Supplementary Materials: Estimating the Exposure of Coral Reefs and Seagrass Meadows to Land-Sourced Contaminants in River Flood Plumes of the Great Barrier Reef: Validating a Simple Satellite Risk Framework with Environmental Data

Caroline Petus, Michelle Devlin, Angus Thompson, Len McKenzie, Eduardo Teixeira da Silva, Catherine Collier, Dieter Tracey and Katherine Martin

Table S1. Operational bio-optical algorithms tested for the retrieval of WQ data gradients [1].

In situ WQ Parameter	Satellite WQ Proxy	Algorithm	Reference
chl-a (ug·L^{-1})	chl-a-gsm (ug·L^{-1})	Garver-Siegel-Maritorena (GSM)	[2,3]
	chl-a-oc3 (ug·L^{-1})	Ocean Colour 3 (OC3)	[4,5]
TSS (mg·L^{-1})	nLw(645) (mW·cm^{-2}·um^{-1}·sr^{-1})	SeaDAS standard processing	
	bbp(555)-qaa (555·nm, m^{-1})	Quasi-Analytical Algorithm (QAA)	QAA, [6]
CDOM (m^{-1})	CDOM+D-qaa (443nm, m^{-1})	Quasi-Analytical Algorithm (QAA)	QAA, [6]
	CDOM+D-gsm (443nm, m^{-1})	Garver-Siegel-Maritorena (GSM)	[2,3]
Kd(PAR)	Kd-Morel (490 nm, m^{-1})	Model of Morel	[7,8]
	Kd-Lee (488 nm, m^{-1})	model of Lee	[9]

Table S2. Summary of water quality variables (WQv) and risk assessment classes defined in Brodie *et al.* risk assessment framework [10]. Magnitude and Likelihood categories (VR: Very Rare, R: Rare, O: Occasional, F: Frequent, VF: Very Frequent) and final risk categories (likelihood x magnitude): VL: Very Low, L: Low, M: Medium, H: High, VH: Very High are from published values or estimated by expert opinion. Likelihood categories for TSS and Chl-a are based on frequency of exceedance of the water quality threshold using remote sensing data and PSII categories are based on a recent assessment of to PSII (modified from [10,11]).

	Risk	*VL*	*L*	*M*	*H*	*VH*	**Justification of the Thresholds Used for Risk Magnitude**
WQv	**Thresholds**	**VR**	**R**	**O**	**F**	**VF**	
Total Suspended Solids (TSS) concentration (mg·L^{-1})	(a) 2	<1	1–10	10–20	20–50	50–100	(a) Threshold correlates strongly with declines in ecosystem condition such as increased macroalgal growth and declining diversity. Average annual threshold for TSS in the Great Barrier Reef Water Quality Guidelines.
	(b) 7	0	<1	1–10	10–20	20–100	(b) Threshold is equivalent to a turbidity of 5 Nephelometric Turbidity Units (NTU). Shown to have various ecosystem effects including coral reef stress, declines in seagrass cover [12], fish habitat choice, home range movement and (above 7.5 NTU) foraging and predator-prey relationships [13].
Chlorophyll concentration (µg·L^{-1})	0.45	<1	1–10	10–20	20–50	50–100	Chlorophyll is an indicator of nutrient enrichment in marine waters. A threshold of 0.45 µg L^{-1} has been identified as an important ecological threshold for macroalgal cover, hard coral species richness, octocoral species richness [14]. Annual average threshold for chlorophyll in the Great Barrier Reef Water Quality Guidelines. Significant benefits for the ecological status of reefs in the Region are likely if mean annual chlorophyll concentrations remain below this concentration.

Table S2. *Cont.*

	Risk	*VL*	*L*	*M*	*H*	*VH*	**Justification of the Thresholds Used for Risk Magnitude**
WQv	**Thresholds**	**VR**	**R**	**O**	**F**	**VF**	
PSII Herbicide concentration ($\mu g \cdot L^{-1}$)	(a) 0.025–0.1						(a) No observable effect;
	(b) 0.1–0.5						(b) Photosynthesis is reduced by up to 10% in corals [15]; seagrass [14–17] and microalgae [18,19]. The effect on primary production is minor.
	(c) 0.5–2.3						(c) Photosynthesis is reduced by between 10% and 50% in corals [13], seagrass [16–19] and microalgae [20,21]. The community structure of tropical microalgae can be affected by concentrations of diuron as low as 1.6 μg/L [22]. The effect on primary production is moderate.
	(d) 2.3–10			No information			(d) Photosynthesis is reduced by between 50% and 90% in corals [15,23]; seagrass [17–19] and microalgae [20,21]. A 50% reduction of growth and biomass of tropical microalgae was also reported in this concentration range [20]. The community structure of tropical microalgae is significantly affected and this causes significant changes in the tolerance of microbial communities to herbicides [22]. The effect on primary production is major.
	(e) >10						(e) Reduced growth and mortality in seagrass [18] and loss of symbionts (bleaching) in corals [24,25].

Material and Method

Method and techniques used to classify the true color images (modified from [26,27]) into 6 color classes (this study) and Primary, Secondary, Tertiary water types [1].

The method used to classify the MODIS true color images into six color classes and is detailed in [26], Section 2.1.1 and summarized in Figure S1—step 1 (Classify daily true color satellite images) below. This methods involve converting true colour images from Red-Green-Blue (RGB) to Intensity-Hue-Saturation (HIS) colour schemes, the definition of 6 colour classes corresponding to plume areas and that describe a gradient in the river borne pollutants as well as two classes corresponding to non-plume areas (cloud and sun glint signatures), the creation of spectral signatures for these respective areas, and the utilization of the created spectral signature to map the full extent of the plume.

Color classes (and their respective spectral signature) corresponding to plume and dense clouds and sun glint were created using a MODIS true color image with large plumes occurring along the whole GBR coast to ensure that color variations within plumes along the latitudinal gradient were incorporated into the spectral signature. The selected image included large areas with no plumes, varied atmospheric conditions (light to dense clouds, haze and sun glint), and sections with no data (not covered by satellite swath). To create the spectral signatures, we used the ArcMap Spatial Analyst isodata clustering tool to perform an unsupervised classification of the selected image. The resulting structure allowed characterization of the natural groupings of cells (*i.e.*, pixels within an image) in multidimensional attribute space, *i.e.*, IHS and RGB spaces for plumes and clouds/sun glint, respectively.

Plume maps produced were assessed using different number of classes based on two criteria: how well the mapped classes identified the river plume boundary (we assessed the classified images against visually interpreted true-color imagery); and whether the variation of selected L2 parameters among the color classes showed the expected gradient (as described by Devlin *et al.* [28]). For each classification the mean value of the two L2 parameters for each color class was plotted. Due to reflectance similarities between land and very turbid plumes occurring in the mouth of the rivers, the full image, was classified without masking out land. This allowed to map very turbid/high TSS plume areas commonly found near river mouths, which are frequently flagged incorrectly as land or very dense clouds. The classification was selected based on 6 color classes as the most appropriate for plume mapping. These classes represent a gradient in exposure to pollutants, from highest in class 1 to lowest in class 6.

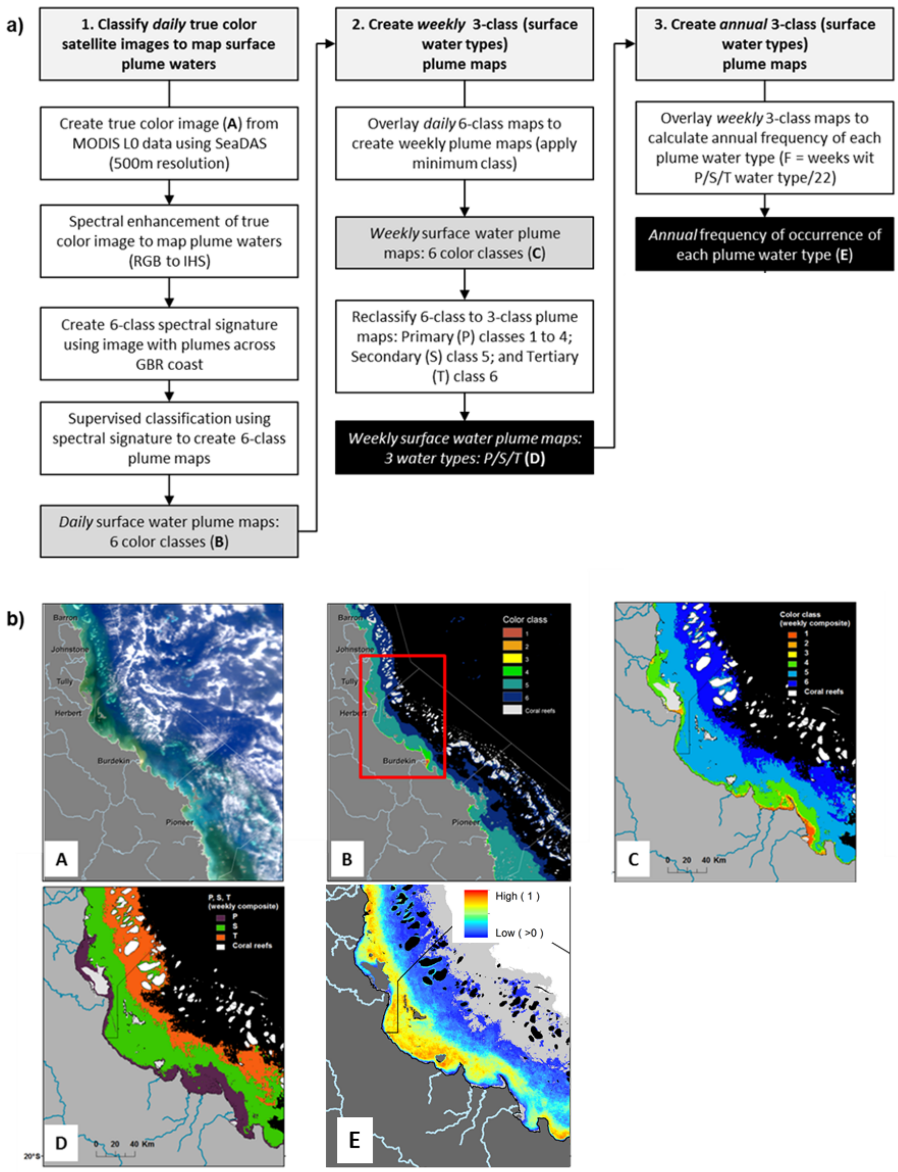

Figure S1. from Devlin *et al.* [26], Modified from [24,25]): Summary of the process followed to build plume water maps with examples of inputs and outputs: (**a**) Plume mapping process: different shadings represent steps (light gray), analyses within steps (white), intermediate outputs (dark gray), and final outputs (black); (**b**) A: MODIS-Aqua true colour image used to create the spectral signature defining 6 color classes for GBR plumes (25 January 2011), B and C: daily 6-color class map (25 January 2011) and weekly composite (19 to 25 January 2011) of 6-class map. D: reclassified map into weekly P, S, T composite (19 to 25 January 2011); E: Frequency of occurrence of the secondary water type in 2011; Figure C to E are zoomed in the Tully-Burdekin area (see red box on panel B).

Finally, a supervised classification was used to map the full extent of plumes and to create a mask representing dense clouds and intense sun glint. Supervised classification uses labeled training data (*i.e.*, the color classes defined in the previous step) to create a spectral signature for each class, which is then used to classify all of the daily input imagery into six-color classes. The ArcMap Spatial Analyst maximum-likelihood classification tool was used to produce: (1) daily 6-class plume maps representing variations in L2 parameters (also used to identify the plume boundary); and (2) masks representing dense clouds and intense sun glint, used to eliminate areas with insufficient information to map plumes. A number of images covering different years, regions and months was selected to confirm the plume extent and overall congruence of our classified plume maps against plume maps produced using the method proposed by Devlin *et al.* [28], and to visually validate the clouds/sun glint masks.

Weekly 6-classes composites were thus created to minimize the amount of area without data per image due to masking of dense cloud cover, common during the wet season, and intense sun glint. The six colour classes can sometimes be reclassified into three plume water types corresponding to the three GBR water types (Primary, Secondary, Tertiary) defined by e.g., [28] (see Figure 1 below; step 2: Create weekly 3-class plume maps). The turbid sediment-dominated waters or Primary water type is defined as corresponding to colour classes 1 to 4 of [26], the chl-a dominated waters or Secondary water type is defined as corresponding to the colour class 5 and the Tertiary water type is defined as corresponding to the colour class 6 [26,27]. Land is thus removed using a shapefile of the Great Barrier Reef (GBR) marine National Resource Management (NRM) boundaries (source: GBRMPA, GBR: Features) and by assigning "No Data" values to any pixels outside of the shapefile boundaries (including land and offshore areas outside of the GBR marine park). Satellite/in-situ match-ups analyses were performed by Devlin *et al.* [27] and validated plume water type maps produced from the re-classification of the colour classes of [26].

Weekly composites were thus resampled at the minimum MODIS spatial resolution (250 × 250 m) using the resampling function of ARCGIS 10.1 and a nearest interpolation resampling technique. This technique uses the value of the closest cell to assign a value to the output cell when resampling ArcGIS.; Weekly composites were thus overlaid (*i.e.*, presence/absence of Primary water type) and normalized, to compute annual normalised frequency maps of occurrence of Primary water type (hereafter annual Primary water frequency maps) (see Figure 1 below, step 3: Create annual 3-class plume maps). Multi-annual normalised frequency composites of occurrence of Primary water types (hereafter multi-annual Primary water frequency composites) are created by overlaying the weekly composites in Arcgis and calculating the median, average and standard deviation frequency values of each cell/year.

Table S3. Proportion of macroalgue in the algal communities (MAp) measured through the MMP. Interpolated data are indicated in italic and with an asterisk.

	MAp		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Burdekin	Geoffrey Bay	GB	73.6	62.5	49.2	41.3	48.6	19.9	66.7	54.2	42.6	73.6
	Havannah Island	HI	49.7	54.0	_*28.2_	2.4	_*1.6_	0.9	_*4.8_	8.7	_*8.7_	49.7
	Lady Elliot	LE	38.3	_*50.5_	62.8	_*54.7_	46.5	_*42.8_	39.1	_*28.7_	18.2	38.3
	Middle Reef	MR	3.1	12.3	_*6.6_	0.8	_*1.8_	2.9	_*11.0_	19.1	_*19.1_	3.1
	Orpheus Island East	OIE	0.0	_*1.0_	1.9	_*1.2_	0.4	0.0	0.8	_*2.1_	3.3	0.0
	Pandora	PAN	78.0	65.8	49.0	17.0	32.0	19.0	40.8	40.4	43.2	78.0
	Pelorus and Orpheus Islands West	POIW	0.0	0.0	0.0	0.0	0.2	0.0	0.3	0.0	0.0	0.0
Fitzroy Basin Association	Barren Island	BI	2.4	4.0	0.6	5.6	4.1	3.0	1.0	0.5	5.9	2.4
	Humpy and Halfway Islands	HHI	49.2	57.9	28.2	39.9	20.5	7.0	66.3	61.1	73.4	49.2
	Middle Island	MI	81.7	_*56.3_	30.9	_*26.2_	21.6	_*40.5_	59.4	_*64.8_	70.3	81.7
	North Keppel Island	NKI	76.9	68.5	_*67.6_	66.7	_*41.8_	16.9	_*32.5_	48.1	65.9	76.9
	Peak Island	PKI	78.1	_*70.5_	62.9	_*43.7_	24.6	33.7	74.5	_*73.3_	72.2	78.1
	Pelican Island	PLI	43.3	54.4	27.5	38.9	10.3	7.2	68.1	58.5	79.9	43.3
Mackay/Whitsunday	Daydream Island	DDI	0.3	8.4	1.9	4.1	1.0	3.7	1.0	4.1	2.8	0.3
	Dent Island	DI	0.3	0.2	_*0.2_	0.2	_*0.2_	0.2	_*0.2_	0.2	_*0.2_	0.3
	Double Cone Island	DCI	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.5	0.2	0.0
	Hook Island	HI	3.0	_*3.2_	3.3	_*3.3_	3.3	_*2.3_	1.2	_*0.6_	0.0	3.0
	Pine Island	PI	23.9	35.4	28.8	28.9	31.9	35.4	35.8	28.8	35.1	23.9
	Seaforth Island	SI	44.8	29.3	_*26.1_	22.9	_*27.9_	32.8	_*34.2_	35.6	_*35.6_	44.8
	Shute and Tancred Islands	STI	0.1	_*0.3_	0.5	_*0.3_	0.0	_*0.6_	1.3	_*1.9_	2.5	0.1

Table S3. *Cont.*

	MAp		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Wet Tropics	Cape Tribulation Mid	CTM	12.8	43.4	13.8	28.3	32.4	47.3	44.0	34.8	43.2	12.8
	Cape Tribulation Nth	CTN	0.6	1.3	1.0	1.4	1.8	2.9	6.8	7.7	1.9	0.6
	Cape Tribulation Sth SOUTH	CTS	0.2	0.1	0.7	**0.6*	0.4	0.3	0.8	**0.8*	0.8	0.2
	Snapper Island North	SIN	0.3	1.8	0.3	1.3	4.4	0.1	1.6	3.0	1.1	0.3
	Snapper Island South	SIS	0.2	14.1	**8.6*	3.0	**13.8*	24.5	**31.1*	37.7	**37.7*	0.2
	Fitzroy Island East	FIE	0.1	13.3	10.8	9.4	16.6	14.8	16.7	21.5	7.2	0.1
	Fitzroy Island West	FIW	0.0	0.0	**0.6*	1.2	**0.7*	0.2	**4.1*	7.9	**7.9*	0.0
	Frankland Group East	FGE	1.7	6.6	9.6	8.6	14.8	7.8	8.7	8.6	6.0	1.7
	Frankland Group West	FGW	0.4	26.2	35.5	28.8	35.4	10.1	36.1	35.1	35.9	0.4
	High Island East	HIE	25.9	**31.3*	36.7	**38.8*	40.9	0.9	48.8	**48.5*	48.3	25.9
	High Island West	HIW	20.7	**51.1*	81.6	**70.3*	59.0	**63.6*	68.2	**69.8*	71.4	20.7
	Dunk Island North	DIN	0.0	25.3	**25.3*	25.4	**14.9*	4.4	**14.1*	23.9	**23.9*	0.0
	Dunk Island South	DIS	73.6	62.5	49.2	41.3	48.6	19.9	66.7	54.2	42.6	73.6
	King	K	49.7	54.0	**28.2*	2.4	**1.6*	0.9	**4.8*	8.7	**8.7*	49.7
	North Barnard Group	NBG	38.3	**50.5*	62.8	**54.7*	46.5	**42.8*	39.1	**28.7*	18.2	38.3

Table S4. Seagrass cover data measured through the MMP. Interpolated data are indicated in italic and with an asterisk.

	Seagrass Cover		2005	2006	2007	2008	2009	2010	2011	2012	2013
Burdekin	Bowling Green Bay	JR	**4.4*	**4.4*	**4.4*	**4.4*	**4.4*	**4.4*	**4.4*	4.4	20.7
	Magnetic Island	MI	34.7	30.6	43.2	28.3	11	7	15.1	28.5	20.9
	Magnetic Island (subtidal)	MI2	**53.6*	**53.6*	**53.6*	53.6	11.8	0.5	6	17.8	27.4
	Townsville	TSV	30.9	16.2	19.9	12.1	7.7	0.9	0	3.2	18.3
Burn. Mary	Rodds Bay	RD	*32.3	*32.3	32.3	30.3	1.3	0.8	0.1	1.1	0
	Urangan	UG	57.3	0	0.2	2.9	6.5	11.7	1.7	9.6	3.2
Fitzroy	Gladstone Harbour	GH	31.2	8.4	24.9	34.6	30.8	35.7	32.6	25.7	29.8
	Great Keppel Island	GK	**5.8*	**5.8*	5.8	1.7	2.3	3.4	2.7	0.8	1.2
	Shoalwater Bay	SWB	33.1	28.7	36.2	26.4	29.2	**21.1*	12.9	9.7	8.7
Mackay Whitsunday	Hamilton Island	HM	**9.7*	**9.7*	9.7	7.8	4.1	5.7	2.4	7.1	3.5
	Midge Point	MP	23.8	25.8	**20.3*	**20.3*	**20.3*	**20.3*	14.7	25.8	33.2
	Pioneer Bay	PI	25.4	25.5	33.4	27.4	34	12.4	0.6	3	15.1
	Sarina Inlet	SI	38.7	3.4	12.7	23.6	7.6	0.5	2.5	4.3	17.6
Wet Tropics	Dunk Island	DI	**12.4*	**12.4*	12.4	15	6.5	2.4	0	0.1	0.3
	Dunk Island (subtidal)	DI2	**6*	**6*	**6*	6	6.1	0.2	0	0.1	0.6
	Green Island	GI	40.2	35.2	37.5	28	36.5	30.8	22.1	28.8	35.1
	Green Island (subtidal)	GI2	**49.9*	**49.9*	**49.9*	49.9	29.5	39.5	36.6	35.3	41.8
	Lugger Bay	LB	3.2	1.2	4.4	7.9	6.6	0.9	0	0	0
	Low Isles	LI	**18.1*	**18.1*	**18.1*	18.1	7	4.2	3.4	2	5.8
	Low Isles (subtidal)	LI2	**19.5*	**19.5*	**19.5*	19.5	7.1	1.4	2.4	2.7	7.5
	Yule Point	YP	8.1	6.2	15.4	22.7	20.1	9.4	2.3	1.3	6.3

Table S5. Mean and standard deviation of water quality concentrations measured in the plume water types (CC1 to CC6).

	WQ Mean ± *stdv*	Tertiary		Secondary		Primary							
		CC6		CC5		CC4		CC3		CC2		CC1	
(a) Predicted concentration	Depth (m)	29.1	±1.3	28.9	±1.8	28.9	±1.3	28.8	±1.1	28.5	±1.6	28.6	±1.4
	Sal.	33.8	±3.6	30.9	±6.3	26.8	±8.3	26.7	±9.3	21.5	±10.3	17.7	±11.2
	CDOM (m^{-1})	0.2	±0.2	0.4	±0.5	0.6	±0.7	0.7	±1.0	1.1	±1.0	1.7	±1.2
	DIN ($mg \cdot L^{-1}$)	1.7	±0.9	1.9	±1.1	2.9	±2.3	3.1	±2.9	4.8	±4.2	5.1	±3.3
	DIP ($mg \cdot L^{-1}$)	0.2	±0.2	0.3	±0.2	0.3	±0.2	0.3	±0.2	0.3	±0.2	0.3	±0.2
	Kd(PAR) (m^{-1})	0.2	±0.1	0.4	±0.3	0.7	±0.5	0.7	±0.5	0.9	±0.6	1.1	±1.0
	TSS ($mg \cdot L^{-1}$)	5.7	±5.3	6.1	±4.5	7.3	±7.0	10.6	±8.4	10.5	±6.0	34.0	±60.8
	Chl-a ($\mu g \cdot L^{-1}$)	0.4	±0.6	0.9	±0.7	1.4	±1.3	2.0	±2.7	2.1	±3.2	2.4	±3.2
	PSII ($\mu g \cdot L^{-1}$) *	0.01	NA	0.01	NA	0.02	NA	0.03	NA	0.03	NA	0.04	0.01

* Wet Tropic data are estimated from a linear statistical model applied on the measured in-situ PSII data.

List of Acronyms

BM: Burnett-Mary (Natural Resource Management region)
Bu: Burdekin (Natural Resource Management region)
CCx: colour classes corresponding to different GBR plume water types (CC1–4: Primary water type, CC5: secondary water type, CC6" tertiary water type)
Chl-a: Chlorophyll-a
CDOM: Coloured Dissolved Organic Matters
CY: Cape York **(**Natural Resource Management region)
DIN: Dissolved Inorganic Nitrogen
DIP: Dissolved Inorgnaic Phosphorus
Fi: Fitzroy (Natural Resource Management region)
GBR: Great Barrier Reef Marine Park
GBRMPA: Great Barrier Reef Marine Park Authority
Kd(PAR): diffuse attenuation coefficient of Photosynthetically Active Radiation
LS_{CCx}: multi-annual Likelihood Score
MMP: Marine Monitoring Program (Available online: http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/reef-2050-marine-monitoring-program)
MAp: proportion of the total cover of algae on a reef that is comprised of macroalgae (as opposed to the cover of macroalgae per se).
MBioIndicator: mean multi-annual seagrass cover and MAp
MODIS: Moderate Resolution Imaging Spectroradiometer
MS_{CCx}: multi-annual Magnitude score (normalized value of R_{CCx})
MW: Mackay-Whitsundays (Natural Resource Management region)
NRM: Natural Resource Management regions
PSII: Photosystem II Herbicides
QAQC: Quality Assurance and Quality Control
R_{CCx}: Ratios between predicted TSS, PSII and Chl-a concentrations in river plumes and corresponding endpoint ecological thresholds. Specific to each colour class (CCx).
RS_{site} and RS'_{site}: "potential" and normalised "potential" river plume risk
SeaDAS: SeaWiFS Data Analysis System
TSS: Total Suspended Solids
ΔBioIndicator: change in seagrass cover and proportion of MAp across years 2005 and 2014
WT: Wet Tropics (Natural Resource Management region)

Reference

1. Petus, C.; Teixera da Silva, E.; Devlin, M.; Álvarez-Romero, A.; Wenger, A. Using MODIS data for mapping of water types within flood plumes in the Great Barrier Reef, Australia: Towards the Production of River Plume Risk Maps for Reef and Seagrass Ecosystems. *J. Environ. Manag.* **2014**, *137*, 163–177.
2. Garver, S.A.; Siegel, D.A. Inherent optical property inversion of ocean color spectra and its biogeochemical interpretation: I. Time Series from the Sargasso Sea. *J. Geophys. Res.* **1997**, doi:10.1029/96JC03243.
3. Maritorena, S.; Siegel, D.A.; Peterson, A.R. Optimization of a semianalytical ocean color model for global-scale applications. *Appl. Opt.* **2002**, *41*, 2705–2714.
4. O'Reilly, J.; Maritorena, S.; Mitchell, B.G.; Siegel, D.A.; Carder, K.L.; Kahru, M.; Garver, S.A.; McClain, C.R. 1998 Ocean color algorithms for SeaWiFS. *J. Geophys. Res.* **1998**, *103*, 24937–24953.
5. O'Reilly, J.E.; Maritorena, S.; O'Brien, M.C.; Siegel, D.A.; Toole, D.; Menzies, D.; Smith, R.C.; Mueller, J.L.; Mitchell, B.G.; Kahru, M.; *et al*. Ocean Color Chlorophyll-a Algorithms for SeaWiFS, OC2 and OC4. In *SeaWiFS Postlaunch Calibration and Validation Analyses Part 3*; Hooker, S.B., Firestone, E.R., Eds.; SeaWiFS Postlaunch Tech. Rep. Ser.; NASA: Washington, DC, USA, 2000; pp. 9–23.
6. Lee, Z.P.; Carder, K.L.; Arnone, R.A. Deriving inherent optical properties from water color: A Multiband Quasi-Analytical Algorithm for Optically Deep Waters. *Appl. Opt.* **2002**, *41*, 5755–5772.

7. Morel, A. Optical modelling of the upper ocean in relation to its biogenous matter content (case 1 waters). *J. Geophys. Res.* **1988**, *93*, 10749–10768.
8. Morel, A.; Huot, Y.; Gentili, B.,Werdell, P.J.; Hooker, S.B.; Franz, B.A. Examining the consistency of products derived from various ocean color sensors in open ocean (Case 1) waters in the perspective of a multi-sensor approach. *Remote Sens. Environ.* **2007**, *111*, 69–88.
9. Lee, Z.P.; Du, K.P.; Arnone, R.A. A model for the diffuse attenuation coefficient of downwelling irradiance. *J. Geophys. Res.* **2005**, doi:10.1029/2004JC002275.
10. Brodie, J.; Waterhouse, J.; Maynard, J.; Bennett, J.; Furnas, M.; Devlin, M.; Lewis, S.; Collier, C.; Schaffelke, B.; Fabricius, K.; *et al*. *Assessment of the Relative Risk of Water Quality to Ecosystems of the Great Barrier Reef. A report to the Department of the Environment and Heritage Protection, Queensland Government, Brisbane*; Report Number 13/28; TropWATER Report 13/28; Australian Centre for Tropical Freshwater Research: Townsville, Australia, 2013.
11. Lewis, S.; Smith, R.; O'Brien, D.; Warne, M.S.J.; Negri, A.; Petus, C.; da Silva, E.; Zeh, D.; Turner, R.D.R.; Davis, A.; *et al*. Assessing the Risk of Additive Pesticide Exposure in Great Barrier Reef ecosystems. In *Assessment of the Relative Risk of Water Quality to Ecosystems of the Great Barrier Reef: Supporting Studies. A report to the Department of the Environment and Heritage Protection, Queensland Government, Brisbane*; TropWATER Report 13/30; Australian Centre for Tropical Freshwater Research: Townsville, Australia, 2013; Chapter 4.
12. Collier, C.J.; Waycott, M.; Giraldo Ospina, A. Responses of four Indo-West Pacific seagrass species to shading. *Mar. Pollut. Bull.* **2012**, *65*, 342–354.
13. Wenger, A.S.; McCormick, M.I. Determining trigger values of suspended sediment for behavioral changes in a coral reef fish. *Mar. Pollut. Bull.* **2013**, *70*, 73–80.
14. De'ath, G.; Fabricius, K.E. Water Quality of the Great Barrier Reef: Distributions, Effects on Reef Biota and Trigger Values for the Protection of Ecosystem Health. In *Final Report to the Great Barrier Reef Marine Park Authority*; Australian Institute of Marine Science: Townsville, Australia, 2008; p. 104.
15. Negri, A.P.; Flores, F.; Röthig, T.; Uthicke, S. Herbicides increase the vulnerability of corals to rising sea surface temperature. *Limnol. Oceanogr.* **2011**, *56*, 471–485.
16. Haynes, D.; Ralph, P.; Prange, J.; Dennison, B. The Impact of the Herbicide Diuron on Photosynthesis in Three Species of Tropical Seagrass. *Mar. Pollut. Bull.* **2000**, *41*, 288–293.
17. Chesworth, J.C.; Donkin, M.E.; Brown, M.T. The interactive effects of the antifouling herbicides Irgarol 1051 and Diuron on the seagrass *Zostera marina* (L.). *Aquat. Toxicol.* **2004**, *66*, 293–305.
18. Gao, Y.; Fang, J.; Zhang, J.; Ren, L.; Mao, Y.; Li, B.; Zhang, M.; Liu, D.; Du, M. The impact of the herbicide atrazine on the growth and photosynthesis of seagrass *Zostera marina* (L.), seedlings. *Mar. Pollut. Bull.* **2011**, *62*, 1628–1631.
19. Flores, F.; Collier, C.J.; Mercurio, P.; Negri, A.P. Phototoxicity of four photosystem II herbicides to tropical seagrasses. *PLoS ONE* 2013, 8, e75798.
20. Magnusson, M.; Heimann, K.; Negri, A.P. Comparative effects of herbicides on photosynthesis and growth of tropical estuarine microalgae. *Mar. Pollut. Bull.* **2008**, *56*, 1545–1552.
21. Magnusson, M.; Heimann, K.; Quayle, P.; Negri, A.P. Additive toxicity of herbicide mixtures and comparative sensitivity of tropical benthic microalgae. *Mar. Pollut. Bull.* **2010**, *60*, 1978–1987.
22. Magnusson, M.; Heimann, K.; Ridd, M.; Negri, A.P. Chronic herbicide exposures affect the sensitivity and community structure of tropical benthic microalgae. *Mar. Pollut. Bull.* **2012**, *65*, 363–372.
23. Jones, R.J.; Kerswell, A.P. Phytotoxicity of photosystem II (PS II) herbicides to coral. *Mar. Ecol. Prog. Ser.* **2003**, *261*, 149–159.
24. Jones, R.J.; Mueller, J.F.; Haynes, D.; Schreiber, U. Effects of herbicides diuron and atrazine on corals of the Great Barrier Reef, Australia. *Mar. Ecol. Prog. Ser.* **2003**, *251*, 153–167.
25. Negri, A.; Vollhardt, C.; Humphrey, C.; Heyward, A.; Jones, R.; Eaglesham, G.; Fabricius, F. Effects of the herbicide diuron on the early life history stages of coral. *Mar. Pollut. Bull.* **2005**, *51*, 370–383.
26. Álvarez-Romero, J.G.; Devlin, M.; Teixeira da Silva, E.; Petus, C.; Ban, N.C.; Pressey, R.L.; Kool, J.; Roberts, J.; Cerdeira,S.; Wenger, A.; *et al*. Following the flow: A Combined Remote Sensing-GIS Approach To Model Exposure of Marine Ecosystems to Riverine Flood Plume. *J. Environ. Manag.* **2013**, *119*, 194–207.

27. Devlin, M.J.; Teixeira da Silva, E.; Petus, C.; Wenger, A.; Zeh, D.; Tracey, D.; Álvarez-Romero, J.; Brodie, J. Combining water quality and remote sensed data across spatial and temporal scales to measure wet season chlorophyll-a variability: Great Barrier Reef lagoon (Queensland, Australia). *Ecol. Process.* **2013**, *2*, 31, doi:10.1186/2192-1709-2-31.
28. Devlin, M.J.; McKinna, L.W.; Álvarez-Romero, J.G.; Petus, C.; Abott, B.; Harkness, P.; Brodie, J. Mapping the pollutants in surface riverine flood plume waters in the Great Barrier Reef, Australia. *Mar. Pollut. Bull.* **2012**, *65*, 224–235.