The relative risk between pollutants on GBR ecosystems and NRM Regions

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with contributions from many others

Contributors

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DEHP for Project funding

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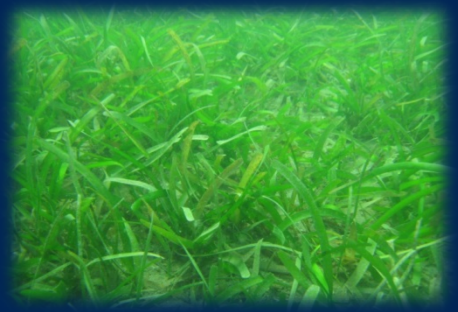
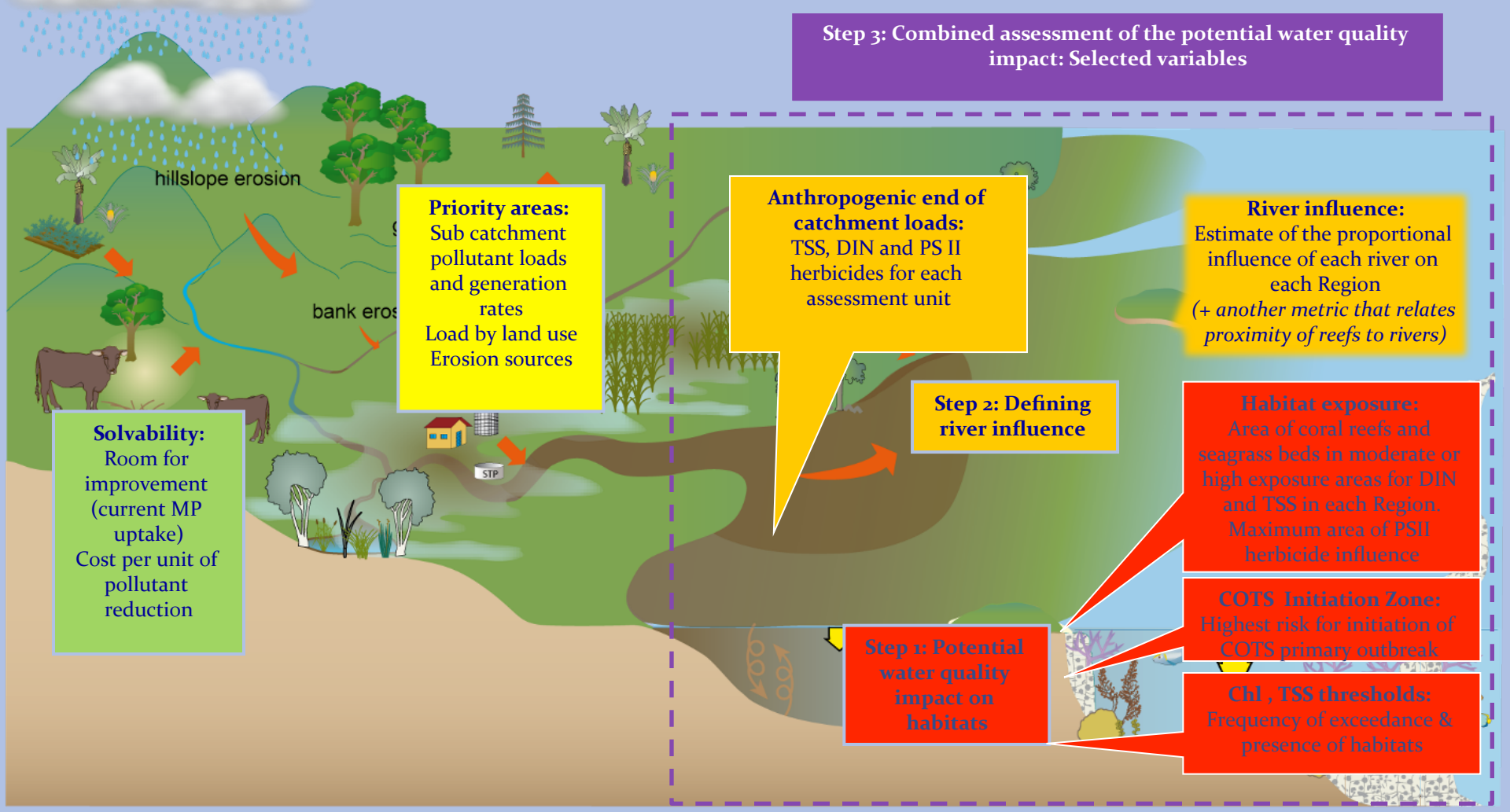
Introduction

- Which issues and what locations to target
- Updated risk assessment undertaken to inform Reef Plan 3 and Reef Rescue 2
  - Follows on from similar exercises at beginning of Reef Plan (2003, 2009) and Reef Rescue
  - 2 aspects - Mathematical risk assessment; supporting studies
  - Combined outputs inform final qualitative / semi-quantitative risk assessment – contributes to SCSU



Scope

- Short timeframe to inform Reef Rescue 2 and Reef Plan 3
- Relative risk of pollutants to GBR marine ecosystems – and specifically corals and seagrass
- Sediments, nutrients (focus DIN), PSII herbicides
- Considering freshwater and estuarine ecosystems in pesticides chapter



Management Prioritisation

- Step 1 Define priority pollutants and priority areas at sub catchment scale
- Step 2: Assess river influence by Regions, pollutants and habitats
- Step 3: Assess relative potential impact by Regions, pollutants and habitats – based on presence of habitat & exceedance of thresholds / exposure
- Step 4: Cumulative assessment of the potential water quality impact - by region and habitats – scores and weightings
- Step 5: Management prioritisation combining all factors using MCAS-S

Combination of information

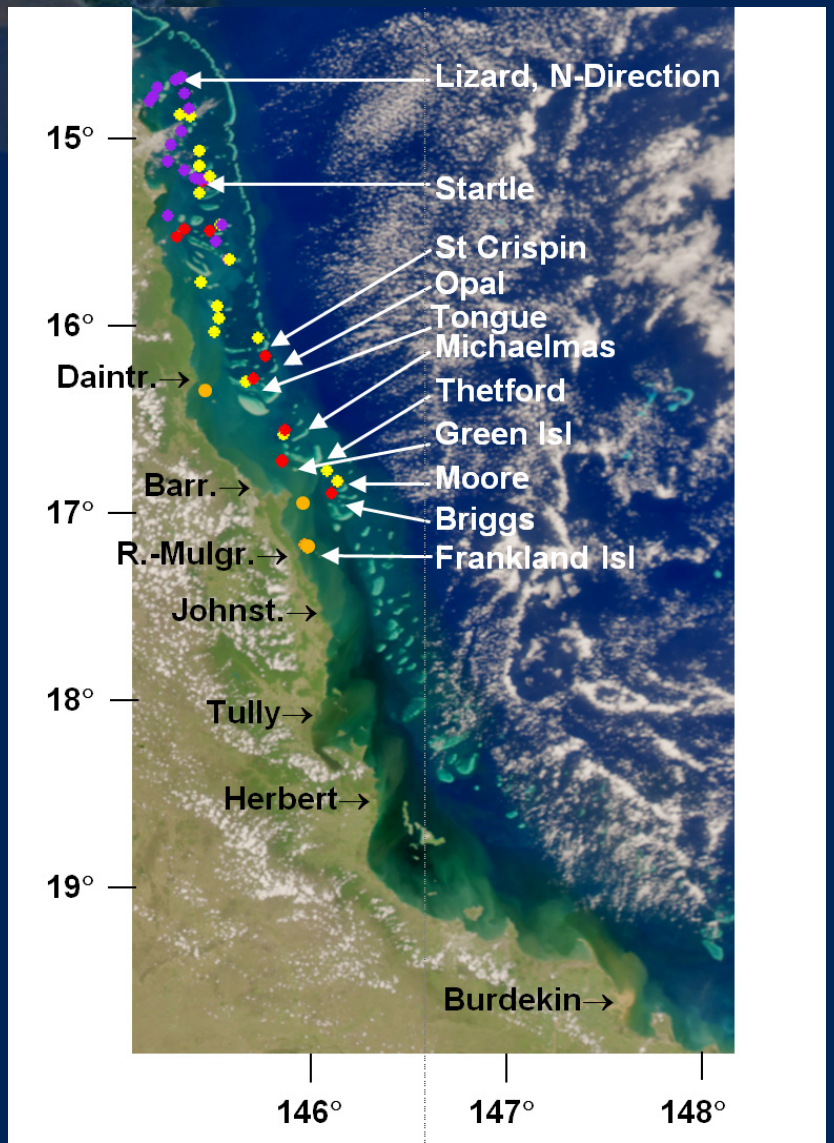
- Supporting studies
- Risk assessment

Supporting Studies

Commissioned to support qualitative assessment of relative risk between pollutants:

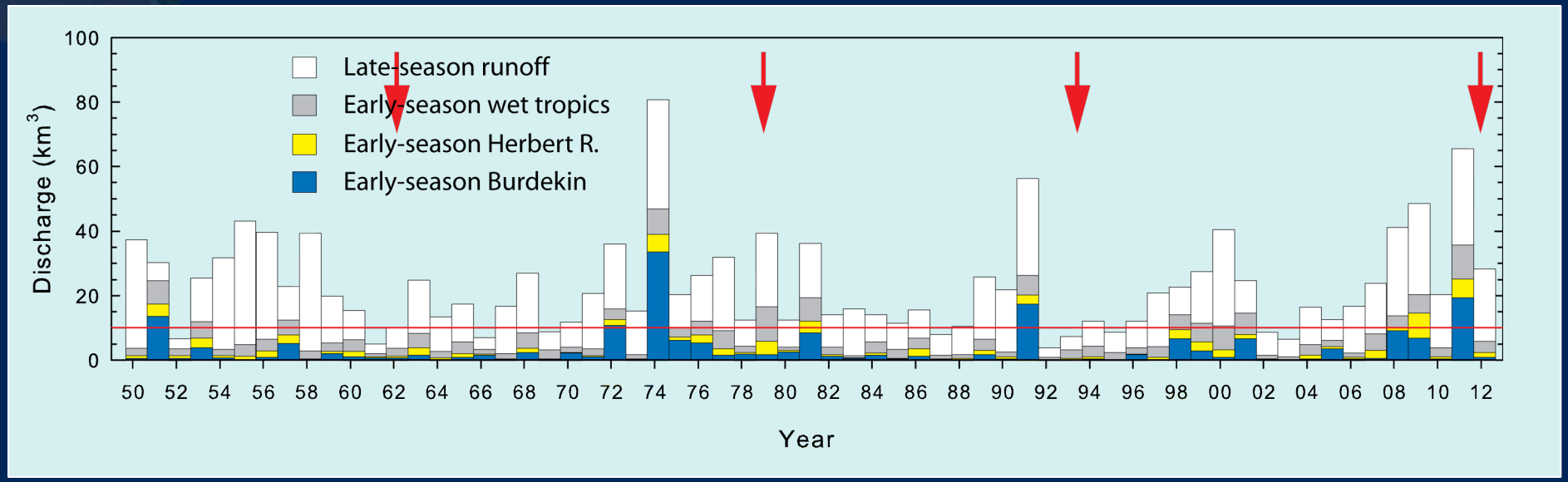
1. COTS case study
2. N:P ratios
3. Phytoplankton populations in flood plumes
4. Suspended sediment effects on reefs and seagrass
5. Flood plume surface exposure mapping
6. Seagrass and WQ case study

Nitrogen and COTS



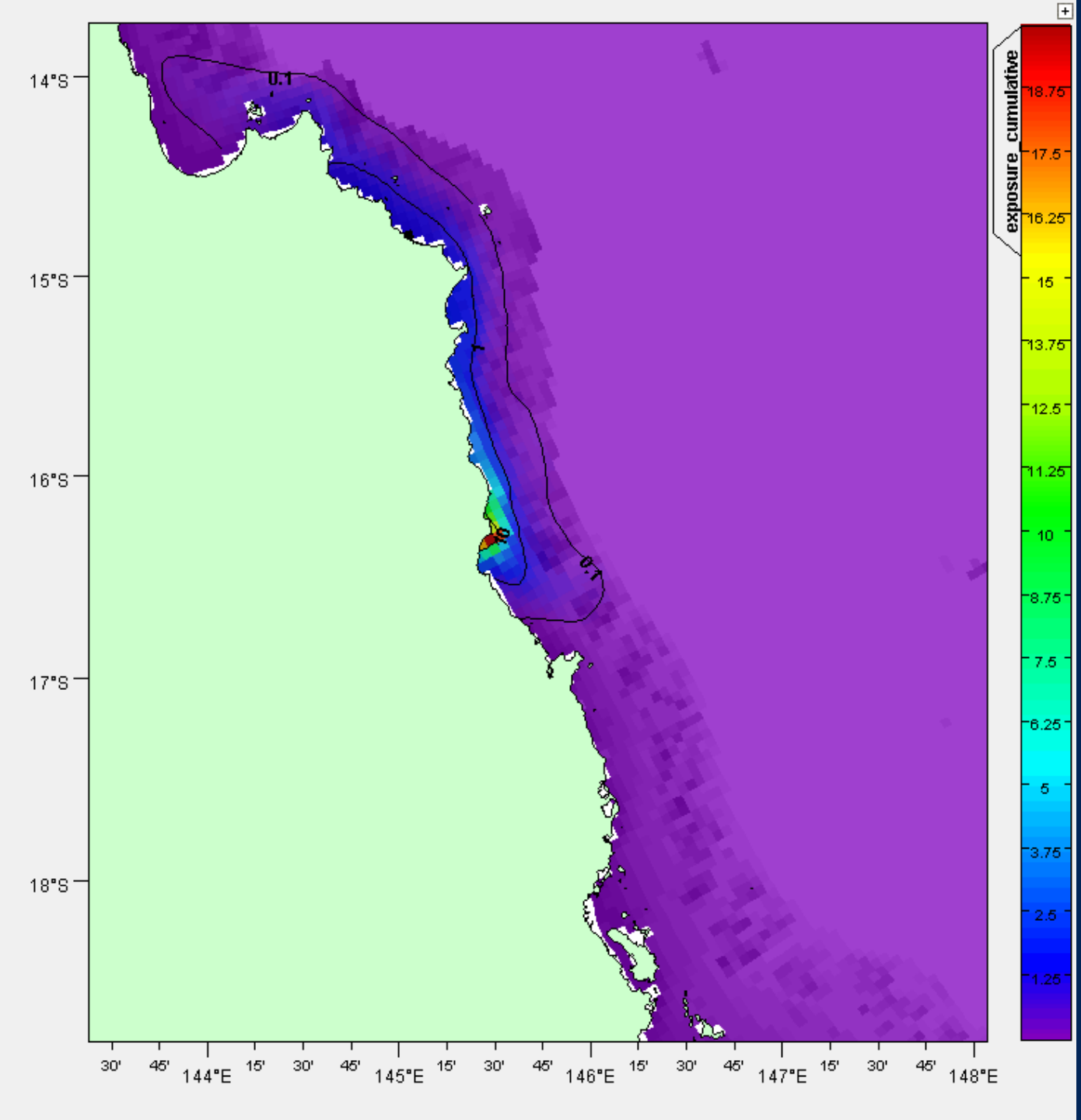
- GBR-wide loss of coral cover due to COTS is estimated to be 1.4% per year over the last 25 years, and a new outbreak is underway.
- It is estimated that COTS have affected >1000 reefs of the ~3000 reefs within the GBR over the last 60 years.
- Positive correlation between river runoff and chlorophyll in GBR lagoon between Cairns and Lizard Island.
- Year-to-year variations in chlorophyll follow runoff
- No apparent correlation between upwelling activity and chlorophyll

Annual and early wet-season runoff to the central GBR (1950-2012)



↓ Nominal outbreak start

——— 10 Km^3



Spatial distribution and intensity of influence (Conc.Days) from Daintree River runoff over the 2010-11 wet season

Relative contribution of individual rivers to nutrient loading of COTS initiation region from hydrodynamic modelling

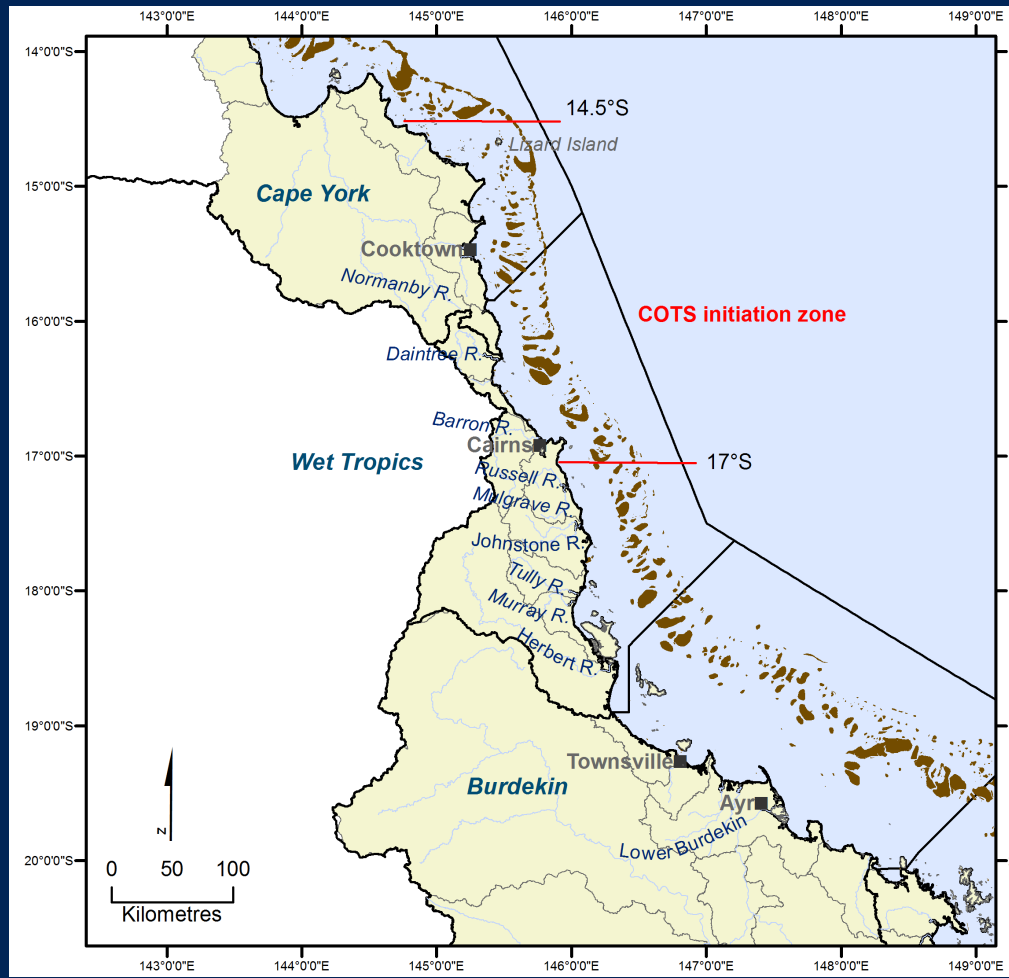
	Normalized Contribution (%)			Ranking		
River	**Total**	**North**	**South**	**Total**	**North**	**South**
Daintree	100	45	55	1	1	1
Barron	52	<1	52	4	6	2
Russell-Mulgrave	60	18	41	2	2	4
Johnstone	29	7	22	6	4	6
Tully	57	16	41	3	3	5
Herbert	7	<1	6	7	7	7
Burdekin	49	4	45	5	5	3

Supporting conclusions

- Nitrogen poses the greatest risk of pollution to coral reefs from catchments between the Daintree and Burdekin Rivers – associated with COTS primary outbreaks.
- Generally nitrogen is more important to manage than phosphorus (local considerations may alter this)
- Suspended sediments discharged from rivers especially the fine fractions (clays) present a high risk to the GBR seagrass and inshore coral reefs
- At smaller scales, particularly in coastal seagrass habitats and freshwater and estuarine wetlands, pesticides can be of high risk.
- Concentrations of a range of pesticides exceed water quality guidelines in many fresh and estuarine waterbodies downstream of cropping lands.
- Based on the risk assessment of the six commonly used herbicides, the Mackay Whitsunday and Burdekin region are considered to be at highest risk.

COTS Initiation Zone

- Outbreaks follow 2-5 years after wet seasons with significant (> 10 Km^3) early season runoff
- Runoff influences nutrient availability - Daintree , Russell-Mulgrave, Johnstone, Tully, Burdekin
- This runoff is associated with outbreak cycles COTS on the northern GBR shelf (15 to 17^0S) that subsequently generate secondary outbreaks throughout the central and southern GBR



N:P story
(Furnas et al)

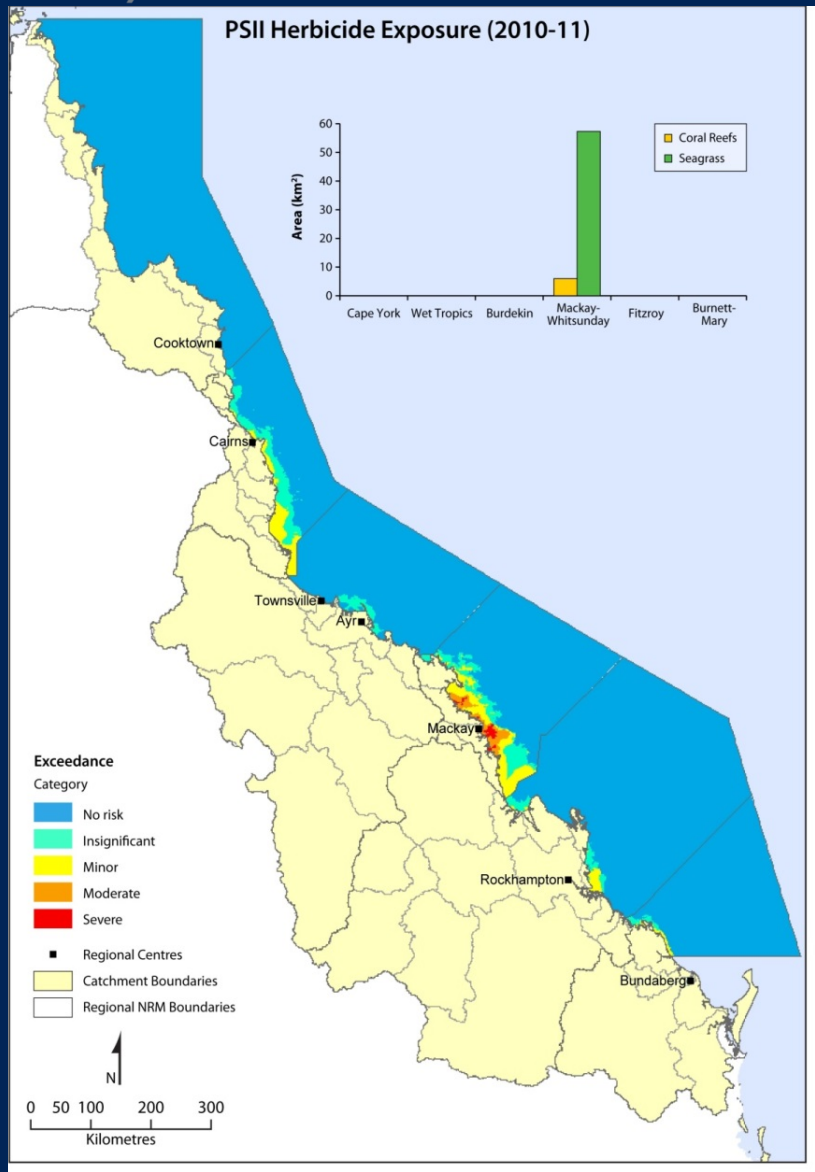
- In general GBR waters are nitrogen limited.
- Total N:P ratio in GBR waters > 16:1 – Plenty of N, but largely unavailable.
- Rivers show differing N:P behaviours (between regions, with discharge).
- Dissolved nutrients - Wet tropics rivers DIN:DIP > 16:1, Dry tropics rivers DIN:DIP < 16:1.
- River PN:PP ≤ 16:1, relatively more P under flooding conditions.

- **Generally nitrogen is more important to manage than phosphorus (local considerations may alter this)**

Pesticides
(Lewis et al)

- Additive risk assessment of plume exposure of PSII herbicides in 2010-2011 using correlation between salinity and pesticide concentrations
  - Diuron, atrazine, hexazinone, ametryn, tebuthiuron and simazine
- At smaller scales, particularly in coastal seagrass habitats and freshwater and estuarine wetlands, pesticides can be of high risk.
- Concentrations of a range of pesticides exceed water quality guidelines in many fresh and estuarine waterbodies downstream of cropping lands.

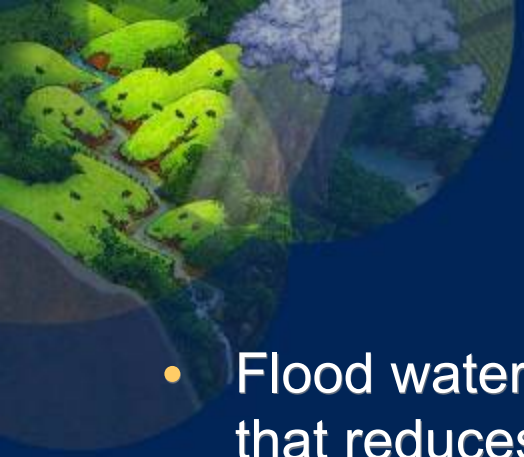
Limitation: Only 6 out of the 34 of the pesticides currently detected - potentially under estimated



Pesticides

- At smaller scales, particularly in coastal seagrass habitats and freshwater and estuarine wetlands, pesticides can be of high risk.
- Concentrations of a range of pesticides exceed water quality guidelines in many fresh and estuarine waterbodies downstream of cropping lands.

- **Based on the risk assessment of the six commonly used herbicides, the Mackay Whitsunday and Burdekin region are considered to be at highest risk.**



Sediment

- Flood waters and resuspension create a turbid water column that reduces the light required by seagrass and corals.
- High turbidity affects ~200 inshore reefs and most seagrass areas.
- Seagrass loss severely impacts turtle and dugong populations.
- On a regional basis the Burdekin and Fitzroy regions present the greatest risk to the GBR in terms of sediment loads.
- Reducing river sediment loads can result in measurably improved water clarity within months to years (ie within WQ Reporting time frames!). Improved water clarity will measurably improve properties of coral reef and seagrass ecosystems.

- **Suspended sediments discharged from rivers especially the fine fractions (clays) present a high risk to the GBR seagrass and inshore coral reefs**

Risk assessment approach

1. The differential risk between pollutants on GBR ecosystems (coral reefs and seagrass)
2. The combined risk of pollutants on GBR ecosystems
3. Overall assessment incorporating end of catchment anthropogenic pollutant loads and potential risk to GBR ecosystems

Risk = likelihood *consequence

- Likelihood is some measure of probability so there is a temporal component
- Calculating probabilities that we can have confidence in requires a long time series, but we have…
  - Low confidence in assessing probability for Chl, TSS – only 1 or 2 observations every 5 days
  - Exposure is based on last 5 years – period includes larger numbers of extreme events than has been the norm
  - We use only 2011 for pesticides
- Likelihood is assessed here as 1 or 0; this is presence/absence of exceedance of a guideline/threshold.

Consequence

- **Consequence is the degree of impact or degree of potential impact.**
- Conventionally, this would mean we know ‘severity’ requiring we understand the implications of ‘dosage’.
- For us, the degree of potential impact is related only to the **area** of coral reefs, seagrass or the NRM region ‘exposed’.
- Thus, ‘risk’ or ‘relative risk’ involves comparing the areas of coral reefs, seagrass and NRM region exposed to different variables.

Framework

Coral Reef Relative Risk Index = Coral Reefs Marine Risk Index + Loads Index + COTS Influence Index
Seagrass Relative Risk Index = Seagrass Marine Risk Index + Loads Index
Relative Risk Index = Coral Reef Relative Risk Index + Seagrass Relative Risk Index

Marine Risk Index

Likelihood = 1 where exceedance or exposure occurs in highest assessment classes; or 0 where no exceedance or exposure occurs

- **TSS threshold exceedance 2mg/L, 7mg/L** *2002-2012*
- **TSS plume loading** *mean 2007-2011*
- **Chl threshold exceedance 0.45µg/L** *2002-2012*
- **DIN plume loading** *mean 2007-2011*
- **COTS Initiation Zone**
- **PSII herbicide modelled concentration 2009-2011**

Consequence = Area of coral reefs or seagrass in highest assessment classes

- **Coral Reef Marine Risk Index = Area of coral reef in highest assessment classes**
- **Seagrass Marine Risk Index = Area of seagrass meadows in highest assessment classes**

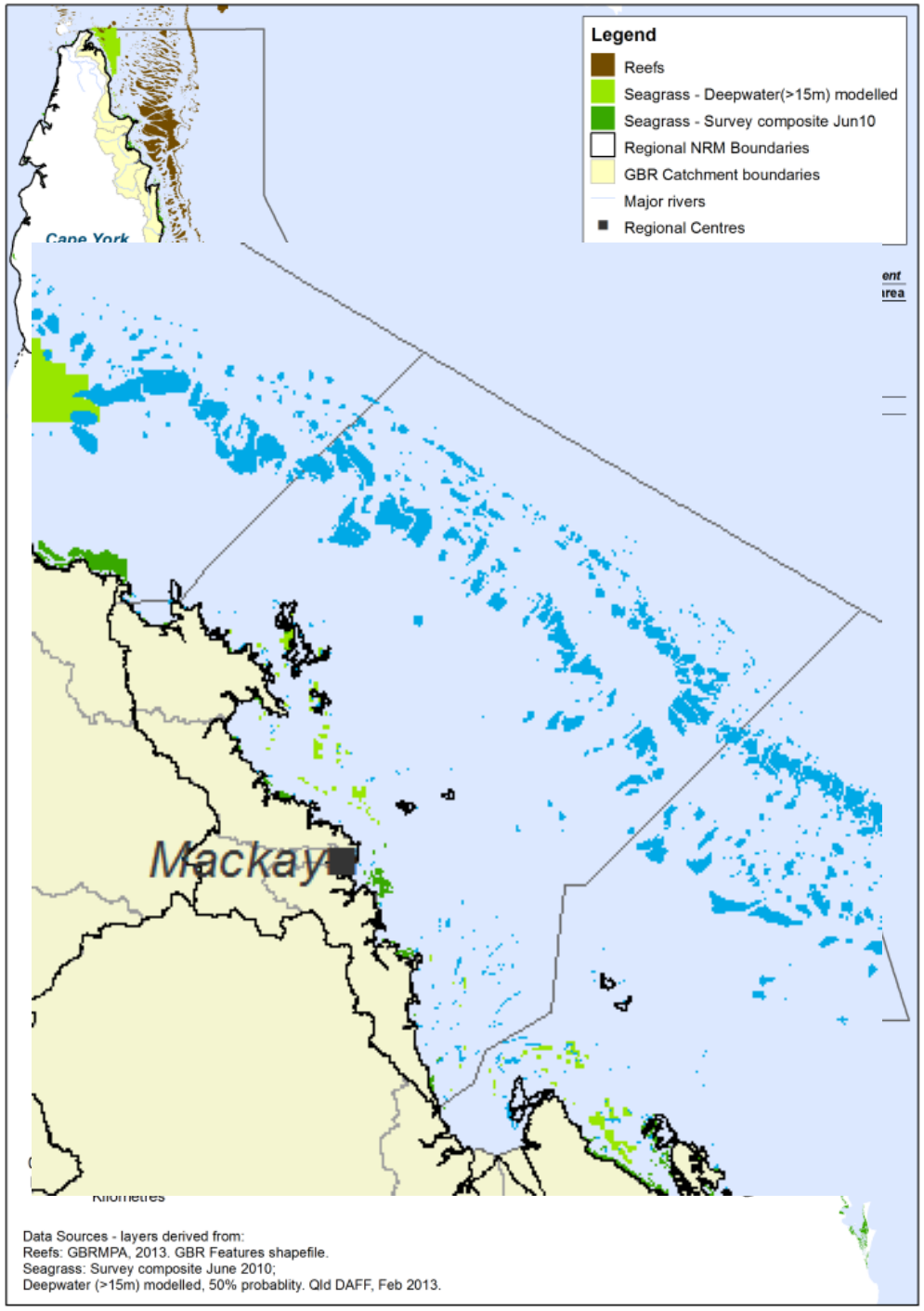
Loads Index

Regional anthropogenic end of catchment loads as proportion of total GBR load

- TSS
- DIN
- PSII herbicides

COTS Influence Index

Regional volumetric contribution of river discharge to COTS Initiation Zone



Distribution of habitats

NRM Region	Area (km^2)		
	Reef	Seagrass	Region Area
Cape York	10,400	11,000	96,000
Wet Tropics	2,400	4,900	31,000
Burdekin	3,000	6,000	47,000
Mackay Whitsunday	3,200	**400**	48,000
Fitzroy	4,900	5,800	85,000
Burnett Mary	300	6,300	37,000
Totals	**24,000**	**35,000**	**346,000**

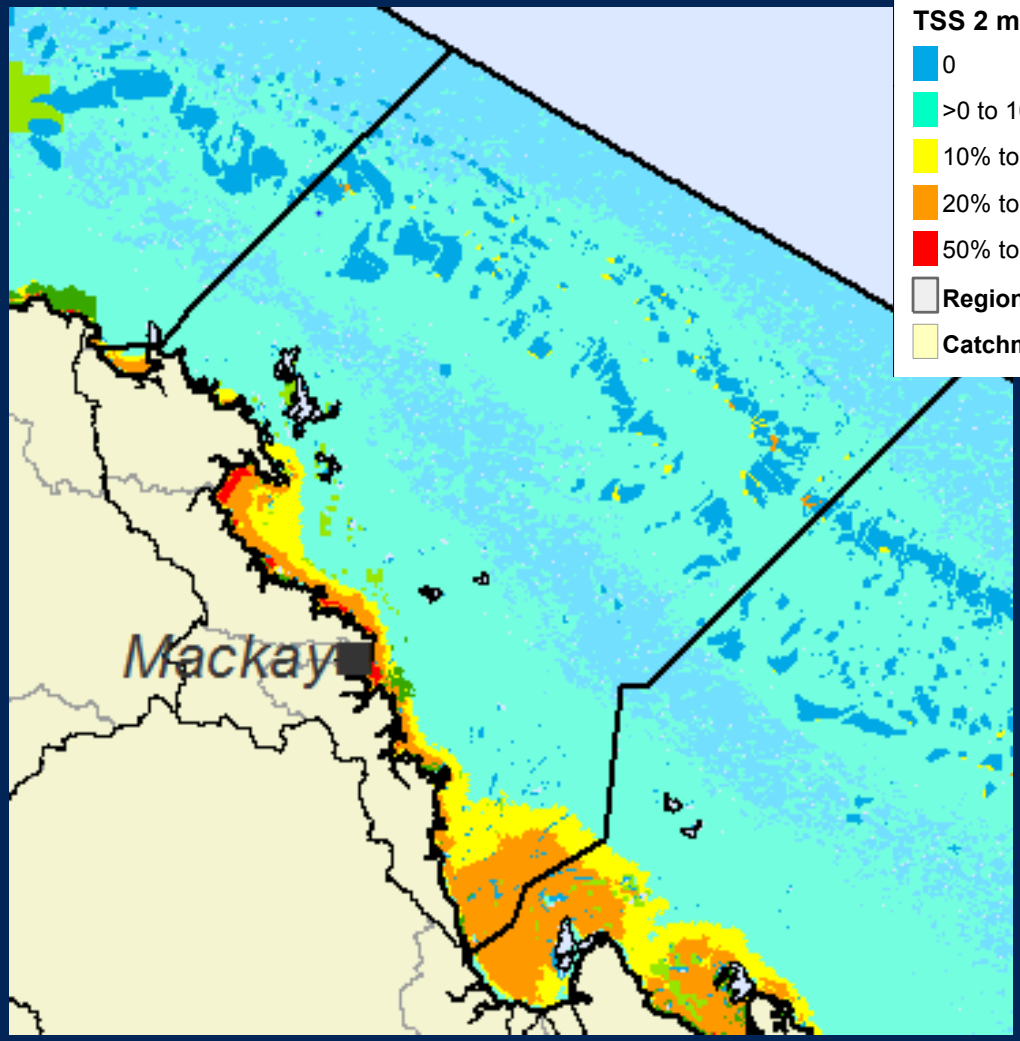
1. Differential risk between pollutants on GBR ecosystems: *coral reefs and seagrass*

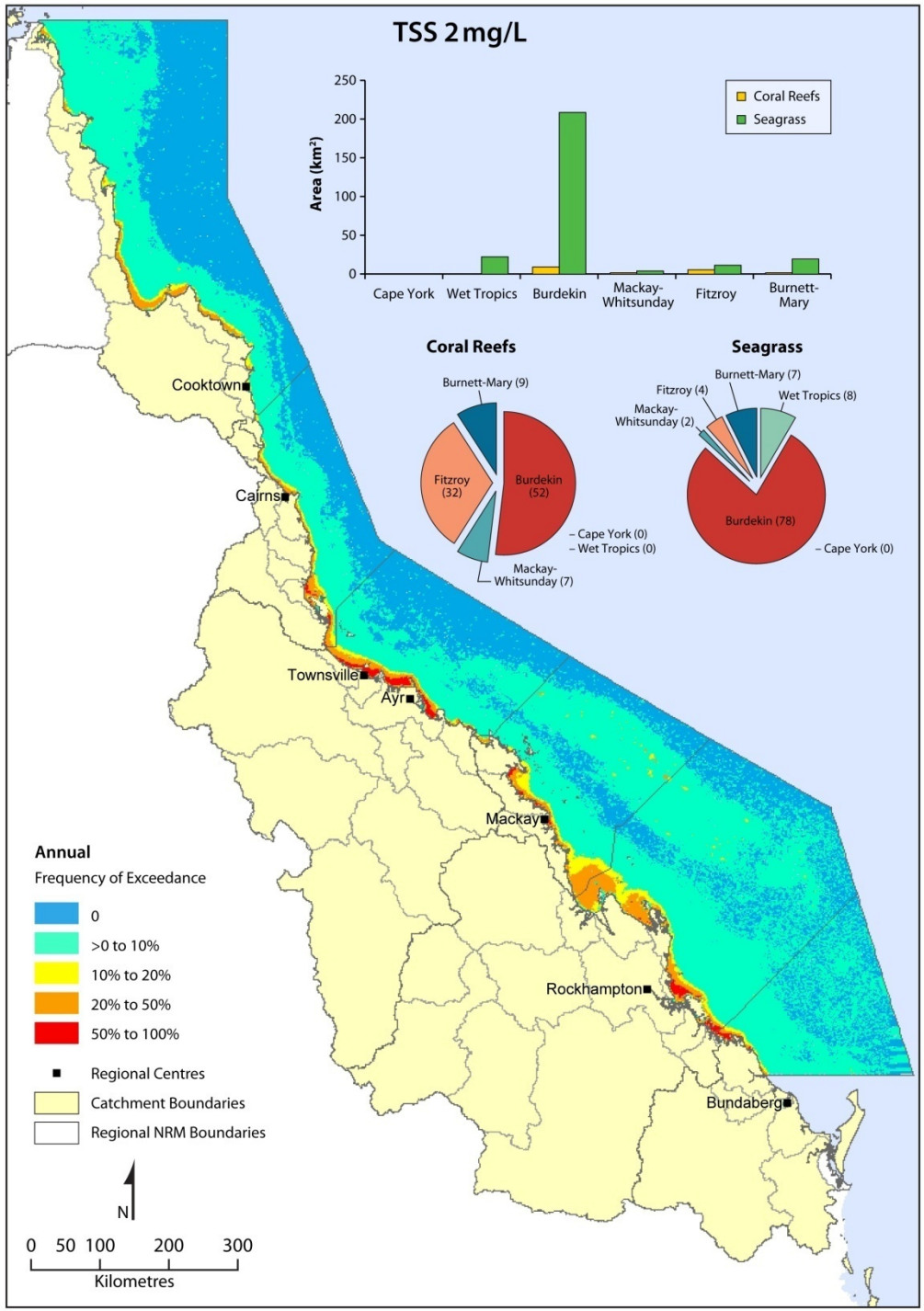
- Calculated the area of coral reefs, seagrass and total area of marine waters for each NRM region in each assessment class for each variable

- To compare results among regions:
  - Used the area affected occurring in the highest assessment class for each variable
  - Normalised against the highest value

- All area calculations were then expressed as a percentage of the maximum (values between 0 and 1) to show relative differences

1. Classified each data layer into assessment classes based on relative risk
2. Calculated the area of coral reefs, seagrass and total area of marine waters for each NRM region in each assessment class for each variable





Example - TSS

- Normalised the area estimates to the maximum area affected

Region	Reefs km²	Score	Seagrass km²	Score
Cape York	<1	0.00	0	0.00
Wet Tropics	<1	0.00	22	0.11
Burdekin	9	1.00	209	1.00
Mackay-Whitsunday	1	0.14	4	0.02
Fitzroy	6	0.61	11	0.05
Burnett-Mary	2	0.18	20	0.09

- Area of reefs and seagrass is <5% of the area in each Region

Seagrass Results

Seagrass	TSS 2mg/L	TSS 5NTU	TSS 07-11	Chl 0.45 ug/L	DIN 07-11	PSII Herb
Cape York	0	0	0	5	0	0
Wet Tropics	11	27	8	14	30	0
Burdekin	100	100	100	100	100	0
Mackay-Whitsunday	2	0	1	7	8	100
Fitzroy	5	27	5	62	81	0
Burnett-Mary	9	0	0	15	32	0

The area of seagrass affected for all variables is greatest in the Burdekin region, except PSII Herbicides

Coral Reef Results

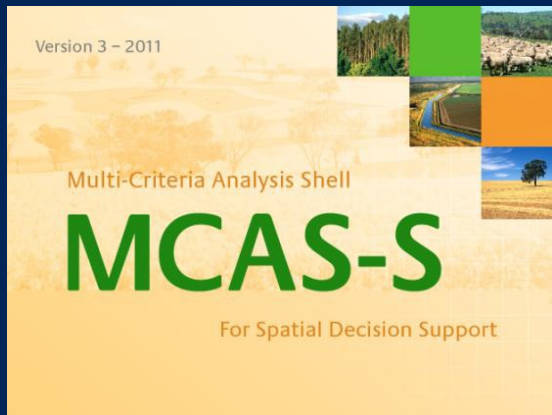
Coral Reefs	TSS 2mg/L	TSS 5NTU	TSS 07-11	Chl 0.45 ug/L	DIN 07-11	COTS Initiation Zone	PSII Herb
Cape York	0	0	0	0	0	100	0
Wet Tropics	0	0	9	1	18	70	0
Burdekin	100	4	100	26	39	0	0
Mackay-Whitsunday	14	0	6	22	6	0	100
Fitzroy	61	100	32	100	100	0	0
Burnett-Mary	18	0	0	9	2	0	0

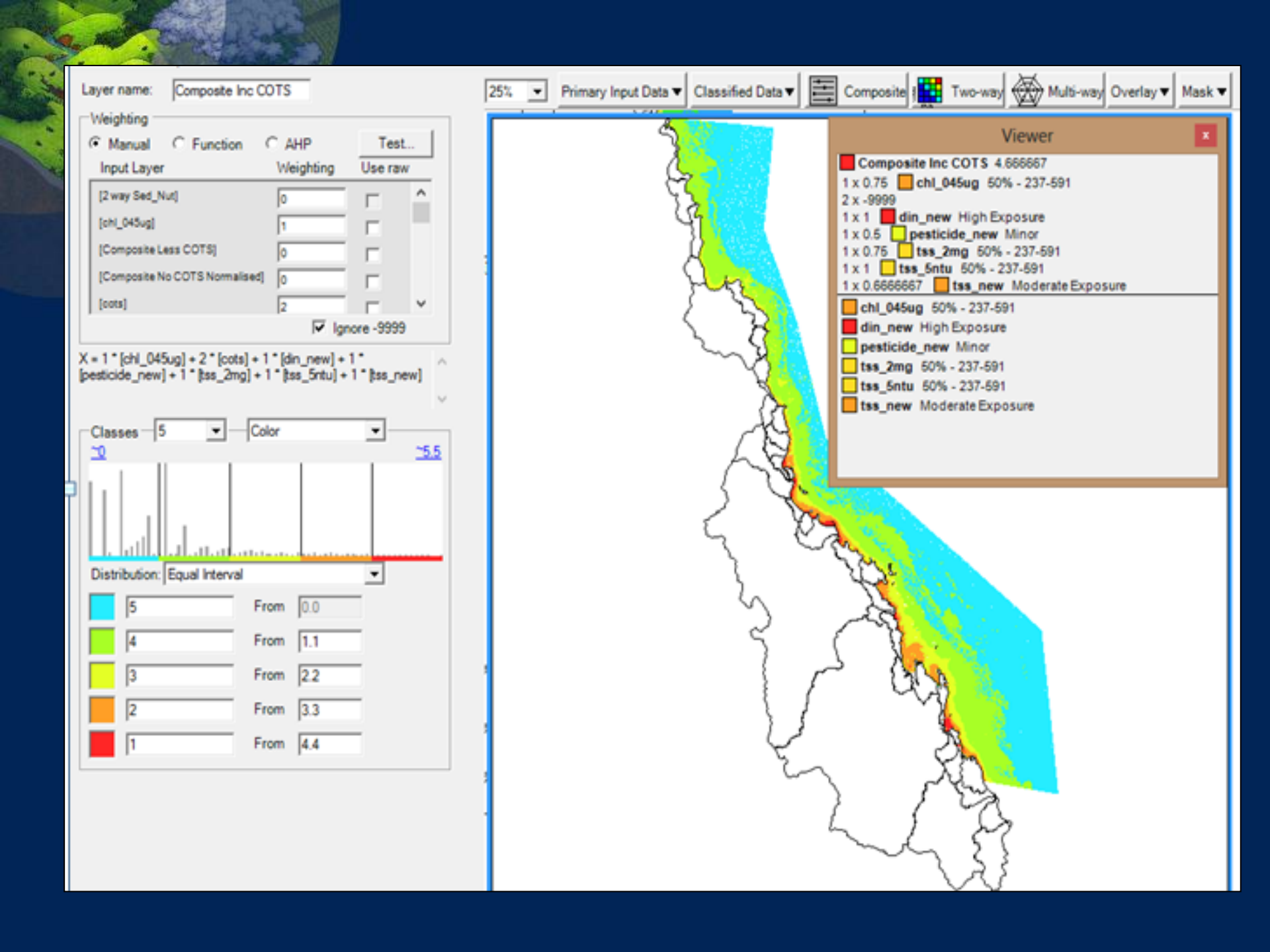
Relative differences between regions

- **Seagrass** – area for all sediment and nutrient variables is greatest in the Burdekin region, but greatest proportion of seagrass in Mackay Whitsunday
- **Coral ree**fs - Burdekin and Fitzroy regions ranked first or second highest for all sediment and nutrient related variables in the assessment.
- The coral reefs located in the **COTS Initiation Zone** are all in the Cape York and Wet Tropics regions, with most (60%+) of them located in Cape York, and 40% in the Wet Tropics region.
- **PSII herbicides** - the Mackay Whitsunday region has by far the highest ecological risk of PSII herbicide exposure (assessed using selected PSII herbicide concentrations), with the highest PSII risk areas extending off the mouths of the Pioneer and O'Connell Rivers and Sandy Creek.

2. Calculation of the combined marine water quality Marine Risk Index

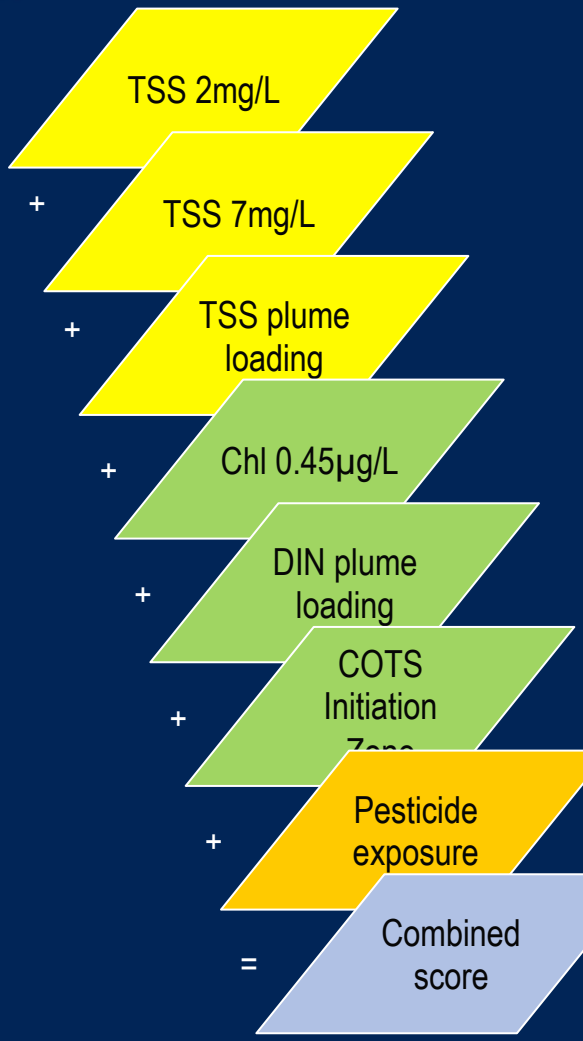
- Used MCASS to develop a score for each pixel
- Composites essentially weight the classes, eg. DIN exposure = 3 classes
  - Low = 0.33; Moderate = 0.66; High = 1
- Results presented in 5 classes
- Calculated area of coral reefs and seagrass in each class (VL to VH)




Layer name: Composite Inc COTS
Weighting
Manual
Function
AHP
Test...
Input Layer
Weighting
Use raw
[2 way Sed_Nut] 0
[chl_045ug] 1
[Composite Less COTS] 0
[Composite No COTS Normalised] 0
[cots] 2
Ignore -9999
X = 1 * [chl_045ug] + 2 * [cots] + 1 * [din_new] + 1 * [pesticide_new] + 1 * [tss_2mg] + 1 * [tss_5ntu] + 1 * [tss_new]
Classes 5
Color
Distribution: Equal Interval
5 From 0.0
4 From 1.1
3 From 2.2
2 From 3.3
1 From 4.4
25%
Primary Input Data
Classified Data
Composite
Two-way
Multi-way
Overlay
Mask
Viewer
Composite Inc COTS 4.666667
1 x 0.75 chl_045ug 50% - 237-591
2 x -9999
1 x 1 din_new High Exposure
1 x 0.5 pesticide_new Minor
1 x 0.75 tss_2mg 50% - 237-591
1 x 1 tss_5ntu 50% - 237-591
1 x 0.6666667 tss_new Moderate Exposure
chl_045ug 50% - 237-591
din_new High Exposure
pesticide_new Minor
tss_2mg 50% - 237-591
tss_5ntu 50% - 237-591
tss_new Moderate Exposure

Example in a pixel

Variables at the scale of 1 km^2 pixel



Example results and scores

High (20-50% exceedance) = 0.8

Very High (20-100% exceedance) = 1.0

High = 1.0

Medium (10-20% exceedance) = 0.6

Medium = 0.66

Out of Zone = 0

Low (0.1-0.5 µg/L) = 0.25

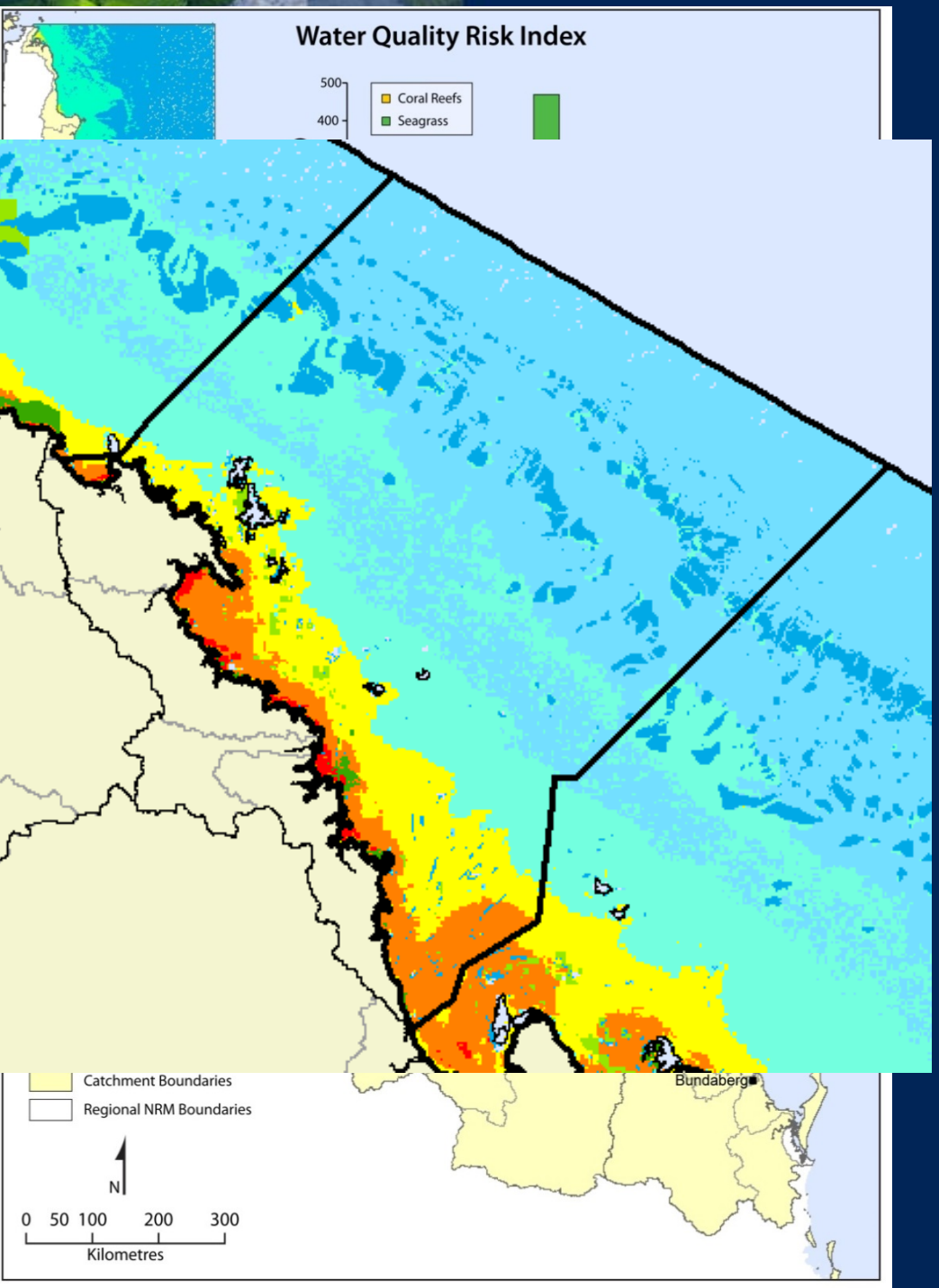
Combined score = 4.31

Assessment classes for combined score:

0 to 0.2 = Very Low
0.2 to 0.4 = Low
0.4 to 0.6 = Medium
0.6 to 0.8 = High
0.8 to 1.0 = Very High

Combined score (normalised)
= 4.31 / 7 (maximum possible)
= 0.62
= High

Marine Risk Index



- Areas of highest risk are constrained to the coast – pattern similar to previous assessments
- Relatively small areas of habitat but highly valued sites
- Greatest areas of highest assessment class:
  - Reefs – Fitzroy
  - Seagrass - Burdekin

Marine Risk Index

- Based on the area of coral reefs and seagrass in the high and very high assessment classes
- Normalised to largest areas to show relative differences between regions

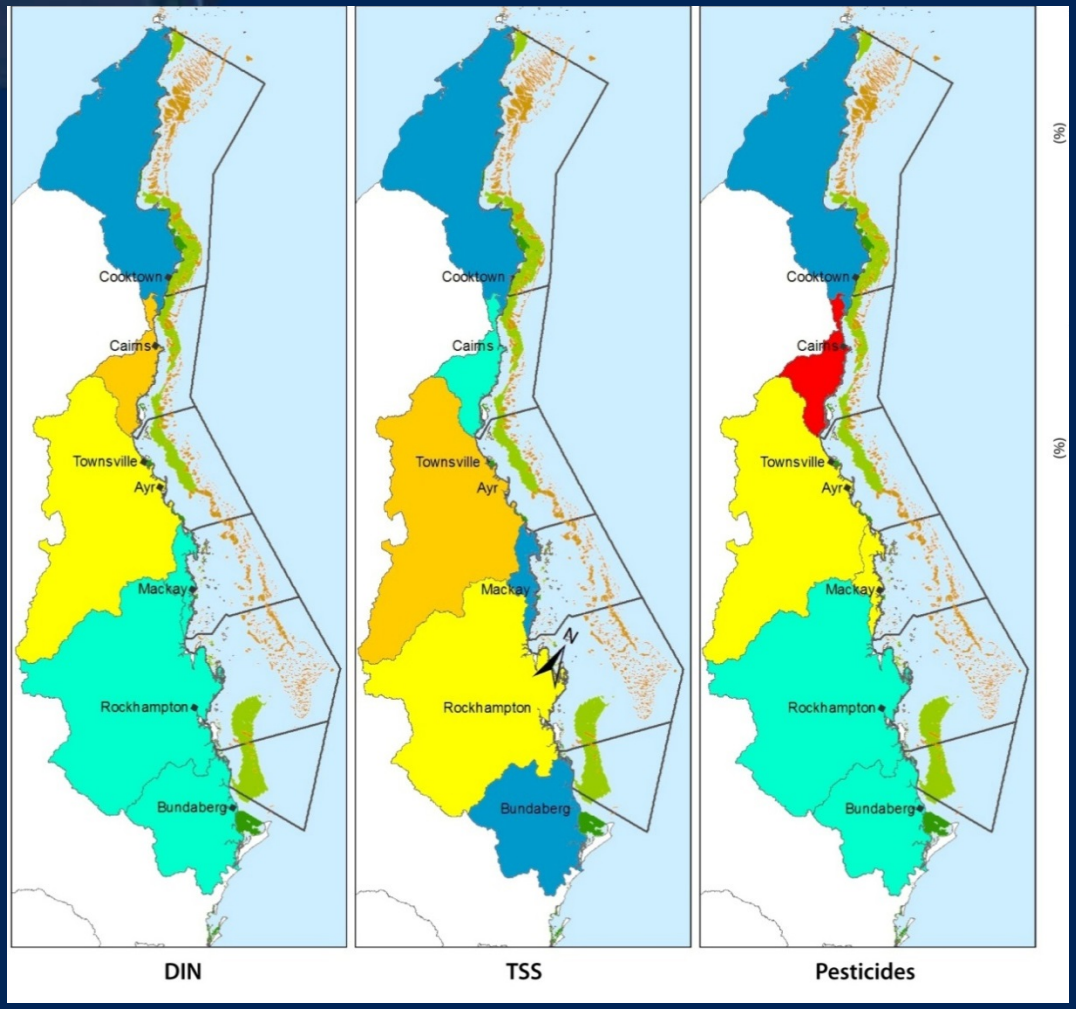
Region	Risk Index – Coral Reefs	Risk Index - Seagrass
Cape York	15	7
Wet Tropics	32	34
Burdekin	13	100
Mackay Whitsunday	59	34
Fitzroy	100	68
Burnett Mary	4	18

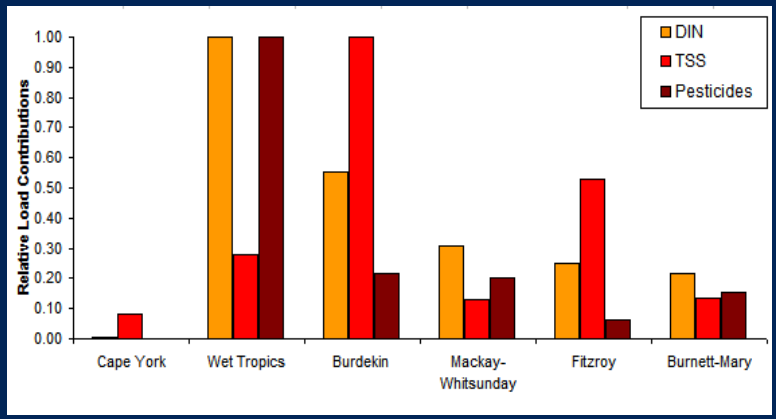
3. Calculation of the relative risk of water quality in the GBR

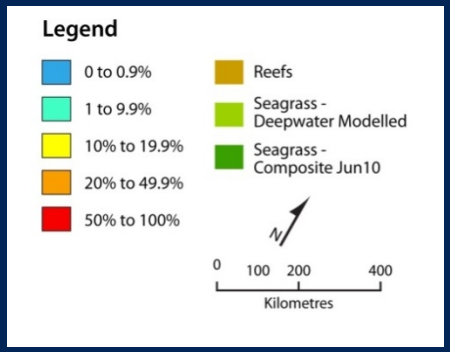
- Combined end of catchment loads information with marine water quality Risk Index
- Marine water quality is influenced by many factors – relating Marine Risk Index to anthropogenic loads attempts to relate results back to the influence driven by anthropogenic influence

- Loads information:
  1. COTS Influence Index – based on volumetric contribution of each river to the COTS Initiation Zone
  2. Loads Index – based on the proportional contribution of each Region to the GBR total anthropogenic load

Linking in loads







Loads Index

- Proportion of regional contributions to total GBR anthropogenic load (2009-10 baseline)

Region	TSS	DIN	PSII	Average	Loads Index	Loads Index Rank
Cape York	3	<1	<1	<1	0.00	6
Wet Tropics	9	20	61	30	1.00	1
Burdekin	32	11	13	19	0.62	2
Mackay Whitsunday	4	6	12	8	0.25	4
Fitzroy	17	5	4	9	0.28	3
Burnett Mary	4	4	9	6	0.20	5
			MAX	*30*		

COTS Influence Index

COTS Influence (reefs only) - developed from the proportion of volumetric river flow into the COTS Initiation Zone by Region – Wet Tropics and Burdekin

COTS Influence Index	Contribution to COTS initiation Zone (%)	Anchored
Cape York	0.00	0.00
Wet Tropics	0.86	1.00
Burdekin	0.14	0.16
Mackay-Whitsunday	0.00	0.00
Fitzroy	0.00	0.00
Burnett-Mary	0.00	0.00
MAX	*0.86*	

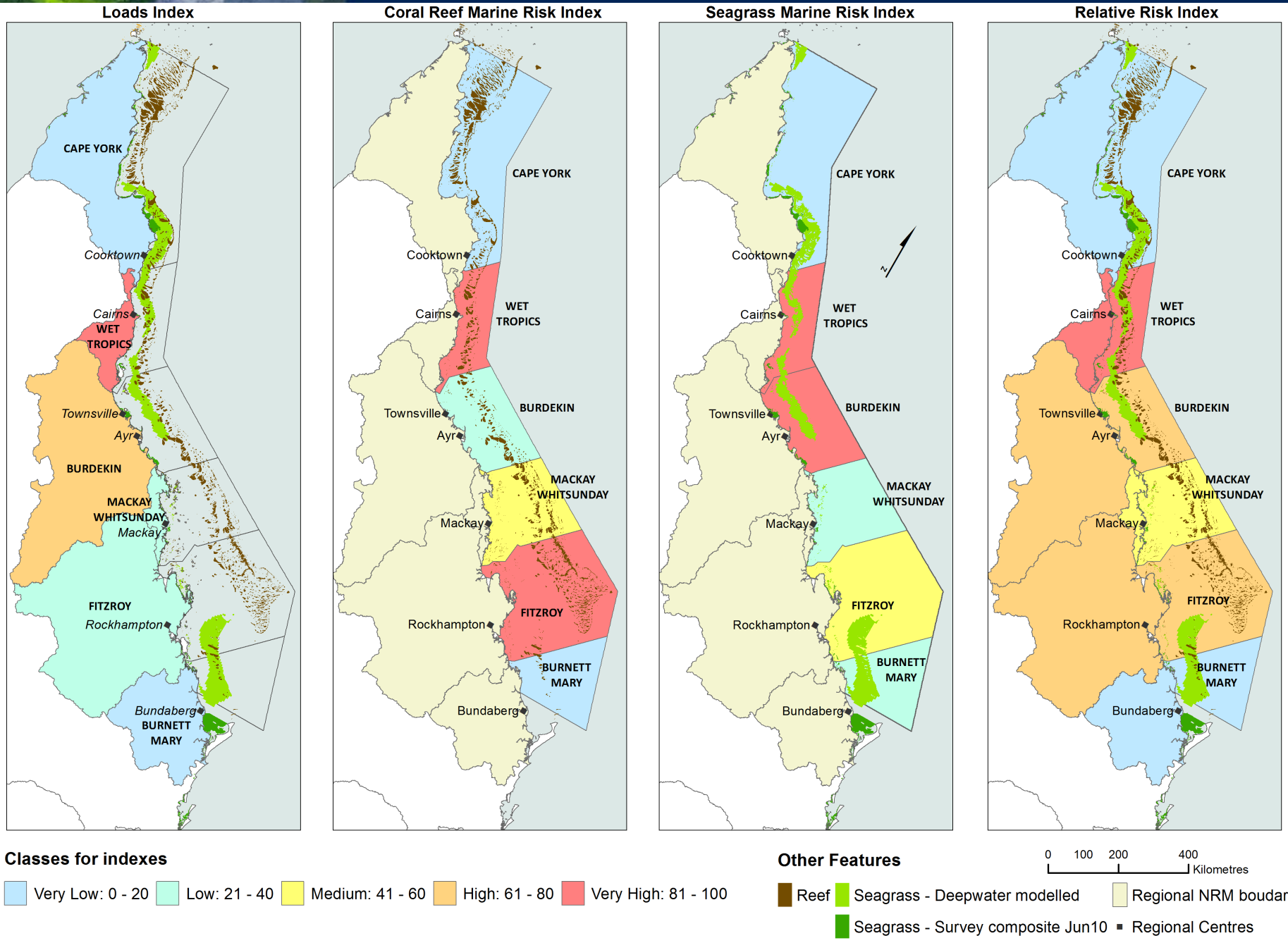
Calculating Relative Risk

Summed the Indexes for coral reefs and seagrass to generate a Final Index

Region	Reef Risk Index	Loads & COTS Index	Sum of Indexes	Final Index Reefs (Anchored)	Rank
Cape York	15	0	15	12	5
Wet Tropics	32	100	132	100	1
Burdekin	13	39	52	40	4
Mackay Whitsunday	59	13	72	54	3
Fitzroy	100	14	114	86	2
Burnett Mary	4	10	14	11	6
		Max	*132*		

Seagrass Risk Index

Region	Seagrass Risk Index	Loads Index	Sum of Indexes	Final Index Seagrass (Anchored)	Rank
Cape York	7	0	7	4	6
Wet Tropics	34	100	134	83	2
Burdekin	100	62	162	100	1
Mackay Whitsunday	34	25	59	37	4
Fitzroy	68	28	96	59	3
Burnett Mary	18	20	38	23	5
		Max	*162*		


Loads Index
Coral Reef Marine Risk Index
Seagrass Marine Risk Index
Relative Risk Index
CAPE YORK
WET TROPICS
BURDEKIN
MACKAY WHITSUNDAY
FITZROY
BURNETT MARY
Cooktown
Cairns
Townsville
Ayr
Mackay
Rockhampton
Bundaberg
Classes for indexes
Very Low: 0 - 20
Low: 21 - 40
Medium: 41 - 60
High: 61 - 80
Very High: 81 - 100
Other Features
Reef
Seagrass - Deepwater modelled
Seagrass - Survey composite Jun10
Regional NRM boudaries
Regional Centres
0 100 200 400
Kilometres

Final Score

Region	Final Index Reefs	Final Index Seagrass	Final Score (Anchored)	Rank
Cape York	12	4	9	6
Wet Tropics	100	83	100	1
Burdekin	40	100	76	3
Mackay Whitsunday	54	37	50	4
Fitzroy	86	59	80	2
Burnett Mary	11	23	19	5

Risk assessment results

From a combined assessment of water quality variables in the GBR and end-of-catchment anthropogenic loads of nutrients, sediments and PSII herbicides:

- **Coral Reefs:** Wet Tropics > Fitzroy > Mackay Whitsunday > Burdekin> Cape York > Burnett Mary
- **Seagrass:** Burdekin > Wet Tropics > Fitzroy > Mackay Whitsunday > Burnett Mary > Cape York

Limitations

- **Unable to use formal Risk matrix of *Likelihood x Consequence* due to limitations with temporal and spatial distribution of data**
- **Inconsistencies in datasets – frequency, technique, extent eg.**
  - Low confidence in assessing probability for Chl, TSS – remote sensing only 1 or 2 observations every 5 days
  - Exposure is based on last 5 years – period includes larger numbers of extreme events than has been the norm
  - We use only 2010 - 2011 for pesticides and selection of PSII herbicides
  - Limited data for Cape York and Burnett Mary compared to other Regions
  - Burnett Mary assessments only include habitats inside the Marine Park boundary, and more recent mapping of reefs in that area not incorporated
  - Need to define extent of influence for each river
  - Inadequate time and resources to undertake full sensitivity analysis

Region	Risk Index		Regional Anthropogenic Load as a proportion of the Total GBR Load			Additional Factors	Management Issues	Associated land uses	Overall Ranking
	Reef	Seagrass	TSS	DIN	PSII				
Cape York	15	7	4	<1	<1	Influence from terrestrial runoff is predominantly from Wet Tropics Rivers	Sediments?	Grazing	LOW
Wet Tropics	32	34	13	43	61	86% volumetric contribution to COTS Initiation Zone	Nutrients Pesticides	Sugarcane Bananas	VERY HIGH
Burdekin	13	100	46	24	13	14% volumetric contribution to COTS Initiation Zone Freshwater wetlands lower Burdekin exposed to high PSII	Sediments Nutrients Pesticides	Grazing Sugarcane	HIGH
Mackay Whitsunday	59	34	6	13	12	Highest risk to pesticide exposure coastal & Sandy Ck	Pesticides	Sugarcane	MODERATE
Fitzroy	100	68	25	11	4	Monitored loads of PSII Herb were high in 2011 (not reflected in modelled baseline)	Nutrients Sediments Pesticides	Grazing Cropping	HIGH
Burnett-Mary	4	18	6	9	9	All variables rank relatively low, however, the reefs and seagrass areas adjacent to the Region but outside of the GBRWHA have not been factored in.			LOW?

Conclusions: Which pollutants?

The greatest risks of pollution to the GBR are from:

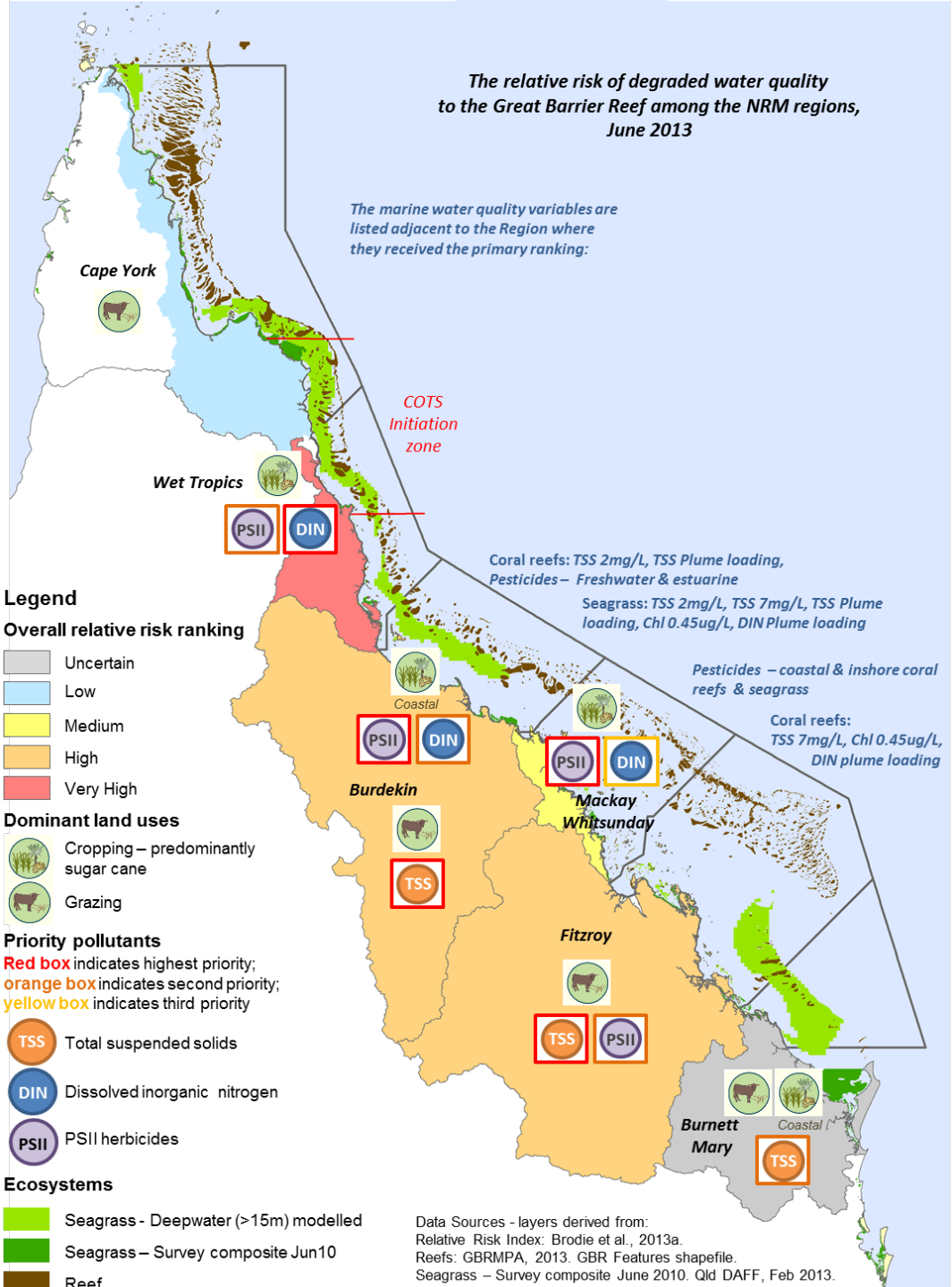
- Nitrogen discharge, associated with crown of thorns starfish outbreaks and their destructive effects on coral reefs
- Fine sediment discharge (with associated nutrients and pesticides) which drives light reduction for seagrass ecosystems and inshore coral reefs
- Pesticide inputs pose a significant risk to freshwater and coastal habitats at smaller scales

Conclusions: Where?

Priority Region for:

- Nitrogen management - Wet Tropics
- PSII herbicide management - Mackay Whitsunday and Burdekin (lower Burdekin)
- Suspended sediment management - Burdekin and Fitzroy
- Recognise variable risk to habitats at regional scales…

Provides the most robust qualitative and semi-quantitative assessment of water quality risk to the GBR to date and is already being used to inform future investment


The relative risk of degraded water quality to the Great Barrier Reef among the NRM regions, June 2013
The marine water quality variables are listed adjacent to the Region where they received the primary ranking:
Cape York
COTS Initiation zone
Wet Tropics
PSII
DIN
Coral reefs: TSS 2mg/L, TSS Plume loading, Pesticides – Freshwater & estuarine
Seagrass: TSS 2mg/L, TSS 7mg/L, TSS Plume loading, Chl 0.45ug/L, DIN Plume loading
Pesticides – coastal & inshore coral reefs & seagrass
Coastal
Coral reefs: TSS 7mg/L, Chl 0.45ug/L, DIN plume loading
Burdekin
Mackay Whitsunday
TSS
Fitzroy
Burnett Mary
Coastal
Legend
Overall relative risk ranking
Uncertain
Low
Medium
High
Very High
Dominant land uses
Cropping – predominantly sugar cane
Grazing
Priority pollutants
Red box indicates highest priority;
orange box indicates second priority;
yellow box indicates third priority
Total suspended solids
Dissolved inorganic nitrogen
PSII herbicides
Ecosystems
Seagrass - Deepwater (>15m) modelled
Seagrass – Survey composite Jun10
Reef
Data Sources - layers derived from:
Relative Risk Index: Brodie et al., 2013a.
Reefs: GBRMPA, 2013. GBR Features shapefile.
Seagrass – Survey composite June 2010. Qld DAFF, Feb 2013.

Thank you!