herbicides and Insecticides for the same basin.

The relative contribution of Other Herbicides (OH) and Insecticides (I) of each basin were calculated using equations 12 and 13, respectively.

$$\text{Relative contribution (OH)} = 100 \times \left(\frac{\%\ \text{affected}_{OH}}{\sum \%\ \text{affected all groups}}\right) \quad (12)$$

$$\text{Relative contribution (I)} = 100 \times \left(\frac{\%\ \text{affected}_{I}}{\sum \%\ \text{affected all groups}}\right) \quad (13)$$

where % affected$_{OH}$ and % affected$_{I}$ are the estimated % of species affected by Other Herbicides and Insecticides, respectively for a basin.

All the relative contribution values were calculated using the above method except for the Murray Basin, where the relative contributions are based directly on measured concentrations for the Murray catchment. This was done for two reasons:

- the Murray is the only basin where no pesticide monitoring data were available for the period included in the Pesticide Risk Baseline (2015/2016 to 2017/2018); and
- while the pesticide mixture toxicity versus land-use relationships were validated as part of the Pesticide Risk Baseline, it was not possible to validate or ground truth the model predictions for the Murray River due to the lack of monitoring data for this basin.

Classification of the Risk Posed by Pesticides

The system of classifying the risk posed by pesticides used in the Pesticide Risk Baseline project (Warne et al., 2020a) was used. This system indicates the magnitude of the risk posed by pesticides using five risk classes ranging from very low to very high risk. These classes were based on the ecological condition used in the Australian and New Zealand water quality guidelines (ANZECC and ARMCANZ, 2000; ANZG, 2018) to determine the appropriate level of protection that should be provided to an ecosystem. The resulting classification scheme is presented in Table 1. In determining the risk classification all pesticide mixture toxicity values were rounded one decimal place.

Table 1. Per cent of species affected and protected with the corresponding risk category and ecological conditions from the Australian and New Zealand water quality guidelines (from Warne et al., 2020b)

Pesticide Mixture Toxicity		**Risk class**	**Ecological condition (ANZECC and ARMCANZ, 2000)**
% Species affected	**% Species protected**		
≤ 1	≥ 99	Very low	High ecological value
> 1 to 5	95 to < 99	Low	Slightly to moderately disturbed
> 5 to 10	90 to < 95	Moderate	Highly disturbed
> 10 to 20	80 to < 90	High	
> 20	< 80	Very High	

Calculation of the Confidence of the Method of Estimating Current Condition

The confidence in the Current Condition calculation method was determined using the method in Warne et al. (2020b). This uses the standard semi-quantitative assessment method used to determine the confidence of all methods that are incorporated into the Reef Water Quality Report Cards (Australian and Queensland governments, 2018b) except that a different method for assessing representivity was used. The alternate method for assessing representivity was developed specifically for the Current Condition calculations (Warne et al., 2020b) as the standard method was not appropriate.

The alternate representivity assessment method is semi-quantitative and considers two key factors:

1. The percentage of the basin monitored by the selected catchments; and
2. The similarity in percent land use values of the basin and the catchment.

The method results in three levels of representivity: high, moderate and low. How the representivity level was determined is presented in Table 2.

Table 2. The method of determining the level of representivity. Both criteria (percent of the basin and percent land use values) for high or low representivity must be met in order to be allocated high or low representivity. If both criteria are not met for high or low representivity then the representivity is classed as moderate. The highest level of representivity that has both criteria met is the allocated representivity

Level of representivity	**Requirements in terms of**	
	Percent of the basin	**Percent land use values**
High	The catchment must be at least 70% of the surface area of the basin[1]	The percent land use values in the catchment and basin must be essentially the same[2]
Moderate	Do not meet the criteria for high or low representivity[3]	
Low	The catchment is 50% or less of the surface area of the basin[1]	The percent land use values in the catchment are markedly different from those of the basin[2]

[1] When representivity was determined for NRM regions this requirement is that the basin must be at least 70% of the surface area of the region. When the representivity was determined for the GBRCA this requirement is that the region must be at least 70% of the GBRCA. [2] When representivity was determined for NRM regions this requirement is that the percent land use values in the basin and the region must be essentially the same. When representivity was determined for the GBRCA, the requirement is that the percent land use values in the region and the GBRCA must be essentially the same. [3] If one of the criteria for High is not met, then the level of representivity is Moderate. Similarly, if one of the criteria for Low is not met, then the level of representivity is Moderate.

The representivity of the Current Condition values for regions and the GBR Catchment Area were determined by awarding a value of 1, 2 or 3 for Current Basin Conditions that had low, moderate or high representivity, respectively. These values for basins were then averaged for each region and converted back to a classification. Essentially, the same process was used to estimate the representivity of the GBR Catchment Area except that it was based on the Current Region Condition values.

The confidence assessment was conducted at three spatial scales: basins, regions and the GBR Catchment Area. The overall confidence at all spatial scales was determined using a weighting system. The weighting scheme was:

Overall confidence = (28 x basin representivity value) + (6 x region representivity value) + (1 x GBRCA representivity value)

The weightings used reflect the fact that there were 28 basins, 6 regions and only 1 GBRCA (Table 4) in the Current Condition calculations. The overall score was then converted to confidence dots using the method in Australian and Queensland governments (2018b) and reported in Table 6.

Results

Current Condition Values for Basins

The Current Basin Condition (CBa)[3] was not calculated for those basins reported in the Reef Report Card 2017 and 2018 (https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card) and in the Pesticide Risk Baseline (Warne et al., 2020a) as having met the pesticide target. Thus, the CBa was not calculated for the Baffle, Barron, Boyne, Endeavour, Jacky Jacky, Jeannie Lockhart, Normanby, Olive Pascoe, Stewart, Shoalwater, Styx and Waterpark basins (Table 3). For these basins the Baseline Basin Condition was adopted as the Current Basin Condition. Where 2019/2020 monitoring occurred in basins that met the Pesticide Risk Baseline target (e.g., Daintree, Black, Burdekin and Don), a Current Condition value was calculated. These values are presented in the report for additional information but will not be reported in the Reef Report Card. It should be noted that as of July 1 2019, the Mossman and Calliope basins, which did not meet the pesticide target in the Pesticide Risk Baseline (Warne et al., 2020a) were not monitored for pesticides and hence their Current Condition could not be calculated. Rather the Baseline Basin Condition values (Warne et al., 2020a) are presented in this report for reference (Table 3). The Reef Report Card reports on all basins that met the target in the Pesticide Baseline report (Warne et al., 2020a) and those basins for which 2019/2020 Current Condition values were derived. Thus for 2019/2020 the Reef Report Card will only report on 33 basins (Table 3).

Table 3. The Baseline (2015/2016 to 2017/2018) and Current (2019/2020) Basin Condition values for the basins included in the Reef Water Quality report cards, representivity ratings for the Current Basin Condition values and the monitoring status of the basins (for colour of the cells, refer to Table 1).

Basin	Baseline Basin Condition (BBa) % species protected (risk category*)	2019/2020 Monitored GBRCLMP Catchments that correspond to the basins	2019/2020 Current Basin Condition (CBa) % species protected (risk category*)	Representivity of CBa**
Cape York Region				
Jacky Jacky	100 (Very low)	Not monitored	100[a]	
Olive Pascoe	100 (Very low)	Not monitored	100[a]	
Lockhart	100 (Very low)	Not monitored	100[a]	
Stewart	100 (Very low)	Not monitored	100[a]	
Normanby	100 (Very low)	Not monitored	100[a]	
Jeannie	100 (Very low)	Not monitored	100[a]	
Endeavour	100 (Very low)	Not monitored	100[a]	
Wet Tropics Region				

[3] In the Reef Water Quality Report Card the terms Current Basin Condition, Current Region Condition and Current Great Barrier Reef Catchment Area Condition were replaced by Pesticide Risk Condition as this was felt to be more meaningful to the target audience.

Basin	Baseline Basin Condition (BBa) % species protected (risk category*)	2019/2020 Monitored GBRCLMP Catchments that correspond to the basins	2019/2020 Current Basin Condition (CBa) % species protected (risk category*)	Representivity of CBa**
Daintree	100 (Very low)	Daintree River at Lower Daintree	100[c]	
Mossman	91 (Moderate)	Not monitored	91[b]	
Barron	100 (Very low)	Not monitored	100[a]	
Mulgrave Russell	91 (Moderate)	Mulgrave River at Deeral	93.1 (Moderate)	High
		Russell River at East Russell		
Johnstone	92 (Moderate)	Johnstone River at Coquette Point	93.9 (Moderate)	Moderate
Tully	93 (Moderate)	Tully River at Euramo	96.2 (Low)	Moderate
Murray	91 (Moderate)	Murray River at Bilyana	96.6 (Low)	Low
Herbert	94 (Moderate)	Herbert River at Ingham	94.3 (Moderate)	Moderate
Burdekin Region				
Black	99 (Very low)	Black River at Bruce Highway	98.7[c]	Low
Ross	97 (Low)	Ross River at Aplins Weir	97.1 (Low)	Moderate
Haughton	86 (High)	Haughton River at Giru Weir Tailwater	83.4 (High)	Moderate
		East Barratta Creek at Jerona Road		
Burdekin	99 (Very low)	Burdekin River at Home Hill	98.8[c]	High
Don	100 (Very low)	Don River at Bowen	100[c]	
Mackay Whitsunday Region				
Proserpine	91 (Moderate)	Proserpine River at Glen Isla	89.7 (High)	Low
O'Connell	84 (High)	O'Connell River at Caravan Park	85.5 (High)	Low
Pioneer	76 (Very high)	Pioneer River at Dumbleton Pump Station (HW)	74.7 (Very high)	High
Plane	71 (Very high)	Plane Creek at Sucrogen Weir	76.5 (Very high)	Low
		Sandy Creek at Homebush		
Fitzroy Region				
Styx	99 (Very low)	Not monitored	99[a]	
Shoalwater	99 (Very low)	Not monitored	99[a]	
Waterpark	100 (Very low)	Not monitored	100[a]	

Basin	Baseline Basin Condition (BBa) % species protected (risk category*)	2019/2020 Monitored GBRCLMP Catchments that correspond to the basins	2019/2020 Current Basin Condition (CBa) % species protected (risk category*)	Representivity of CBa**
Fitzroy	96 (Low)	Fitzroy River at Rockhampton	94.9 (Moderate)	High
Calliope	98 (Low)	Not monitored	98[b]	
Boyne	99 (Very low)	Not monitored	99.0[a]	
Burnett Mary Region				
Baffle	99 (Very low)	Not monitored	99.0[a]	
Kolan	96 (Low)	Kolan River at Booyan Boat Ramp	98.1 (Low)	Low
Burnett	97 (Low)	Burnett River at Quay Street Bridge	98.2 (Low)	High
Burrum	92 (Moderate)	Elliott River at Riverview Boat Ramp	95.5 (Low)	Moderate
		Gregory River at Jarrett's Road		
Mary	95 (Low)	Mary River at Churchill Street	95.0 (Low)	High

[a] These current conditions were not calculated for 2019/2020. Rather they are the Basin Baseline values from the Pesticide Risk Baseline report (Warne et al., 2020a). [b] These values are Baseline Basin values. These were inserted because pesticide monitoring was not conducted at these sites in 2019/2020 but they were monitored in 2018/2019 and if no values were included then the Region and GBRCA current condition values would be affected. [c] While Current Condition values were calculated for 2019/2020 these will be reported in the Reef Water Quality Report Card as 'Target met' because this basin or region was determined to meet the target in the Pesticide Risk Baseline report (Warne et al., 2020a). This classification will not be reconsidered until the next Pesticide Risk Baseline is determined. * The derivation and cut-offs of the risk categories are presented in **Error! Reference source not found.**. ** Representivity of Current Condition calculation is not reported if a basin met the target or was not monitored in the 2019/2020 sampling year (as was the case for the Mossman and Calliope basins). An explanation of how the classification was made is provided in the "Representivity in Reporting on Pesticides" spreadsheet.

Of the 35 basins included in the Reef Water Quality report cards, the Current Basin Condition for 2019/2020 was determined for 16 basins. For the remaining 19 basins the percent of species protected were obtained from the Pesticide Risk Baseline report (Warne et al., 2020a) for reasons already described. Of the 16 basins with Current Basin Condition estimates, 7 had a low risk, 4 had a moderate risk, 3 had a high risk and 2 basins had a very high risk (Table 3). The Baseline Basin Condition estimates for the same 16 basins had 5 basins with low risk, 7 with moderate risk, 2 with high risk and 2 with very high risk (Table 3).

The absolute change in the percentage of species protected between the Baseline Basin Condition (2015/2016 to 2017/2018) and Current Basin Condition (2019/2020) for all basins ranged from 0.0% to 5.6% (Table 3) with a mean absolute change of 1.6%. The risk posed by pesticides in 2019/2020 increased for two basins compared to the Pesticide Risk Baseline (Table 3). However, the risk only increased to the next risk class (i.e., the Fitzroy changed from low to moderate risk and the Proserpine changed from moderate risk to high risk). The risk in 2019/2020 decreased for three basins (Burrum, Murray and Tully) compared to the Pesticide Risk Baseline, but the risk only decreased from moderate to low risk) (Table 3). The risk

classification did not change for the remaining 11 basins (Table 3). These changes in risk generally occurred because the Baseline Basin Condition was close to the upper or lower limit of a risk class and the subsequent small change was sufficient to change the risk class. There was no geographical clustering of the basins that increased or decreased their risk classification.

Current Condition Results for NRM Regions and the GBRCA

The Current Region Condition estimates and the Current GBR Catchment Area Condition estimates are presented in Table 4. The Current Region Condition estimates ranged from 82.3% species protection for the Mackay Whitsunday region to 98.1% species protection for the Burnett Mary region. It is important when interpreting these estimates to remember that they are the weighted averages for the waterways within the region and the GBRCA, and the risk posed by pesticides in individual waterways could be markedly different. For example, while the Current Condition for the Burdekin region is close to the target (i.e., 97.7%) the Current Condition estimates for individual basins range from 83.4% to 100% (Table 4).

The Current Region Condition estimates for all NRM regions were equal to or exceeded 95% species protection apart from the Mackay Whitsunday region (82.3% species protection). For 2019/2020 none of the five NRM regions that were assessed[4] met the pesticide target of protecting at least 99% of species at the mouth of rivers. The Current Condition for the GBR Catchment Area was estimated to be 96.7% species protection, thus the GBR Catchment Area also did not meet the pesticide target in 2019/2020. These estimates are very similar to those reported in the Pesticide Risk Baseline (Warne et al., 2020a), with the maximum difference being an increase of 1.8% species protection for the Mackay Whitsunday region. At the GBR Catchment Area level the Current Condition estimate was 96.7% species protection while in the Pesticide Risk Baseline the reported GBRCA Baseline Condition estimate was 97% species protection. It is important to note that the changes observed between the Current Condition and Pesticide Risk Baseline estimates should not be interpreted as indicating that progress has or has not been made to meeting the pesticide target. This is because the Current Condition estimates do not fully account for climatic variability and thus any observed difference between the Pesticide Risk Baseline and the Current Condition could be entirely or partly due to annual differences in climate.

Table 4. Current Basin Condition values[b] used to calculate Current Region Condition and Current GBRCA Condition, with their risk classification (for colour of the cells, refer to Table 1).

Basin	Current Basin Condition (% species protected)	NRM Region	Current Region Condition (% species protected)	GBRCA	Current GBRCA Condition (% species protected)
Daintree	100.0[a]	Wet Tropics	96.1	GBRCA	96.7
Mossman	91.0[b]				
Barron	100.0[c]				
Mulgrave Russell	93.1				

[4] The Cape York NRM region was not assessed in 2019/2020 as it met the target in the Pesticide Risk Baseline (Warne et al., 2020a).

Basin	Current Basin Condition (% species protected)	NRM Region	Current Region Condition (% species protected)	GBRCA	Current GBRCA Condition (% species protected)
Johnstone	93.9				
Tully	96.2				
Murray	96.6				
Herbert	94.3				
Black	98.7[a]	Burdekin	97.7		
Ross	97.1				
Haughton	83.4				
Burdekin	98.8[a]				
Don	100.0[a]				
Proserpine	89.7	Mackay Whitsunday	82.3		
O'Connell	85.5				
Pioneer	74.7				
Plane	76.5				
Styx	99.0[c]	Fitzroy	95.0		
Shoalwater	99.0[c]				
Waterpark	100.0[c]				
Fitzroy	94.9				
Calliope	98.0[b]				
Boyne	99.0[c]				
Baffle	99.0[c]	Burnett Mary	98.1		
Kolan	98.1				
Burnett	98.2				
Burrum	95.5				
Mary	95.0				

[a] While Current Condition values were calculated for 2019/2020 these will be reported in the Reef Water Quality Report Card as 'Target met' because once a basin, region or the GBRCA was determined to meet the target in the Pesticide Risk Baseline report Warne et al., 2020a) this classification will not be reconsidered until the next Pesticide Risk Baseline is determined. [b] The values for the Mossman and Calliope basins are Baseline Basin Condition values, not Current Basin Condition values. These were inserted because pesticide monitoring was not conducted at these sites in 2019/2020 but they were monitored in 2018/2019 and if no values were included then the Region and GBRCA current condition values would be affected. These values will not be presented in the Reef Water Quality Report Card. [c] These current conditions were not calculated for 2019/2020. Rather they are the Basin Current Condition values from the Pesticide Risk Baseline report (Warne et al., 2020a).

Relative Contribution of Pesticide Groups to the Total Pesticide Toxicity

It is recommended that the relative contribution values of basins where the Current Basin Condition meets the pesticide target (i.e., at least 99% species are protected) are not reported in the Reef Report Card 2020 as with such a small percentage of species being affected the relative contributions are unstable and highly variable. The relative contributions of PSII Herbicides, Other Herbicides and Insecticides to the Total Pesticide Toxicity for each basin are presented in Table 5.

The median relative contributions for all basins of PSII herbicides, Other Herbicides and Insecticides to the Total Pesticide toxicity in 2019/2020 were approximately 57%, 35% and 7%, respectively[5]. The corresponding relative contribution values for pesticide groups in the Pesticide Risk Baseline were 47%, 32% and 17%, respectively (Warne et al., 2020a). The relative contributions of individual pesticides for 2016/2017 to 2018/2019 are diagrammatically provided in the Great Barrier Reef annual Catchment Loads Monitoring Program story maps (https://www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef/modelling-and-monitoring#story-map).

The basins could be divided into five groups based on the relative contributions of the pesticide groups:

- Dominated by PSII Herbicides (Johnstone, Tully, Herbert, Haughton, O'Connell, Plane and Burnett basins)
- Dominated by PSII Herbicides but with a significant contribution by Insecticides (>18%) (Murray, Pioneer and Proserpine basins)
- Dominated by Other Herbicides (Burrum, Fitzroy and Mary basins) but with a significant contribution by PSII Herbicides
- Dominated by Other Herbicides but with a significant contribution by Insecticides (>18%) (Ross and Kolan basins)
- All three groups contribute fairly evenly (Mulgrave-Russell basin).

It is important when interpreting these estimates to remember that they are the area-weighted averages for each basin, and the risk posed by pesticide groups in individual waterways or portions of a waterway (e.g. tributaries or reaches) could be markedly different. A pesticide group may still have an influence on pesticide mixture toxicity at smaller spatial scales (e.g., in individual waterways or portions of a waterway), even if the relative contribution at the basin level is reported as 0% in Table 5. Also, the Current Condition and relative contribution estimates do not fully account for inter-annual climatic variability and thus any observed change could be at least partly be due to this factor.

Table 5. The relative contribution (%) of PSII Herbicides, Other Herbicides and Insecticides for each basin. It is not recommended to include the relative contribution values for the shaded cells as these basins met the pesticide target and the contribution values are unstable. All values have been rounded to whole numbers.

Basin	**Relative contribution of each pesticide group (%)**		
	PSII	**OH**	**I**
Jacky Jacky	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Olive Pascoe	Not assessed (met target in 2017/2018 Reef Water Quality report card)		

[5] The median values do not necessarily sum to 100%, nor would this be expected as these values are determined separately for each pesticide group.

Basin	Relative contribution of each pesticide group (%)		
	PSII	OH	I
Lockhart	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Stewart	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Normanby	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Jeannie	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Endeavour	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Daintree	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Mossman	Not assessed (not monitored in 2019/2020)		
Barron	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Mulgrave Russell	42	25	33
Johnstone	62	38	0
Tully	68	32	0
Murray	64	13	23
Herbert	71	24	5
Black	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Ross	1	77	22
Haughton	59	39	2
Burdekin	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Don	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Proserpine	50	30	20
O'Connell	69	31	0
Pioneer	59	22	19
Plane	55	37	8
Styx	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Shoalwater	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Waterpark	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Fitzroy	31	69	0
Calliope	Not assessed (not monitored in 2019/2020)		
Boyne	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Baffle	Not assessed (met target in 2017/2018 Reef Water Quality report card)		
Kolan	0	69	31
Burnett	67	27	6

Basin	Relative contribution of each pesticide group (%)		
	PSII	OH	I
Burrum	28	72	0
Mary	25	66	9
Median (all unshaded basins)	57	35	7

Confidence of Current Condition Estimates

The confidence scores that were awarded to the Current Condition estimates for basins, regions, the GBRCA and over all spatial scales are presented in Table 6 (Australian and Queensland Governments 2020). The confidence score was high (four stars) at the basin level but decreased as the spatial scale increased, with the GBRCA estimates scoring two stars. When considering all spatial scales together (from basins to the GBRCA) the confidence rating was determined to be to four stars. Justification for this confidence ranking can be found in the GBR Catchment Loads Monitoring Program methods document for the Reef Water Quality Report Card (Australian and Queensland Governments 2020).

Table 6. Table of the confidence score for basins, regions, the GBRCA and overall spatial scales and how these values were determined.

Spatial scale	Maturity of method	Validation	Representivity	Directness	Direct error	Total score	Confidence score
Basin	1.5	3	3	2	2	11.5	****
Region	1.5	1	2	2	1	7.5	**
GBRCA	1.5	1	1	2	1	6.5	**
Overall	1.5	2.6	2.8	2	1.8	10.6	****

Additional Material

An Excel spreadsheet where all the calculations were conducted is available upon request from wqi@qld.gov.au.

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