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The Pesticide Risk Baseline

Predicting pesticide mixture toxicity to protect the Great Barrier Reef

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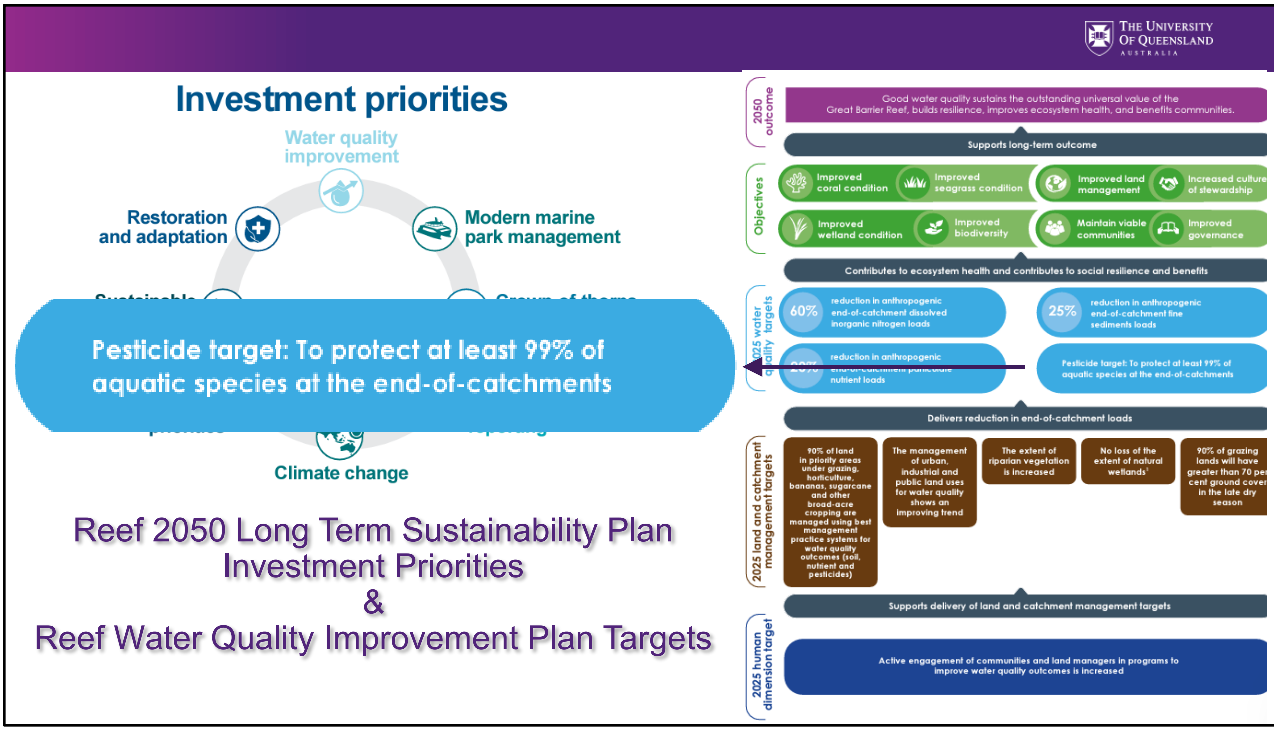

A little background first -

The Australian State and Fed govs have acted to protect the Reef by putting in place the Reef 2050 LTSP that lists WQ Improvement as one of its 8 investment priorities
Sitting underneath is the WQIP that sets WQ targets based on scientific research into the causes of Reef decline – the bits in light blue are the WQ targets
The targets for sediment and nutrients are load based, so we are talking a reduction in the amount of sediment/nutrients in tonnes or kT
Whereas the target for pesticides is worded in terms of ecosystem protection – this means the pesticide target is not amount based, but RISK based
The target is to protect at least 99% of aquatic species at the end of catchments for the combined effects of ALL pesticides (i.e. mixtures)

The Pesticide Risk Metric (PRM) allows for reporting against the Reef WQIP risk-based pesticide reduction target by calculating mixture toxicity on WQ monitoring data
The PRM has been a functional part of regional report cards since 2014 and the greater Reef Plan and WQIP since 2019

The Pesticide Risk Metric (PRM)

PSII herbicides	Other herbicides	Insecticides
Ametryn	2,4-D	Chlorpyrifos
Terbuthylazine	Fluroxypyr	Fipronil
Atrazine	Isoxaflutole	Imidacloprid
Hexazinone	Pendimethalin	
Metribuzin	Triclopyr	
Simazine	Metsulfuron-methyl	
Prometryn	MCPA	
Diuron	Haloxyfop	
Tebuthiuron	Imazapic	
	Metolachlor	

- ✓ Regularly detected
- ✓ Species sensitivity distribution
- ✓ Registered for use in Australia
- ✓ Lab analysis

The PRM is based on the foundational ecotox methods of species sensitivity distributions (SSDs), combined with the Response Addition model of joint toxicity

Warne et al (2023) Estimating the aquatic risk from exposure to up to twenty-two pesticide active ingredients in waterways discharging to the Great Barrier Reef

These are the 22 reference pesticides in the current version on the PRM
To understand the toxicity of pesticides we use the Species Sensitivity Distribution (SSD) method
We follow the Nationally endorsed guidelines to build these SSDs using high quality toxicity data for aquatic species
The key is to have enough data points to adequately represent the ecosystem in question

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Time series mixture toxicity for each water sample (percent affected fraction)

Methods and data

Table 4. Risk categories used to assess pesticide risk

Pesticide Risk Metric value		Risk Category	Ecological Condition (ANZWQG)
% 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	

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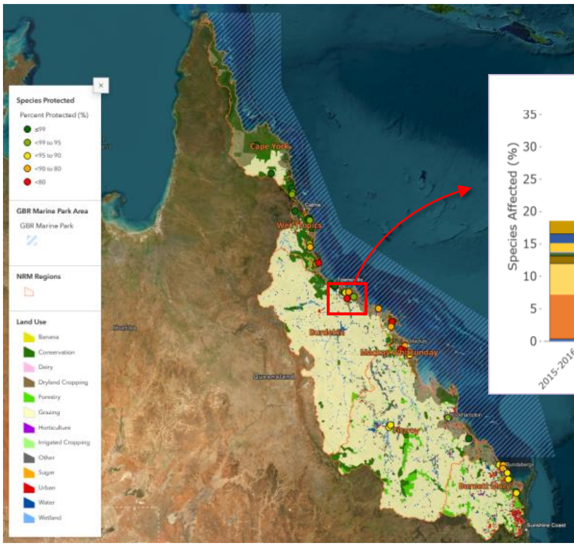
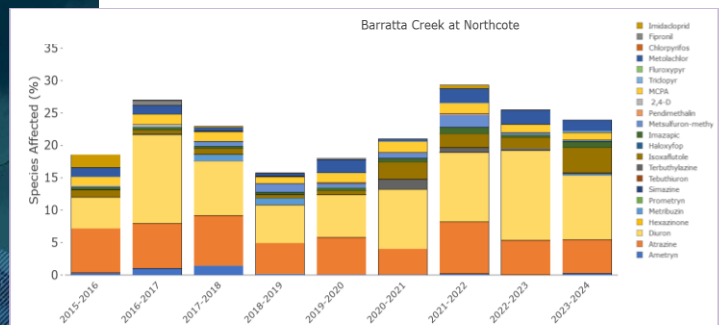
We can run this calculation for every sample in a time series to get an idea of risk over time (exposure)
When overlaid with water level or discharge it is possible to see the impact of runoff events and overland flow
Because we use the same SSD method as the Australian & New Zealand Water Quality Guidelines (ANZGs), the PRM risk categories also align to the ecological condition classes
For example, a Slightly to Moderately Disturbed ecosystem should be >95% protected (light green) and HEV zones like the Great Barrier Reef (GBR) should be >99% protected (dark green)

Data to information

Contribution to risk (pesticide active ingredient)



Each **land use** has specific pesticides that can be applied so we see patterns in this data



Methods and data

Average wet season risk is a way of looking at the magnitude and duration of exposure over time
We would like to see that the ecosystem is either not exposed to risk or has time to recover between episodes
The wet season is chosen as the 'high risk' window when contaminants are most likely to enter a waterway via overland flow

Run the calculations yourself

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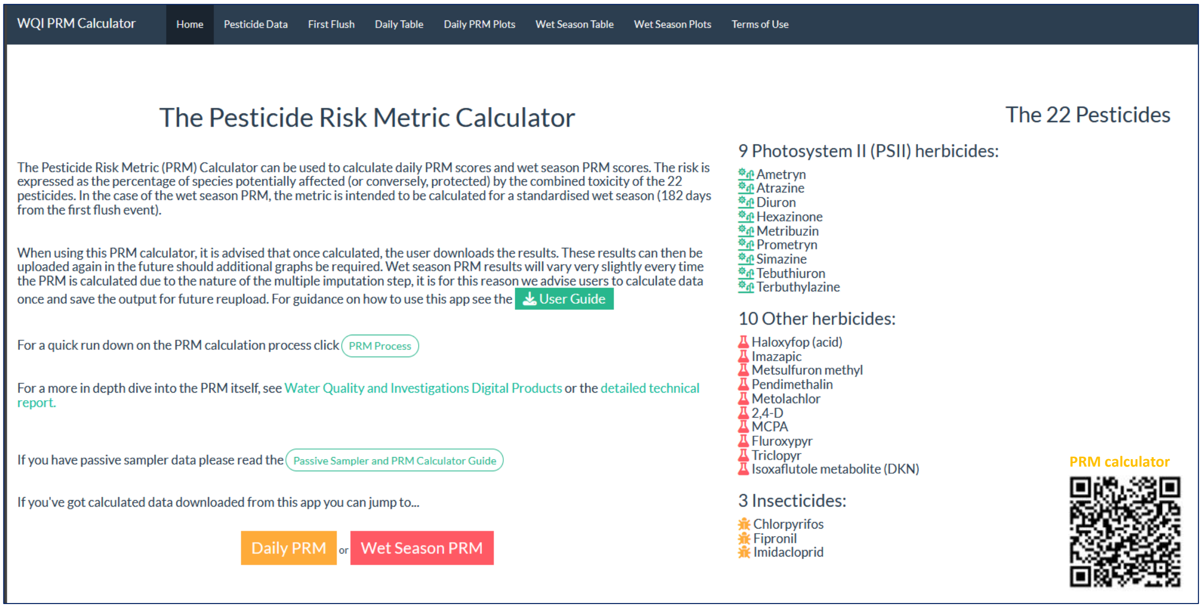

Free R Shiny app

- Methods summaries
- Upload your own data, run calculations, export results
- No need to interact with code
- Automated plotting
- Does not store your data

The Reef report card

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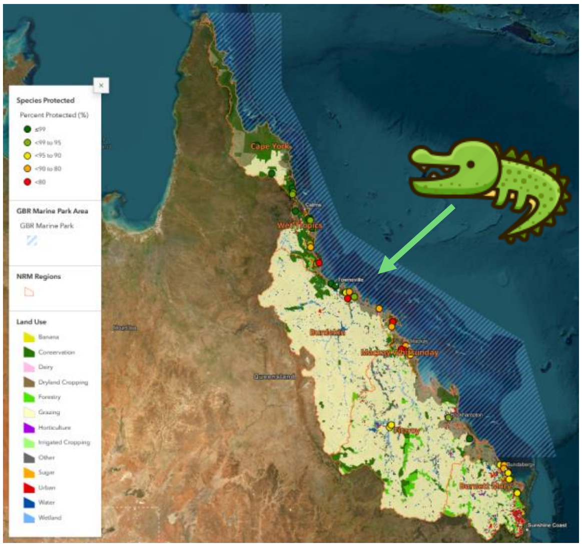
Why did we need to predict mixture toxicity when we have monitoring data already?



We could calculate PRM for all 22 chemicals and the contributing pesticide groups at the monitoring site:

- PSII herbicides
- Insecticides
- Other herbicides (e.g. auxins)

However, the WQIP target is 99% protection at the river mouth for all 35 basins. We also needed to gauge pesticide risk at the NRM and GBR scale for the Reef report card.

The problem:
To develop statistical relationships to fill in 'missing' data for non-monitored areas

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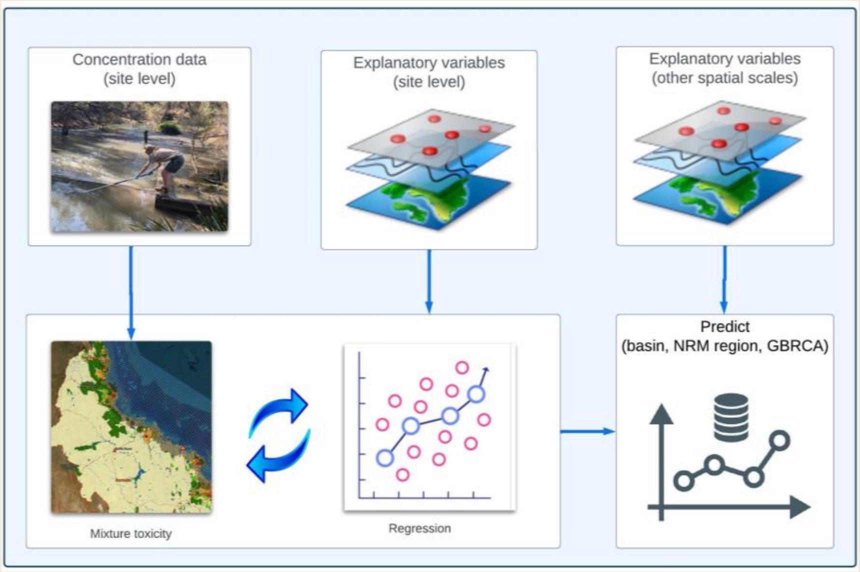
The WQIP pesticide target is for **end-of-catchments** and is reported at the basin, NRM region, and whole of GBR catchment area scales
Our monitoring was as far down in the catchments as possible given safety and logistical constraints (extreme flow events, crocodiles, etc)
Also needed to be able to accurately measure riverine discharge – estuaries are not easy to measure
197 different waterways discharging to the GBR lagoon – can't possibly monitor them all

Predictive model development

Process overview



Iterative approach:

68 unique site/year combinations
- 80% used for training set
- 20% used for validation set

Removal of highly correlated variables to reduce multi-collinearity

Forward and backward step-wise regression for variable selection

Examination of diagnostic plots & assumption testing

Examined Box-Cox and GAM plots to guide data transformations

Removed outliers and/or leveraging sites

To build the models, statistical relationships were developed between pesticide monitoring data, and various land use, spatial, and hydrological variables at the site level. Pesticide monitoring data from the GBRCLMP between 2015 – 2018 were used as the training data set. Once validated, these relationships were used to predict pesticide mixture toxicity at the basin, NRM region, and whole of GBRCA scale for the Great Barrer Reef report card 2017 and 2018 (Australian Government and Queensland Government, 2019).

Variables used in relationships

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Land-use variables	Hydrological variables	Site variables
% Banana	Average rainfall	NRM region
% Conservation	Average % rainfall	Basin
% Dryland Cropping	Maximum rainfall	Catchment
% Forestry	Maximum % rainfall	Latitude
% Grazing Forested	Total rainfall	Longitude
% Grazing Open	Average soil moisture	AMTD
% Horticulture	Total soil moisture	Monitored catchment surface area
% Irrigated Cropping	Maximum soil moisture	
% Sugar	Average % runoff	
% Urban	Maximum % runoff	
% Water		
% Wetland		
% Other		

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30 or so explanatory variables
Land uses variables such as agriculture and urban development were key predictors in the model, highlighting the impact of human activities on pesticide delivery to waterways in the GBR catchment area.

Total toxicity relationship (for the 22 pesticides)

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Variables	Coefficient	Std. Error	Probability
% Dryland cropping	18.09	4.70	0.00036
% Sugar cane	10.09	0.89	2×10^{-16}
% Sugar cane^2	-4.44	0.88	7.59×10^{-6}
% Conservation	-1.83	0.47	0.00033
% Horticulture	-39.55	7.86	7.46×10^{-6}
% Urban	20.48	6.82	0.0043
Intercept	2.68	0.21	2×10^{-16}

Separate models derived for PSII herbicides, Insecticides, and Other herbicides (e.g. auxins, ALS inhibitors)

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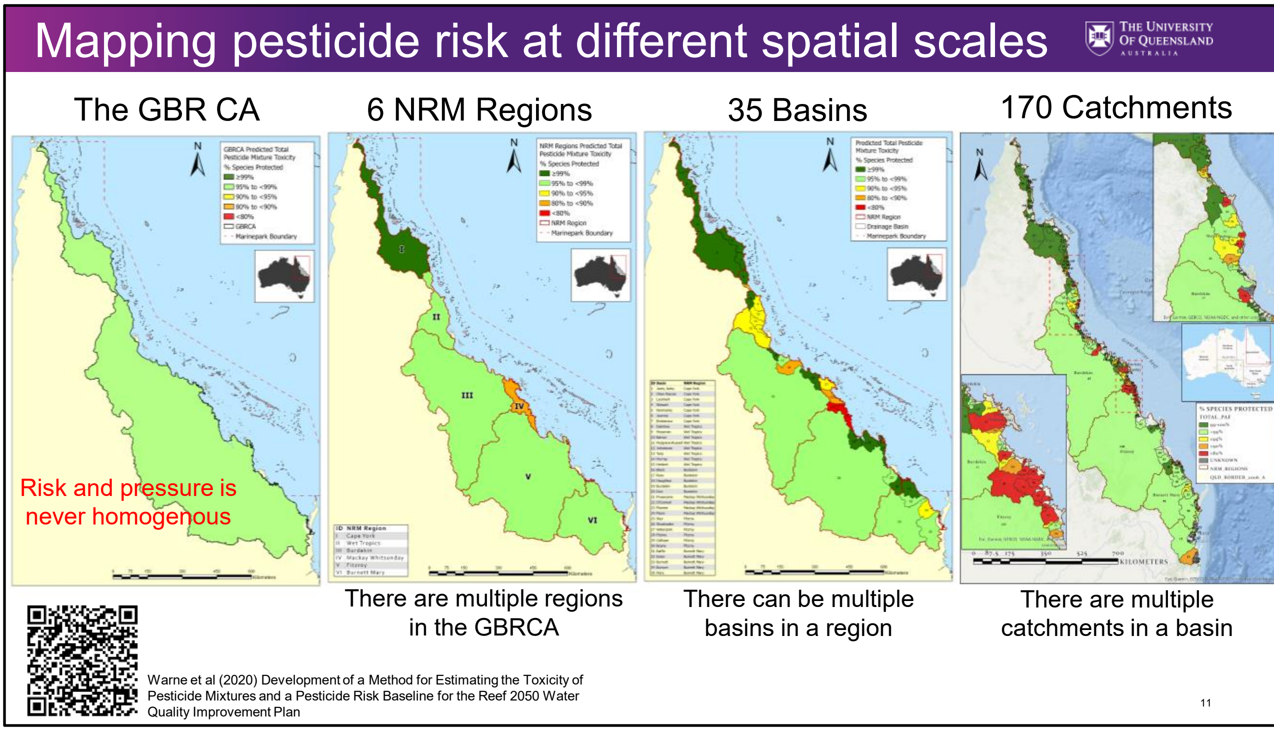
The relationships explain 60 to 80% of the variation in pesticide risk for four pesticide groups: all 22 pesticides, photosystem II (PSII) inhibiting herbicides, other herbicides, and insecticides.

Proportion of sugar cane in the upstream catchment was the strongest predictor of mixture toxicity in all four models



At the largest spatial scale, the entire GBR catchment area achieved 97% protection of aquatic species.
Our findings indicated that 71 to 100% of aquatic species were protected at the basin level.
significant spatial variability was observed across different regions, PSII herbicides were generally the highest contributors to overall mixture toxicity, followed by other herbicides and insecticides.

Reef report card

Providing information to guide investment

The PRB provided an assessment of pesticide mixture risk in the catchments draining to the GBR lagoon, as well as the number and types of pesticides driving the risk (Warne et al., 2020). In addition to providing results for the Reef report card, this information has allowed for the prioritisation of investment for the reduction of pesticide risk to the GBRCA.

Targeted resourcing and outreach

Using the data to create change

Mika Rowston

Enhancing Water Quality in the Great barrier Reef Catchments through Sustainable Agricultural Practices and Technological Innovation

Session J.1, #129

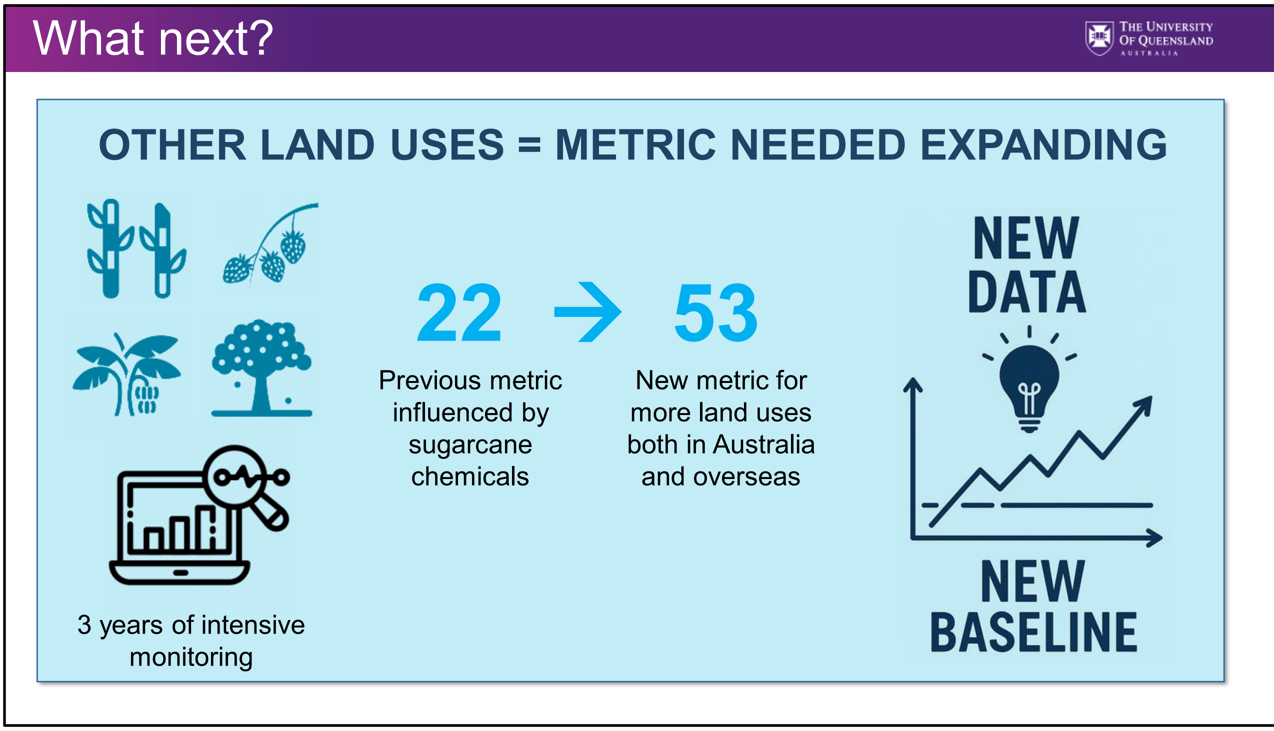
Tuesday 3/06/2025, 1200-1300

Ryan Turner

Water quality improvements for the Great Barrier Reef catchments: Can we achieve change through Carrots and Sticks, or do we also need Golden Nuggets?

Session J.2, #144

Thursday 5/06/2025, 1430-1500



The PRM has recently been expanded from 22 to 53 pesticide active ingredients across multiple modes of action, including fungicides for the first time.

- The new PRM is applicable to a broader range of land uses, both in Australia and overseas
- The number and type of pesticides detected at a site will depend on upstream land use
- For the 22 pesticides with revised SSDs, our understanding of toxicity has improved
- Where possible, data for local species like corals has been added (e.g. NESP project), meaning, the revised risk metric is more relevant to the waters we need to protect

New mixture estimates = we need to redo the predictive models

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Thank you

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The reality…
Pesticides rarely occur in isolation

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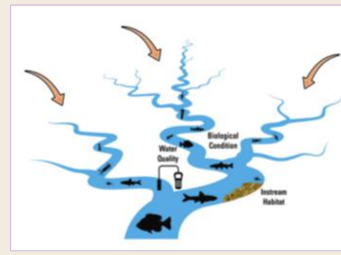
Pesticide mixtures were present in up to 82% of samples from the Great Barrier Reef catchment area between 2011-2016

(3741 samples from 18 river and creek catchments)

Single plant protection product

Combined application of products

Complex mixture in stream



Spilsbury et al 2020

Warne et al 2020

Research has shown that mixtures are the norm out there (not just in Aus but around the world)

Depending on the composition of the mixture and duration of exposure, they can impact the structure, function, and resilience of aquatic ecosystems

The expanded Pesticide Risk Metric

PSII herbicide	Other Herbicide	Insecticide	Fungicide
Ametryn	**2,4-D**	**Chlorpyrifos**	*4-Hydroxy Chlorothalonil*
Amicarbazone	Acifluorfen	Acetamiprid	Carbendazim
Atrazine	Flumetsulam	Bifenthrin	Epoxiconazole
Bromacil	Flumioxazin	Chlorantraniliprole	Flutriafol
Diuron	**Fluroxypyr**	Clothianidin	Mancozeb
Fluometuron	Glyphosate	Diazinon	Propiconazole
Hexazinone	Halosulfuron-methyl	Dimethoate	
Metribuzin	**Haloxyfop (acid)**	Dinotefuran	
Prometryn	Imazamox	**Fipronil**	
Simazine	**Imazapic**	Flupyradifurone	
Tebuthiuron	***Isoxaflutole metabolite (DKN)***	**Imidacloprid**	
Terbuthylazine	**MCPA**	Methomyl	
	Metolachlor	Methoxyfenozide	
	Metsulfuron methyl	Spinetoram	
	Paraquat	Tetraniliprole	
	Pendimethalin	Thiacloprid	
	Picloram	Thiamethoxam	
	Triclopyr		

Bold = included in previous version of Pesticide Risk Metric
Italics = metabolite

Warne et al (2018) Revised method for deriving Australian and New Zealand water quality guideline values for toxicants

These PAIs represent a much broader range of land uses in Aus and many of these chems are important overseas so the metric now has international applicability
Includes a lot more insecticides, and fungicides for the first time
Also included are a number of practice change chems for example flupyradifurone which has been put forward by Bayer a replacement for IMI in sugarcane

The ones in bold are the 22 that were already in the metric to allow for the continuation of historical reporting (tox data behind them has been revised – I'll get to that shortly)
Ones in italics are metabolites

4OH
Isoxaflutole

Key features of the new metric - based on what we've been told about potential practice change or freq of detection in the monitoring data:

- Fungicides for the first time – mainly detected around Hort and bananas
- Insecticides:

- We have added another 5 neonics, making 6 with IMI (Acetamiprid, Clothianidin, Thiacloprid, Thiamethoxam, Dinotefuran). These are prominent in Europe and Canada where the use of IMI has been restricted, but we also see them popping up in the GBRCA, particularly around horticulture in the BM
- We also have possible flupyradifurone which has been suggested as an IMI replacement in cane by Bayer
- Tetraniliprole → which we have been told can be used for stem injection in bananas in the much the same way as IMI
- Diazinon → was thought to be an issue mainly around pineapples in SEQ but we now know it also pops up around bananas and tree crops like macadamias
- Methomyl → carbamate insecticide that can be used for cane grubs and army worms in cane, can also be used against banana weevils, and a variety of pests in mixed hort
- Methoxyfenozide → really only see this around hort in the BM

Herbicide space:
- Halosulfuron methyl → a post-emergent herbicide used to control nutgrass and other sedges in cane
- Bromacil → thought this one was mainly an SEQ issue but it also pops up a lot around SC and hort in the GBRCA. Good for residual weed control.

Other:
- includes fungicides for the first time (mainly found around hort and bananas so will contribute to risk at those sites)
- We have added another 5 neonics, making 6 with IMI (Acetamiprid, Clothianidin, Thiacloprid, Thiamethoxam, Dinotefuran). These are prominent in Europe and Canada where the use of IMI has been restricted, but we also see them popping up at monitoring sites downstream of horticulture.
- We also have possible flupyradifurone which has been suggested as an IMI replacement in cane by Bayer

Also of note:
- Diazinon → was thought to be an issue mainly in SEQ but shows up around cane, hort and bananas through the GBRCA too. PC95 is 0.091ug/L, max detection 2016-2022 is 1.1, det freq up to 44%.
- Methomyl → detected up to 4.7ug/L and 39% around hort and high intensity SC. PC95 is 0.26ug/L so this one will contribute to risk in the PRM
- Methoxyfenozide → mainly detected around hort in the BM. Det freq up to 100% and max detection 17ug/L (2016-2022). The PC95 is 2.2 so this one will contribute to risk.
- Halosulfuron methyl → detected mainly around cane, is quite toxic so will contribute to risk. PC95 is 0.027, det freq up to 40%, max detection

0.36ug/L

- Bromacil → thought this one was mainly an SEQ issue but it also pops up a lot around SC and hort. PC95 is 1.2ug/L, max det freq 84% and max concentration 10ug/L