Determining the Current Pesticide Condition 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.
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 2018/2019.
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://arcg.is/1TG9e1
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 region)	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 region. There are six NRM regions that contain waterways that discharge to the Great Barrier Reef; these are Cape York, Wet Tropics,

Term	Definition
	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 for the period 2015/2016 to 2017/2018.
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. (2020).
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, usually released annually, 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., 2020). The 22 pesticides are: 2,4-D, ametryn, atrazine, chlorpyrifos, diuron, fipronil, fluroxypyr, haloxyfop, hexazinone, imazapic, 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). 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 toward 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., 2020). 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).

Methods for measuring the risk posed by pesticides for comparison against the pesticide target (2018/2019 to 2020/2021) were developed. Three alternative methods were considered and the one adopted in this report was deemed to be the most scientifically rigorous and transparent approach. It 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 adopted method calculates the risk posed by pesticides in the reporting year, termed the Pesticide Current Condition. This 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, Pesticide Current 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.

The selected method was used to determine the Current Condition (in terms of the percentage of species protected and risk class) in 27 basins, 6 Natural Resource Management Regions and the Great Barrier Reef Catchment Area (the definitions of these terms are presented in the Glossary). The Current Condition values ranged from 72.3% to 100% of aquatic species being protected at the basin level. In seven basins, it was estimated that at least 99% of species were protected in 2018/2019 and thus aquatic organisms in those basins faced a very low risk from pesticides. Of the remaining 20 basins, it was estimated that 8 faced a low risk, 6 faced a moderate risk, 5 faced a high risk and only 1 basin faced a very high risk from pesticides. The Current Condition values for NRM regions, apart from Cape York, which was not assessed[1], ranged

[1] The pesticide risk baseline had met the 99% species protection target for all basins in the Cape York region, as reported in the Reef Water Quality Report Card 2017 and 2018. Pesticide risk will be reassessed for all basins and

from 80.7% species protection for the Mackay Whitsunday region to 98.3% species protection for the Burdekin region. The Current Condition for the GBR Catchment Area was estimated to be 97.2% species protection. Therefore, 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 2018/2019. The median relative contributions of PSII Herbicides, Other Herbicides and Insecticides to the Total Pesticide toxicity (refer to Glossary for definitions) in 2018/2019 for the 27 basins that did not meet the pesticide target, were estimated to be 41%, 35% and 13%, respectively, which are similar to those in the Pesticide Risk Baseline (Warne et al., 2020).

The confidence rating of the method for calculating Current Condition was determined using a slight modification of the standard Reef report card method. The confidence rating of Current Condition estimates was determined to be four stars for basins, two stars for regions and one star for the Great Barrier Reef Catchment Area estimate. The confidence rating of the method (across all scales) was two stars.

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.

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 by 50% (Australian and Queensland governments, 2009) and 60% (Australian and Queensland governments, 2013). However, the harmful effects of pesticides are not controlled by the 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. (2020) and reported in the Reef Water Quality Report Card 2017 and 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 pesticides currently pose relative to the pesticide target at each spatial scale, a new method using monitoring data was required. This report examines the suitability of three potential methods, selects the best method and uses it to estimate the Total Pesticide mixture toxicity (Current Condition) for 35 basins, 6 NRM regions and the GBRCA that will be used in the Reef Report Card 2019.

Potential Methods for Estimating Total Pesticide Mixture Toxicity

Three potential methods were identified to calculate the Current Condition for pesticides. A brief explanation of each method, its strengths and limitations are presented below (Table 1). The methods are presented in descending order of preference.

Table 1. Description of three potential methods for estimating the Current Condition (percentage of species protected) presented in descending order of preference

Method	Description	Strengths	Limitations
1. Adjust the Pesticide Risk Baseline Condition values for basins using monitoring data for 2018/2019 (Figure 1)	In this method, the relative difference between the monitoring data from 2015/2016 to 2017/2018 (used to develop the Pesticide Risk Baseline) and that of the current reporting year (2018/2019) is calculated and then used to adjust the Baseline Condition values at the basin, region and GBRCA scales. It will provide an estimate of the Current Condition (percentage of species protected) at a location.	• This method is based on monitoring data in combination with results from the Pesticide Risk Baseline. • It is possible to calculate Current Condition at the basin, NRM Region or GBRCA scales.	• It is only possible to estimate the Current Condition of basins where a catchment within the basin was monitored in 2018/2019 (Figure 1). • Several monitoring sites were discontinued in 2019/2020. Therefore, in the future, there will be fewer basins for which the Current Condition can be estimated and included in Reef report cards. • The method assumes that changes that occur in a monitored catchment also apply to the basin, irrespective of the patterns of land use in the catchment and basin. • The results are an estimate of Current Condition and the effect of climate will not be removed. • This method does not permit reporting on annual progress to the Pesticide Target.

Method	Description	Strengths	Limitations
2. Report the Current Condition for catchments monitored in 2018/2019 (Figure 2)	In this method, monitoring data for 2018/2019 are used to calculate the percentage of species protected (Current Condition) using the Pesticide Risk Metric (Warne et al. 2020).	• There is very high confidence in the reported Current Condition values. • There is no complex modelling involved. • The results are the same as those reported in the Regional report cards and the GBRCLMP StoryMaps (Napel et al., 2019a; 2019b; Water Quality & Investigations, 2020).	• Only the Condition of catchments monitored in 2018/2019 can be reported in the Reef report card. • Pesticide risk is relevant only at the point where sampling occurs (note the difference between Figure 1 and Figure 2). • No Current Condition information is available at the basin, NRM Region or GBRCA scales. • The results are an estimate of Current Condition and the effect of climate will not be removed. • This method does not permit reporting on annual progress to the Pesticide Target.
3. Apply the methods used to calculate the Pesticide Risk Baseline (Warne et al., 2020) to the 2018/2019 monitoring data	In this method, monitoring data for 2018/2019 are used to derive new pesticide mixture toxicity vs. land use relationships (as was done to derive the Pesticide Risk Baseline – Warne et al., 2020). Suitable quality relationships are then used to estimate the percent of species protected at the 35 basins, the 6 NRM regions and the GBRCA.	• The results are calculated using the same method as that used to derive the Pesticide Risk Baseline. • The results are based on monitoring data. • Estimates of the Current Condition are available for the 35 basins, 6 NRM regions or the GBRCA that are reported on in Reef report card.	• There are a limited amount of data available - one year of data at each monitoring site. • Approximately two thirds of the data will be used to derive the relationships that predict pesticide mixture toxicity (Warne et al., 2020) and one third will be used to validate the relationships. • Because of the limited data available (see above) there is no certainty that high quality relationships can be developed. This will then necessitate adopting one of the other methods. • The results would be an estimate of Current Condition and the effect of climate will not be removed. • This method does not permit reporting on progress to the Pesticide Target.

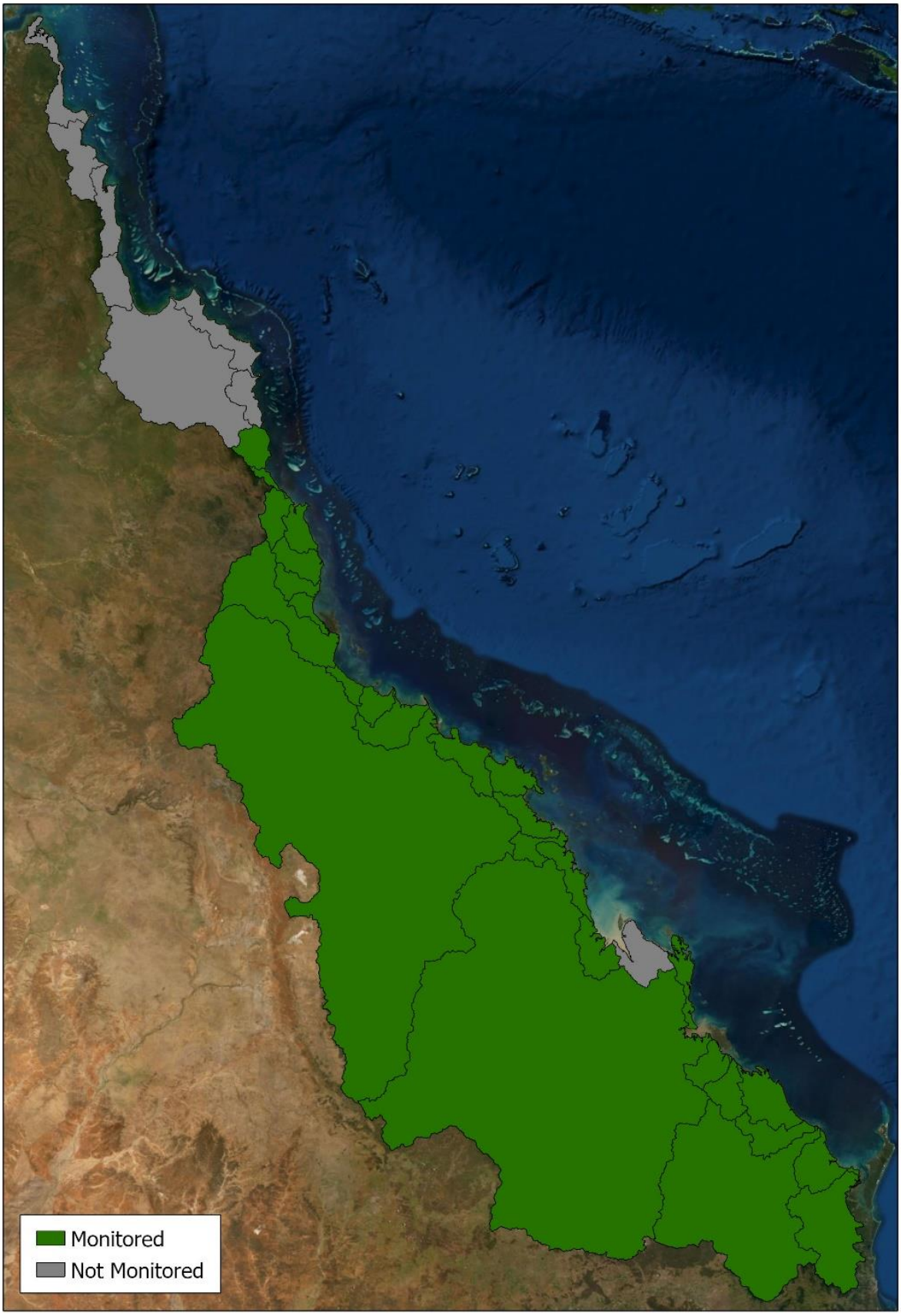

Figure 1. Using method 1, the Current Condition can only be estimated for basins where monitoring occurs. In the 2018/2019 year there was no pesticide monitoring in the Cape York NRM region, or the Shoalwater basin (indicated by the grey shading)

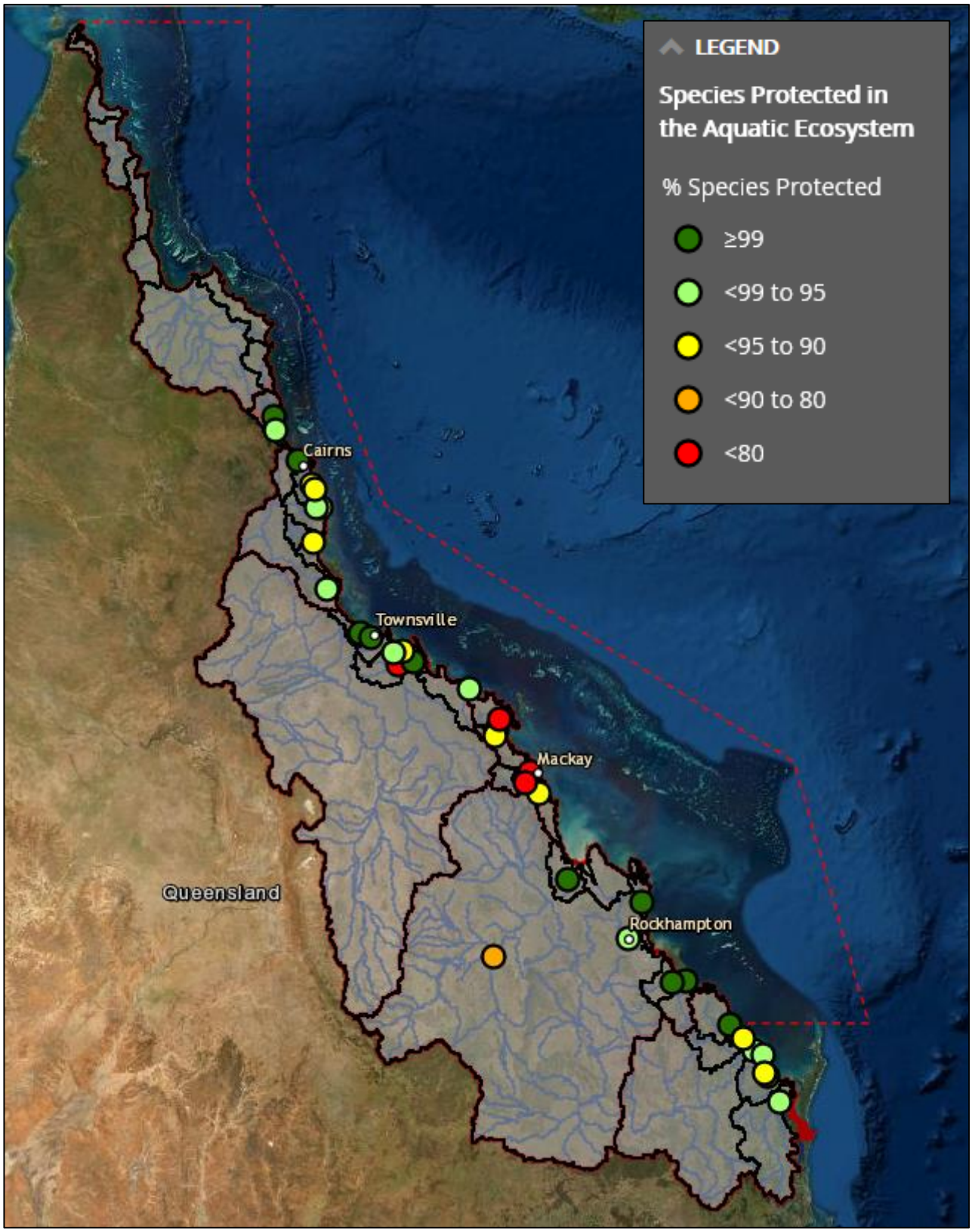

Figure 2. Using method 2, the estimates of Current Condition only apply to the point of the waterway where sampling occurs, not the catchment upstream of the monitoring site, nor the area downstream (image from the 2017—2018 GBRCLMP StoryMap, Napel et al., 2019a)

The first method (Table 1) is the preferred method and was used for estimating the pesticide Current Condition.

Methods

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 2018/2019. 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 Pesticide Risk Baseline Region Condition and CBa is the Current Basin Condition.

The various estimates of Current Condition were all calculated using Total Pesticide toxicity data (the toxicity of all 22 pesticides included in the msPAF calculations, Warne et al., 2020) unless stated otherwise.

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

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

where BBa is the Pesticide Risk Baseline Basin Condition, CCa is the Current Catchment Condition (the Condition in 2018/2019) and BCa is the Pesticide Risk 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.

$$\mathrm{CBa} = \mathrm{BBa} \times \left(\frac{\boldsymbol{BCa} - \boldsymbol{CCa}}{\mathrm{BCa}}\right) \qquad (2)$$

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

$$\boldsymbol{CCa} = \left(\frac{\mathrm{CCa}_1 \times \mathrm{SACa}_1}{\mathrm{SAB}}\right) + \left(\frac{\mathrm{CCa}_2 \times \mathrm{SACa}_2}{\mathrm{SAB}}\right) \ldots \qquad (3)$$

$$\boldsymbol{BCa} = \left(\frac{\mathrm{BCa}_1 \times \mathrm{SACa}_1}{\mathrm{SAB}}\right) + \left(\frac{\mathrm{BCa}_2 \times \mathrm{SACa}_2}{\mathrm{SAB}}\right) \ldots \qquad (4)$$

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. 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

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

where BR is the Pesticide Risk Baseline Region Condition, $\boldsymbol{CBa}$ and $\boldsymbol{BBa}$ are the surface area-corrected averages of the Current Basin Condition and the Pesticide Risk 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

$$\boldsymbol{CBa} = \left(\frac{\mathrm{CBa_1 \, x \, SABa_1}}{\mathrm{SAR}}\right) + \left(\frac{\mathrm{CBa_2 \, x \, SABa_2}}{\mathrm{SAR}}\right) + \ldots \quad (6)$$

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

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

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

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

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

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

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., 2020), 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 and is to be included in the Reef Water Quality Report Card 2019 (https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card).

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.

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

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.

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

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

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

As with the calculation of Current Condition, the relative contribution was not calculated for those basins that met the pesticide target in the Pesticide Risk Baseline report (e.g., the Cape York basins) (Warne et al., 2020). In addition, no pesticide monitoring data were available for Cape York basins for 2018/2019.

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., 2020) and the Reef Water Quality Report Card 2017 and 2018 (https://www.reefplan.qld.gov.au/tracking-progress/reef-report-card) 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 2. In determining the risk classification all pesticide mixture toxicity values were rounded off to the nearest integer.

Table 2. Per cent of species affected and protected with the corresponding risk category and ecological conditions from the Australian and New Zealand water quality guidelines

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

All methods that are incorporated into the Reef Water Quality Report Cards use a semi-quantitative assessment for reporting the confidence of the results they generate (Australian and Queensland governments, 2018b). Confidence is determined by assessing: the maturity of the method; whether the method has been validated; the representativeness of the data used in the calculation to the indicator being modelled; how directly the data used measures the indicator being reported; and the magnitude of the error in the results. This same approach was used to determine the confidence of the method for estimating Current Condition with one exception. The existing method for assessing the representivity of the method was not appropriate to the data used in calculating the Current Condition values. Therefore, a new method was developed to assess representivity.

The method is a semi-quantitative method that considers two key factors:

1. The percentage of the basin monitored by the selected catchments; and
2. How similar are the 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 in presented in Table 3.

Table 3. 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 it was based on the Current Region Condition values.

Results

Current Condition Values for Basins

The Current Basin Condition (CBa) 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., 2020) as having met the pesticide target. Thus, the CBa was not calculated for the Jacky Jacky, Olive Pascoe, Lockhart, Stewart, Normanby, Jeannie, Endeavour and the Shoalwater basins (Table 4). It should be noted that as of July 1, 2019 several sites were no longer monitored for pesticides and hence their Condition cannot be calculated in the future (Table 4). Decisions made regarding the commissioning or decommissioning of monitoring sites is part of the on-going review of the GBRCLMP and reflects changing monitoring needs, logistics and funding. These sites, in addition to those mentioned above, are the Mossman, Barron, Styx, Waterpark, Calliope, Boyne and the Baffle basins (Table 4). Thus for 2018/2019 the Current Basin Condition can be reported for 27 basins but from 2019/2020 onwards the Current Basin Condition can only be reported for 20 basins[2] (Table 4).

Table 4. Whether or not the Current Basin Condition (CBa) can be reported for basins in 2018/2019 and for 2019/2020 onwards

Basin	**Can the Current Basin Condition be reported in**	
	2018/2019	**2019/2020 onwards[1]**
Cape York Region		
Jacky Jacky	No	No
Olive Pascoe	No	No
Lockhart	No	No
Stewart	No	No
Normanby	No	No
Jeannie	No	No
Endeavour	No	No
Wet Tropics Region		
Daintree	Yes	Yes
Mossman	Yes	No
Barron	Yes	No
Mulgrave Russell	Yes	Yes
Johnstone	Yes	Yes
Tully	Yes	Yes

[2] This number could change if the number of monitoring sites changes after this report is released. Note that omission of monitoring going forward from 2019/20 constitutes a return to a routine monitoring regime. The extra sites were included during 2017/18 to 2018/19 to inform the Pesticide Risk Baseline (Warne et al. 2020).

Basin	Can the Current Basin Condition be reported in	
	2018/2019	2019/2020 onwards[1]
Murray	Yes	Yes
Herbert	Yes	Yes
Burdekin Region		
Black	Yes	Yes
Ross	Yes	Yes
Haughton	Yes	Yes
Burdekin	Yes	Yes
Don	Yes	Yes
Mackay Whitsunday Region		
Proserpine	Yes	Yes
O'Connell	Yes	Yes
Pioneer	Yes	Yes
Plane	Yes	Yes
Fitzroy Region		
Styx	Yes	No
Shoalwater	No	No
Waterpark	Yes	No
Fitzroy	Yes	Yes
Calliope	Yes	No
Boyne	Yes	No
Burnett Mary Region		
Baffle	Yes	No
Kolan	Yes	Yes
Burnett	Yes	Yes
Burrum	Yes	Yes
Mary	Yes	Yes

[1.] Whether or not the Current Basin Condition can be calculated or not could change if the number and location of monitoring sites changes after the release of this report.

Of the 35 basins in the Reef report card, the Current Basin Condition was only determined for 27 basins – the basins of the Cape York Region and the Shoalwater were not included as they met the pesticide target

in the Pesticide Risk Baseline (2015/2016 to 2017/2018)[3]. Of the 27 basins with Current Basin Condition estimates 7 had a very low risk, 8 had a low risk, 6 had a moderate risk, 5 had a high risk and 1 basin had a very high risk (Table 5). The Baseline Basin Condition estimates for the same 27 basins had 9 basins with a very low risk, 6 with low risk, 8 with moderate risk, 2 with high risk and 2 with very high risk (Table 5).

The absolute change in the percentage of species protected between the Baseline Basin Condition (2015/2016 to 2017/2018) and Current Basin Condition (2018/2019) for all basins ranged from 0.0% to 7.5% (Table 5) with a mean absolute change of 1.2%. The risk posed by pesticides in 2018/2019 increased for six basins compared to the Pesticide Risk Baseline (Table 5). However, the risk only increased to the next risk class (i.e., three changed from very low to low risk, one changed from low to moderate risk and two changed from moderate to high risk). The risk in 2018/2019 decreased for three basins compared to the Pesticide Risk Baseline, but the risk only decreased to the next risk class (one changed from low to very low risk, one changed from moderate to low risk and one changed from very high to high risk) (Table 5). The risk classification did not change for the remaining 18 basins (Table 5). 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.

Table 5. The Baseline Basin Condition (BBa), the catchment used to modify the BBa, the Current Basin Condition (CBa) estimates and the representivity of the CBa. Note the basins of the Cape York region and the Shoalwater were not included as they met the Pesticide Target in the Pesticide Risk Baseline and there were no monitoring data available.

Basin	Baseline Basin Condition (BBa) % species protected (risk category*)	Monitored GBRCLMP Catchments that correspond to the basins	Current Basin Condition (CBa) % species protected (risk category*)	Representivity of CBa**
Wet Tropics Region				
Daintree	100 (Very low)	Daintree River at Lower Daintree	99.7 (Very low)	Moderate
Mossman	91 (Moderate)	Mossman River at Bonnie Doon	89.2 (High)	Moderate
Barron	100 (Very low)	Barron River at Rinks Close Jetty	100 (Very low)	High
Mulgrave Russell	91 (Moderate)	Mulgrave River at Deeral	92.4 (Moderate)	High
		Russell River at East Russell		
Johnstone	92 (Moderate)	Johnstone River at Coquette Point	93.5 (Moderate)	Moderate
Tully	93 (Moderate)	Tully River at Euramo	94.8 (Moderate)	Moderate

[3] Basins in Cape York and the Shoalwater, which met the target in the Pesticide Risk Baseline, are also 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.

Basin	Baseline Basin Condition (BBa) % species protected (risk category*)	Monitored GBRCLMP Catchments that correspond to the basins	Current Basin Condition (CBa) % species protected (risk category*)	Representivity of CBa**
Murray	91 (Moderate)	Murray River at Bilyana	95.4 (Low)	Low
Herbert	94 (Moderate)	Herbert River at Ingham	94.4 (Moderate)	Moderate
Burdekin Region				
Black	99 (Very low)	Black River at Bruce Highway	99.3 (Very low)	Low
Ross	97 (Low)	Ross River at Aplins Weir	97.6 (Low)	Moderate
Haughton	86 (High)	Haughton River at Giru Weir Tailwater	84.7 (High)	Moderate
		East Barratta Creek at Jerona Road		
Burdekin	99 (Very low)	Burdekin River at Home Hill	99.3 (Very low)	High
Don	100 (Very low)	Don River at Bowen	100 (Very low)	Low
Mackay Whitsunday Region				
Proserpine	91 (Moderate)	Proserpine River at Glen Isla	83.5 (High)	Low
O'Connell	84 (High)	O'Connell River at Caravan Park	85.2 (High)	Low
Pioneer	76 (Very high)	Pioneer River at Dumbleton Pump Station (HW)	80.5 (High)	High
Plane	71 (Very high)	Plane Creek at Sucrogen Weir	72.3 (Very high)	Low
		Sandy Creek at Homebush		
Fitzroy Region				
Styx	99 (Very low)	Styx River at Ogmore	98.9 (Low)	Moderate
Waterpark	100 (Very low)	Waterpark at Corbett's Landing	100 (Very low)	Moderate
Fitzroy	96 (Low)	Fitzroy River at Rockhampton	95.9 (Low)	High
Calliope	98 (Low)	Calliope River at Old Bruce Highway	98.1 (Low)	Low
Boyne	99 (Very low)	Boyne River at Boyne Island	98.9 (Low)	High

Basin	Baseline Basin Condition (BBa) % species protected (risk category*)	Monitored GBRCLMP Catchments that correspond to the basins	Current Basin Condition (CBa) % species protected (risk category*)	Representivity of CBa**
Burnett Mary Region				
Baffle	99 (Very low)	Baffle Creek at Newton Road	98.9 (Low)	Moderate
Kolan	96 (Low)	Kolan River at Booyan Boat Ramp	100 (Very low)	Low
Burnett	97 (Low)	Burnett River at Quay Street Bridge	98.8 (Low)	High
Burrum	92 (Moderate)	Elliott River at Riverview Boat Ramp	94.0 (Moderate)	Moderate
		Gregory River at Jarretts Road		
		Burrum River at Buxton Boat Ramp		
Mary	95 (Low)	Mary River at Churchill Street	92.4 (Moderate)	High

* The derivation and cut-offs of the risk categories are presented in Table 2. ** An explanation of how the classification was made is provided in the "Representivity in Reporting on Pesticides" spreadsheet.

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. The confidence score was high (four stars) at the basin level but decreased as the spatial scale increased, with the GBRCA estimates scoring one star. When considering all spatial scales together (from basins to the GBRCA) the confidence rating was averaged to two stars.

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	0.5	3	3	2	2	10.5	****
Region	0.5	1	2	2	1	6.5	**
GBRCA	0.5	1	1	1	1	4.5	*
Overall (average)	0.5	2	1	1	2	6.5	**

Current Condition Results for Regions and the GBR

The Current Region Condition estimates and the Current GBR Catchment Area Condition estimates are presented in Table 7. The Current Region Condition estimates ranged from 80.7% species protection for the Mackay Whitsunday region to 98.3% species protection for the Burdekin region. It is important when interpreting these estimates to remember that they are the weighted average 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., 98.3%) the Current Condition estimates for individual waterways range from 84.7% to 100% (Table 5).

The Current Region Condition estimates for all NRM regions exceeded 95% species protection apart from the Mackay Whitsunday region. For 2018/2019 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 97.2% species protection, thus the GBR Catchment Area did not meet the pesticide target in 2018/2019. These estimates are very similar to those reported in the Pesticide Risk Baseline (Warne et al., 2020), with no region changing by as much as 1% species protection. At the GBR Catchment Area level the Current Condition estimate was 97.2% while in the Pesticide Risk Baseline the reported GBRCA Baseline Condition estimate was 97%. It is important to note that the changes observed between the Current Condition and Pesticide Risk Baseline estimates should not be interpreted as indicating 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.

[4] The Cape York NRM region was not assessed in 2018/2019.

Table 7. Current Condition values calculated for basins, natural resource management (NRM) regions and the Great Barrier Reef Catchment Area (GBRCA) with their risk classification (colour of the cells, refer to Table 2).

Basin	Current Basin Condition (% species protected)	NRM Region	Current Region Condition (% species protected)	GBRCA	Current GBRCA Condition (% species protected)
Daintree	99.7	Wet Tropics	95.8	GBRCA	97.2
Mossman	89.2				
Barron	100.0				
Mulgrave Russell	92.4				
Johnstone	93.5				
Tully	94.8				
Murray	95.4				
Herbert	94.4				
Black	99.3	Burdekin	98.3		
Ross	97.6				
Haughton	84.7				
Burdekin	99.3				
Don	100.0				
Proserpine	83.5	Mackay Whitsunday	80.3		
O'Connell	85.2				
Pioneer	80.5				
Plane	72.3				
Styx	98.9	Fitzroy	95.9		
Waterpark	100.0				
Fitzroy	95.9				
Calliope	98.1				
Boyne	98.9				
Baffle	98.9	Burnett Mary	97.8		
Kolan	100.0				
Burnett	98.8				
Burrum	94.0				
Mary	92.4				

Relative Contribution of Pesticide Groups to the Total Pesticide Toxicity

The relative contributions of PSII Herbicides, Other Herbicides and Insecticides to the Total Pesticide Toxicity for each basin are presented in Table 8. The relative contribution was calculated for all basins, other than those of Cape York region and one in the Fitzroy region (Shoalwater basin). However, 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 2019 as with such a small percentage of species being affected the relative contributions are unstable and highly variable. This applies to seven basins - the Barron, Black, Burdekin, Daintree, Don, Kolan and Waterpark.

The median relative contributions for all basins of PSII herbicides, Other Herbicides and Insecticides to the Total Pesticide toxicity in 2018/2019 were 41%, 35% and 13%, respectively. These were similar to the corresponding values in the Pesticide Risk Baseline of 47%, 32% and 17%, respectively (Warne et al., 2020). When the unstable relative contributions (the shaded cells in Table 8) were removed, the median relative contributions of PSII herbicides, Other Herbicides and Insecticides were 51%, 28% and 13%, which were still similar to those in the Pesticide Risk Baseline (Warne et al., 2020).

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

- Dominated by PSII Herbicides (Mossman, Johnstone, Tully, Herbert, Proserpine, O'Connell, Pioneer, Plane and Burnett basins)
- Dominated by Other Herbicides (Ross, Fitzroy, Calliope, Burrum, Mary basins)
- PSII and Other Herbicides jointly dominate (Haughton and Styx basins)
- All three groups contribute fairly evenly (Baffle and Mulgrave-Russell basins)
- Dominated by insecticides (Boyne and Murray basins).

Table 8. 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 relative contribution values are unstable. All values are rounded off to the nearest whole digit and therefore the three values for each basin may not sum to 100 percent.

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			
Lockhart			
Stewart			
Normanby			
Jeannie			
Endeavour			
Daintree	27	0	73
Mossman	54	24	22
Barron	0	76	24
Mulgrave Russell	40	28	33

Basin	Relative contribution of each pesticide group (%)		
	PSII	OH	I
Johnstone	53	36	10
Tully	59	22	18
Murray	41	11	48
Herbert	63	23	14
Black	1	93	7
Ross	2	68	30
Haughton	59	41	0
Burdekin	87	11	2
Don	0	100	0
Proserpine	50	18	32
O'Connell	71	27	2
Pioneer	59	28	13
Plane	63	24	13
Styx	52	47	1
Shoalwater	Not assessed (met target in 2017/2018 Reef Report Card)		
Waterpark	48	35	17
Fitzroy	34	66	0
Calliope	26	67	6
Boyne	16	24	60
Baffle	23	45	32
Kolan	0	66	34
Burnett	78	15	7
Burrum	28	72	0
Mary	39	57	3
Median (all 27 basins)	41	35	13
Median (20 unshaded basins)	51	28	13

Additional Material

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

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