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Reef Rescue Marine Monitoring Program: using Remote Sensing for GBR wide water quality.
Final Report for 2011/12 Activities

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EXECUTIVE SUMMARY

Given the size and variability of conditions within the Great Barrier Reef (GBR) catchments and receiving waters, monitoring the water quality in the GBR lagoon waters is challenging. *In situ* monitoring data tends to be sparse in both space and time and as a result, remote sensing is now recognised as a suitable and cost-effective technique for the large-scale monitoring of coastal water quality. It is a particularly attractive alternative because it provides synoptic views of the spatial distribution of concentrations of chlorophyll-a (CHL) and total suspended solids (TSS), as well as the water clarity and the absorption by coloured dissolved organic matter (CDOM) of near-surface water. The daily frequency of satellite sensors improves our ability to identify patterns of spatial variation over scales of kilometres to hundreds of kilometres and temporal scales of days to years. Yet, The Great Barrier Reef Marine Park Authority (GBRMPA) and the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program need management-relevant products from remote sensing data that provide information beyond that of simple concentration maps. Hence, this report delivered management-relevant information of flood events and inshore water quality compliance based on tailored temporal and spatial analysis of remote sensing data.

Data collected by Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua sensor provide a time series from November 2002 to present of water quality estimates with spatial coverage at 1 km resolution for the whole-of-GBR lagoon, nominally on a daily basis (except overcast days). The water quality estimates were retrieved from the MODIS Aqua time series using two coupled physics-based inversion algorithms developed to accurately retrieve water quality parameters for the optically complex waters of the GBR lagoon (Brando et al. 2008, Schroeder et al. 2008, Brando et al. 2010, Brando et al. 2010, Brando et al. 2012, Schroeder et al. 2012). This was necessary because CHL concentrations retrieved with the MODIS standard algorithms provided by NASA are up to two-fold inaccurate in GBR waters (Qin et al., 2007), while CSIRO's regionally parameterised algorithms account for the significant variation in concentrations of CDOM and TSS and achieve more accurate retrievals (Brando et al. 2010, Brando et al. 2010). For this report the whole MODIS aqua time series was reprocessed with the most recent updates in NASA's software (SeaDAS version 6.4), incorporating the improved knowledge of instrument temporal calibration to improve temporal stability of the time series of the MODIS AQUA aging sensor. The MODIS time series was then processed with the latest parameterization of CSIRO's coupled physics-based inversion algorithms. As such, all the results presented in this report supersede the previous reports.

The combination of expanding catchment development and modification of land-use has resulted in a significant decline in the quality of water flowing into the reef lagoon over the past 150 years (Schaffelke et al. 2012, Waterhouse et al. 2012). Flood events in the wet season are the main delivery mechanism for nutrients, sediments and pesticides from the adjacent catchments into the Reef lagoon. The freshwater plume extent into the GBR lagoon during the wet season was estimated from MODIS measurements by applying a threshold to maps of aggregated seasonal maximum CDOM absorption. The freshwater extent based on the CDOM maximum provides a conservative estimate of the extent as the flood plumes could have extended further in cloudy or overcast days and hence not been captured with the satellite imagery. The estimated freshwater extent for the whole Great Barrier Reef World Heritage Area (GBRWHA) was highly correlated to the total freshwater discharges (R^2=0.835), the freshwater extent for 2011/2012 was similar in magnitude to 2007-2010 period as observed with the MODIS time series. The estimated freshwater extent for 2011/2012 was larger than in 2010/2011 only

for the Burdekin and Burnett Mary regions, while for Fitzroy and the Wet Tropics it was higher than the median extents observed with the MODIS time series.

The GBRMPA released specific Water Quality Guidelines for the Marine Park in 2009 (hereafter called the Guidelines). These Guidelines provide triggers for management action where exceedance occurs and threshold levels for analysis of current condition as well as trend monitoring. The exceedance of the Guidelines was assessed for two water quality variables that can be retrieved accurately from remote sensing: CHL and TSS retrieved from MODIS Aqua using CSIRO's algorithms. The exceedance assessment results evaluated for CHL and TSS were presented as maps of exceedance of the Guidelines, i.e. when mean values for the year (and seasons) exceed the thresholds, as well as the Exceedance Frequency that provides the number of days where the concentration exceeded the threshold divided by the number of days with (error-free) data for that period. The spatial patterns in exceedance were a function of the coastal to offshore gradients that can be observed in the median maps as well as the different trigger values between the Enclosed Coastal and Open Coastal waters as well as the Midshelf and Offshore areas.

The two component indicators of the Paddock to Reef marine water quality index (CHL and TSS) are based on the spatial extent of non-compliance in the Inshore water body. The Inshore water body includes the Open Coastal waters and the Enclosed coastal waters that have been delineated in this report as a case-study to show the effect of delineation on compliance estimates. As the guideline values for CHL and TSS for the Enclosed Coastal waters are higher than those for the Open Coastal water body, this study demonstrated that the relative area of non-compliance for the Inshore waters is over-estimated if the Enclosed waters delineation is not taken in account. Hence the delineation of the Enclosed Coastal water body improved the estimates of the spatial extent of non-compliance and the Paddock to Reef marine water quality index. It is recommended to GBRMPA that the proposed delineation of the Enclosed Coastal waters should be taken in consideration together with other data sources including the Queensland Wetlands 2009 data, depth contours, hydrodynamics and sources of freshwater input to the coast prior to selecting the final water body delineation for formal implementation in the Guidelines. This report provides a consistent re-assessment of the exceedance of the Guidelines for past reporting years. As such, all the results presented in this report supersede the previous reports.

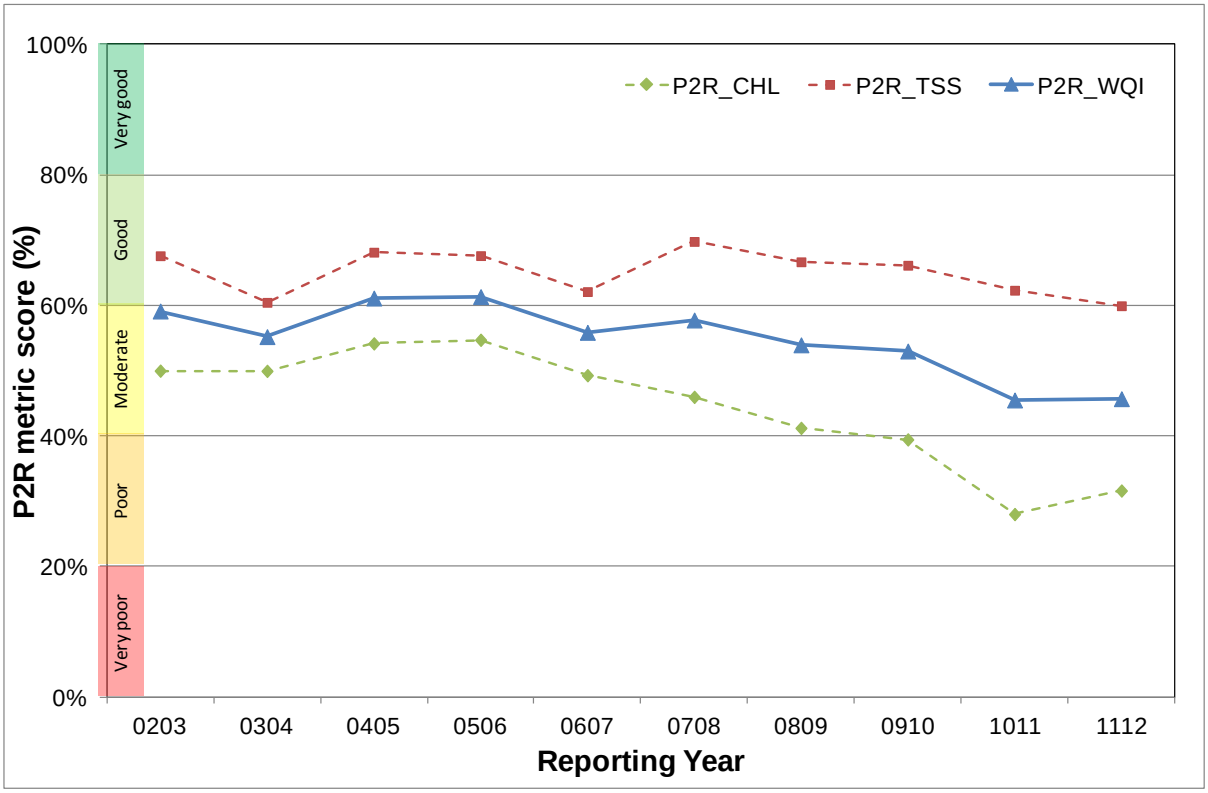
The marine water quality for this reporting year for the whole GBR was scored as "moderate", reflecting the one "poor" and three "moderate" scores for P2R_WQI in the four reporting regions that contribute the whole of GBR score (the regional scores for Cape York and Burnett Mary are excluded from calculations of the overall GBR score for each metric as limited field information was used for the parameterization and validation on the remote sensing retrievals). The scores for the two component indicators for the whole GBR were "poor" for P2R_CHL and "moderate" for P2R_TSS, reflecting the "very poor" to "moderate" regional scores for P2R_CHL and "moderate" to "good" regional scores from P2R_TSS.

The marine water quality index was similar to the reporting year 2010/11 and lower than for the previous reporting years for all regions, as well as the whole GBR, reflecting the high freshwater discharges from the GBR catchments in 2010/11 and 2011/12 and the associated estimated freshwater plume extent.

The MMP water quality monitoring uses three complementary approaches to collect data at various spatial (location, region, and whole GBR lagoon) and temporal (ad hoc, daily, 10-minutely) scales: traditional direct water sampling from research vessels, in situ data loggers at a small number of

selected inshore reef locations and remote sensing techniques. While data loggers provide detailed information on the local variability in water quality parameters, remote sensing observations provide extensive spatial coverage at 1 km resolution. The comparison of the remote sensing based results with other MMP components like the site-specific inshore water quality monitoring provided a consistent assessment of Guideline exceedance. Given the spatial and temporal complexity of the data, a separate research project carried out with Reef Rescue Research and Development funding for 2011 - 2013 is developing an integrated assessment and reporting framework for a comprehensive and more easily interpretable assessment of GBR water quality. This will enable these datasets to meet the requirements of the monitoring and modelling strategies for the Paddock to Reef reporting.

	P2R_CHL	P2R_TSS	P2R_WQI
Cape York*	Moderate (47)	Good (76)	**Good (62)**
Wet Tropics	Very poor (9)	Moderate (57)	**Poor (33)**
Burdekin	Poor (34)	Good (65)	**Moderate (50)**
Mackay Whitsunday	Moderate (58)	Moderate (60)	**Moderate (59)**
Fitzroy	Very poor (19)	Moderate (58)	**Poor (38)**
Burnett Mary *	Very poor (15)	Very Good (92)	**Moderate (53)**
GBR	**Poor (32)**	**Moderate (60)**	**Moderate (46)**



ACKNOWLEDGMENTS

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1 INTRODUCTION

Water quality is a key issue for the health of the Great Barrier Reef (GBR, all abbreviations and acronyms of this report are summarized in Table 1), catchments and for the communities, industries and ecosystems that rely on good water quality in North Queensland.

The Great Barrier Reef Water Quality Protection Plan (GBRWQPP) was released by the Australian and Queensland Governments in October 2003 with the ultimate goal to 'halt and reverse the decline in water quality entering the reef within 10 years'. The Reef Plan Marine Monitoring Program (now Reef Rescue Marine Monitoring Program, MMP hereafter) was established to assess the health of key marine ecosystems (inshore coral reefs and seagrasses), the condition of water quality in the inshore GBR lagoon and water quality of water masses entering the Great Barrier Reef during the wet season. The MMP is currently funded under the Australian Government's Reef Rescue initiative and is managed directly by the Great Barrier Reef Marine Park Authority (GBRMPA).

This report describes the activities carried out under the projects "Reef Rescue Marine Monitoring Program – Assessment of Terrestrial Run-off Entering the Reef" and "Reef Rescue Marine Monitoring Program – Inshore Marine Water Quality Monitoring".

The underlying activity for both projects is the acquisition, processing with regionally valid algorithms, validation and transmission of geo-corrected Moderate Resolution Imaging Spectroradiometer (MODIS) ocean colour imagery. MODIS ocean colour imagery was used to quantify for the GBR near-surface concentrations of key water quality variables: total suspended solids (TSS) as an indicator of water clarity, coloured dissolved organic matter (CDOM) as a tracer of terrestrial discharge of low salinity waters, and chlorophyll-a (CHL) as an indicator of phytoplankton biomass and a proxy for nutrient availability.

Key objectives of the two projects are to:

- Report on methodological development to detect trends and anomalies in the data based on long-term datasets, and how techniques have improved integration with *in situ* monitoring data;
- Provide summary images derived from MODIS data for TSS, CHL and CDOM within the inshore and offshore areas during the wet and dry seasons;
- Assess the temporal and spatial variation in the extent of available 2011/12 river flood plumes across the 6 GBR natural resources management (NRM) regions; and
- Contribute to the Paddock to Reef (P2R) reporting by assessing the exceedance of water quality guidelines for two of the water quality variables that can be retrieved from remote sensing, namely CHL and TSS retrieved from MODIS Aqua using CSIRO's algorithms.

Section 2 of this report will provide details on the methods used to retrieve water quality from satellite imagery and how management relevant information is produced from time series of satellite imagery. Section 3 will provide a proposed delineation of the Enclosed Coastal waters for the Great Barrier Reef World Heritage Area (GBRWHA) and will assess how it affects the estimates of the spatial extent of non-compliance and the Paddock to Reef marine water quality index. In section 4 the assessment of the P2R marine water quality index and the exceedance of the Guidelines is described for the whole GBRWHA and the six NRM reporting regions with maps and tables summarising the

exceedance results for CHL and TSS. All P2R calculations presented in this report were performed including the proposed delineation of the Enclosed Coastal waters.

Table 1 List of acronyms used in this report.

AIMS	Australian Institute for Marine Science
ANN	Artificial Neural Network
CDOM	Coloured Dissolved Organic Matter
CHL	Chlorophyll
DAAC	Distributed Active Archive Centre (NASA)
EF	Exceedance frequency, calculated as the ratio of the number of days where the concentration exceeded the threshold to the number of days with (error-free) data for that period.
EG	Exceedance of the Guidelines, determined by comparing the mean values for the year (and seasons) to the appropriate Guideline thresholds
ESA	European Space Agency
GBR	Great Barrier Reef
GBRWHA	Great Barrier Reef World Heritage Area
GBRMPA	Great Barrier Reef Marine Park Authority
IOCCG	International Ocean Colour Coordinating Group
LMI	Linear Matrix Inversion
MODIS	MODerate resolution Imaging Spectrometer (operated by NASA) sensors
MODIS-Terra	Launched in 1999 – a nominal 10:30 equatorial overpass time
MODIS-Aqua	Launched in 2002– a nominal 13:30 equatorial overpass time
MERIS	Medium Resolution Imaging Spectrometer (operated by ESA); a nominal overpass time of ca 10:00 AM
NASA	National Aeronautics and Space Administration
NAP	Non algal particulate matter (i.e the concentration of Total Suspended Solids minus the dry weight of algal particles)
NRM	Natural Resource Management
OCR	Ocean Colour Radiometry
P2R	Paddock to Reef
P2R_CHL	Paddock to Reef indicator for marine water quality, based on the Relative extent of exceedance of the Guidelines for Chlorophyll
P2R_TSS	Paddock to Reef indicator for marine water quality, based on the Relative extent of exceedance of the Guidelines for Chlorophyll
P2R_WQI	Paddock to Reef marine water quality index, calculated for as the average value of the metric scores for the two component indicators, i.e.

	P2R_WQI=(P2R_CHL+P2R_TSS)/2
REEF50	Relative extent of exceedance frequency greater than 0.50, i.e. when the median values are used for the assessment of the Guidelines.t
REEG	Relative extent of exceedance of the Guidelines, i.e. when the mean values are used for the assessment of the Guidelines.
RT	Radiative transfer
SA	Semi analytic
SeaDAS	SeaWiFS Data Analysis System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor (Launched in 1997) a nominal overpass time of ca 12:00 AM
TSS	Total Suspended Solids
WQIP	Water Quality Improvement Plan

2 METHODS

Given the size and variability of conditions within the GBR catchments, monitoring the water quality in the GBR lagoon waters is challenging. The MMP water quality monitoring uses three complementary approaches to collect data at various spatial (location, region, and whole GBR lagoon) and temporal (ad hoc, daily, 10-minutely) scales: traditional direct water sampling from research vessels, *in situ* data loggers at a small number of selected inshore reef locations and satellite based remote sensing. While data loggers provide detailed information on the local variability in water quality parameters, remote sensing observations provide extensive spatial coverage at 1 km resolution.

Remote sensing is a suitable and cost-effective technique for monitoring of coastal water quality, because it provides synoptic views of the spatial distribution of CHL, CDOM and TSS concentrations, and water clarity of near-surface water. The data generated from regular daily satellite acquisition of the GBR region should help to identify patterns of spatial variation over scales of kilometers to hundreds of kilometres and temporal scales of days to years. Management-relevant products from remote sensing data that provide information beyond that of a simple concentrations map are needed by management agencies to make more informed decisions.

2.1 Regionally valid retrieval of water quality parameters from satellite imagery

Based on studies conducted in the Fitzroy River estuary (Brando et al. 2006, Oubelkheir et al. 2006) and the Mossman Daintree coastal waters (Steven et al. 2007), it has been demonstrated that the NASA standard global Ocean Colour algorithms are inaccurate in nearshore GBR waters (Qin et al. 2007). Subsequently there has been considerable effort in developing regionally appropriate algorithms for these optically complex GBR waters. Studies commissioned by GBRMPA on water quality monitoring (Schaffelke et al. 2006) and optical characterisation of coastal waters (Blondeau-Patissier et al. 2009) have also been undertaken and contribute to the development of regionally appropriate algorithms using a semi-analytical physics-based approach parameterised and validated with local measurements (Brando et al. 2010, Brando et al. 2010).

In this work we coupled two physics-based inversion algorithms to improve the accuracy of water quality estimates from MODIS Aqua data in GBR Lagoon coastal waters. Firstly, an atmospheric correction algorithm based on inverse modelling of radiative transfer simulations and Artificial Neural Network (ANN) inversion is used to derive the remote sensing reflectance at mean sea level (Schroeder et al. 2007, Schroeder et al. 2008). Then, the inherent optical properties and the concentrations of the optically active constituents, namely CHL, non-algal particulate matter (NAP, i.e the concentration of Total Suspended Solids minus the dry weight of algal particles) and CDOM, were retrieved using an adaptive implementation of the Linear Matrix Inversion (LMI, Hoge and Lyon 1996) that incorporates regional and seasonal knowledge of specific Inherent Optical Properties (Brando et al. 2008, Brando et al. 2012, Schroeder et al. 2012).

As the ANN atmospheric correction uses as input MODIS Top-Of-Atmosphere radiance spectra, the MODIS aqua time series is first processed with NASA's software (SeaDAS) to Level 2, and then with CSIRO's coupled physics-based inversion algorithms. In this report the parameterization of both the ANN atmospheric correction and the adaptive Linear Matrix Inversion (a-LMI) water quality

algorithm were revised to improve accuracy in turbid waters and reduce over-estimates of TSS concentrations in the Midshelf. The comparison of MODIS Aqua retrievals of CHL, CDOM and NAP data to *in situ* data showed that the a-LMI water quality algorithm coupled with the ANN atmospheric correction is more accurate than NASA's algorithms for GBR waters. The uncertainty for the retrieval of CHL, CDOM and TSS with the coupled physics-based inversion algorithms was 89%, 68% and 77%, respectively. The parameterization and validation on the remote sensing retrievals was mainly based on observations performed in coastal and lagoonal waters during the dry season between Keppel Bay and the Wet Tropics region. The accuracy of the retrieval is likely to likely to be lower in shallow and turbid waters systems such as Princess Charlotte Bay, Broad Sound and Shoalwater Bay, as there is no data available for parameterization and validation. Details on the algorithm's theoretical basis, parameterization and validation are provided in Appendix 1.

2.2 Management relevant remote sensing products to monitor water quality in GBR

If environmental managers are to take full advantage of remote-sensing capabilities then products that translate remotely-sensed scenes into useful information for managers are required. From daily remote sensing data, it is possible to produce a number of derived products suited to the specific needs of end-users or to particular geographic regions. Maps are the most common product and depending on user requirements, any number of variables or derived indices and attributes can be mapped over specified spatial aggregations and/or over timescales ranging from days to years. A prime example of management-relevant products are those providing water quality compliance information for environmental reporting (Brando et al. 2010).

This section will provide details on the methods used to generate all the maps and tables of the main body of the report (section 4). Section 3 will provide a delineation of the Enclosed Coastal waters for the GBRWHA and will assess how it affects the estimates of the spatial extent of non-compliance and the Paddock to Reef marine water quality index.

2.2.1 Water quality maps

For this report the whole MODIS aqua time series was reprocessed with the most recent updates in NASA's software (SeaDAS version 6.4), incorporating the improved knowledge of instrument temporal calibration to improve temporal stability of the time series of the MODIS AQUA aging sensor. Furthermore, the parameterization of both the ANN atmospheric correction and the adaptive Linear Matrix Inversion (a-LMI) water quality algorithm were revised to improve accuracy in turbid waters and reduce over-estimates of TSS concentrations in the Midshelf. As such, all the results presented in this report supersede the previous reports.

To visualize the data and to produce all derive products all daily MODIS pixels are remapped into a standard 1km grid. All spatial and temporal analyses are thus performed on the daily gridded data. In this report, seasonal median maps for CHL and TSS are presented for each reporting region. The seasonal median values for the wet and dry seasons were calculated for each pixel in the region from the valid (i.e. cloud-free and error-free) daily observations. Seasonal maps that indicate the number of valid observations (i.e. cloud-free and error-free) used for calculating the median values are also presented.

The number of image observations per pixel location that were used in calculating the median values for each season show number of observation vary from 30 to about 90, even if 150-170 images were available for each season to provide data for the dry season and the wet season depending on the reporting region. The low number of observations is a result of the strict quality control criteria applied to the imagery: pixels with cloud or cloud shadow, low view and illumination angles (solar zenith and observer zenith higher than 60 degrees) were flagged and dismissed as were pixels where the atmospheric correction failed. For the identification of clouds, the default threshold value of 2.7% the Rayleigh-removed TOA reflectance at 869 nm was used. We also dismissed the pixels with a high error between modelled and measured spectra, which indicates that the underlying inversion model was not able to retrieve meaningful concentrations. These dismissals caused the dearth of pixels in the very near coastal areas. As a result of this stricter quality control implemented since the 2009/10 MMP report (Brando et al. 2010), the number of available observations for each pixel is lower than reported in previous reports (i.e. up to the 2008/09 MMP report Brando et al. 2010).

The number of available observations is substantially lower in the wet season than the dry season for all regions. This is due to higher cloud cover in the wet/monsoonal season. It is possible that the cloud cover introduces a bias in the sampling that could affect the estimate of the median and mean concentration or any other statistical summary of the data. The effect of cloud cover on the estimation of statistical parameters such as the mean and median needs to be investigated further using time series data from moored sensors or the output from biogeochemical models.

2.2.2 Estimate of freshwater extent

Riverine freshwater plumes connect the land with the receiving coastal and marine waters and are the major transport mechanism for nutrients, sediments and pollutants into the GBR lagoon. The extent and duration of freshwater plumes can have significant implications for the health of marine ecosystems such as seagrasses and coral reefs. Low salinity runoff waters may transport natural and anthropogenic contaminants into the sea, and can directly stress marine ecosystems that are adapted to higher salinity levels (Burrage et al. 2003). Concentrations of riverine pollutants have been attributed to the specific land use of the catchments and positive correlations have been reported between river-discharged material and water quality of the GBR receiving waters (Brodie et al. 2008, Kennedy et al. 2012).

The dynamics of a flood plume as it moves freshwater from the river mouth into the marine environment can be described in terms of the hydrodynamic and chemical behaviour. At first flood plumes contain elevated concentrations of sediments (and associated nutrients and contaminants). Later, when particulate matter falls out of the plume waters the plume is characterised mainly by the presence of the dissolved materials and the associated nutrients (Devlin et al. 2012) .

In freshwater plumes, CDOM concentrations are high and are largely derived from terrestrial sources, making CDOM a quasi-conservative tracer of terrestrial discharge of low salinity waters. Negative correlations between CDOM and sea surface salinity have been established from in-situ data in several studies (Ferrari and Dowell 1998, Bowers and Brett 2008, Astoreca et al. 2009, Molleri et al. 2010). In this report we use CDOM as a surrogate for salinity to estimate low salinity waters indirectly from MODIS ocean colour observations for the entire GBR region as detailed in Schroeder et al. (2012). Based on a linear regression of 250 GBR-wide concurrent *in-situ* CDOM and salinity measurements a relationship was used to establish a cut-off threshold of CDOM absorption at 443nm of 0.24 m^{-1} corresponding to a salinity of 30±4 PSU (Figure 1) (Schroeder et al. 2012). The freshwater extent for

the wet season can be estimated by applying the threshold for freshwater mapping (0.24 m^{-1} ⇔ 30±4 salinity) to the maximum CDOM values for the wet season.

The remote sensing algorithms adopted in this study cannot differentiate between the sources of CDOM, which for this aim are assumed to be mainly influenced by flood waters during the wet seasons. As a consequence any estimated freshwater extent is potentially biased by additional supratidal, intertidal and subtidal and oceanic CDOM sources such as bacterial degradation of phytoplankton, mangroves, sea grass beds, coral reef and benthic organisms living in the sediment (Schroeder et al. 2012 and references therein). However, the CDOM production of these additional non-runoff related sources is usually much lower than the applied CDOM absorption threshold of 0.24 m^{-1} at 443 nm (Schroeder et al. 2012).

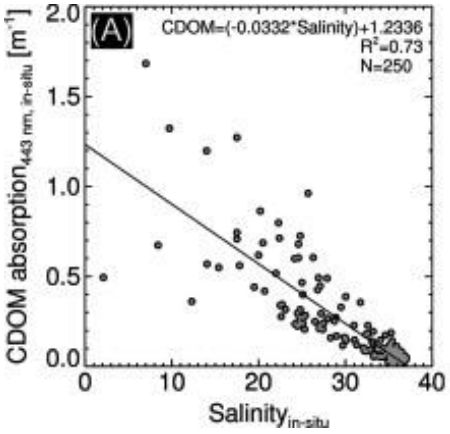


Figure 1. Linear regression of concurrent in situ CDOM absorption (443 nm) and salinity measurements. Modified from Figure 4 of Schroeder et al. (2012).

Unusually high CDOM absorption was observed from remote sensing by Schroeder et al. (2012) for the mid and outer shelf reefs of the Mackay and Fitzroy NRM regions, which are not directly influenced by flood waters. In these regions remotely-sensed CDOM absorption was observed to vary between 0.15 and 0.2 m^{-1} at 443 nm and further *in-situ* measurements are needed to understand these high values in off-shore waters. The conservative CDOM threshold for freshwater mapping (0.24 m^{-1} ⇔ 30±4 salinity) enables to separate the autochthonous reef matrix CDOM production from the estimate of freshwater plume extent for the wet season.

Shallow coastal embayment, where turbidity is dominated by tidal resuspension of bottom sediments composed of terrigenous mud in the near-shore areas are also regions where CDOM may not be attributed solely to terrestrial runoff. The freshwater extents estimated for these regions are potentially overestimated if no rivers empty directly into these embayments, e.g. Broad Sound. For this region an along-shore transport of northward directed freshwater from the Fitzroy River is observed in years of high discharge only (Schroeder et al. 2012).

2.2.3 Evaluation of compliance to guidelines

In addition to the median concentration maps, the exceedance of water quality guidelines was assessed for CHL and TSS retrieved from MODIS Aqua imagery using CSIRO's algorithm. The exceedance could also be evaluated for the recently published regional Secchi Depth algorithm based of *in situ* data collected by AIMS(Weeks et al. 2012).

A set of water quality guideline values and objectives was released in 2009 by federal and state legislation for the GBR, with an effort to avoid inconsistency in the regions of overlap. Version 3 of the Queensland Water Quality Guidelines (DERM 2009) was released to promote regionally and locally relevant guideline water quality values for Queensland coastal waters which extend up to 3 nautical miles offshore. Regionally-specific environmental values and objectives have been set in the GBR catchments in the P2R program and in some specific areas through the development of Water Quality Improvement Plans (WQIPs). GBRMPA released the Water Quality Guidelines for the Marine Park (hereafter called the Guidelines) in 2009 and identified five types of water bodies: the Enclosed Coastal waters, the Open Coastal waters, the Midshelf waters, the Offshore waters, and the Coral Sea (GBRMPA 2009). Much of the Great Barrier Reef Marine Park lies beyond Queensland state waters but there is an area of overlap within the nearshore coastal waters for which protocols have been agreed. Namely, Queensland guidelines are to be adopted for all waters inshore of and within the Enclosed Coastal zone. Offshore from the Enclosed Coastal zone and within waters of the GBR Marine Park, the Guidelines will apply, even if the boundary of the Enclosed Coastal zone lies inside the three nautical mile zone (DERM 2009).

Figure 2 reports the regional and cross shelf boundaries defined by GBRMPA for the MMP 2008/09 reporting and used for this study. These boundaries were delineated by implementing in a GIS environment the "Approximate water body delineations of the Open Coastal, Midshelf and Offshore marine water bodies in the six NRM regions" (Table 2)(Table 1, GBRMPA 2009). The water bodies vary in width from north to South in the GBRWHA, as the outer boundary of the water bodies was defined as function of the relative distance across the shelf boundaries for each NRM region. The figure also includes the proposed delineation of the Enclosed Coastal waters derived for GBRMPA based on a statistical analysis of a decade of satellite data. More details on the methods are provided in Section 3 of this report.

The methods used in this study to evaluate compliance were originally developed to provide a demonstration of the use of remotely-sensed data in the assessment of exceedance of the Guidelines (Brando et al. 2010). These methods were then implemented in the 2008/09 and 2009/10 MMP reports (Brando et al. 2010, Brando et al. 2010) to contribute to the indicators and metrics for the P2R reporting for marine water quality (RWQPP 2011, RWQPP 2011).

Table 2 Approximate distance from shore for the outer boundary of the Open Coastal, Midshelf and Offshore marine water bodies in the six NRM regions from the Great Barrier Reef Marine Park Authority Water Quality Guidelines (Table 1 at page 12 of GBRMPA 2009).

NRM region	Open Coastal (km)	Midshelf (km)	Offshore (km)
Cape York	6	24	250
Wet Tropics	6	24	170
Burdekin	12	48	180
Mackay-Whitsunday	15	60	280
Fitzroy	20	80	340
Burnett-Mary	7	28	270

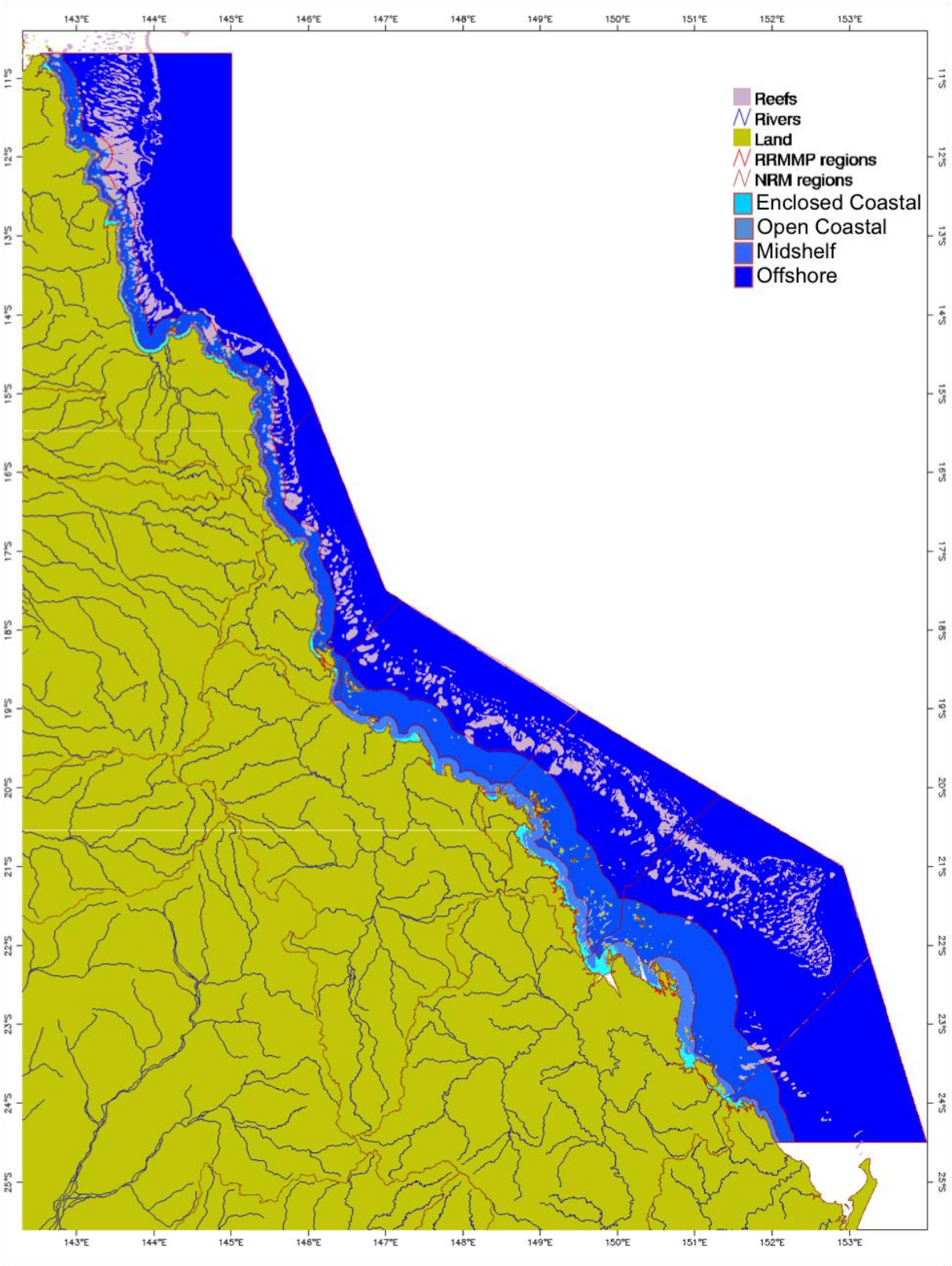


Figure 2. Regional and cross shelf boundaries defined by GBRMPA for the MMP 2008/09 reporting (red lines), the cyan areas identify the Enclosed Coastal waters delineated in this report based on a statistical analysis of a decade of satellite data

Compliance to the Guidelines for CHL and TSS are presented as maps illustrating the exceedance of the Guidelines (EG) and the exceedance frequency (EF). EG is determined by comparing the mean values for the year (and seasons) to the appropriate Guideline thresholds, while EF is calculated as the ratio of the number of days where the concentration exceeded the threshold to the number of days with (error-free) data for that period. EF values higher than 0.50 indicate the median concentrations for the year (and seasons) exceeded the Guideline thresholds.

In previous reports we have shown that given the skewness of the raw data, the median CHL concentrations are a more representative measure of central tendency than the arithmetic mean, particularly for the wet season (Brando et al. 2011). Moreover, the estimate of the mean values for the wet season, and to a lesser extent for the whole year, are more likely to be affected than the estimate of the median values by the "non-sampling" of the higher values due to cloud cover. In an attempt to address this issue, in this report the exceedance of the Guidelines for CHL and TSS is evaluated by comparing the mean as well as the median values of the variables to the appropriate seasonal and regional values, even if the mean values are identified in the Guidelines.

The Guideline trigger values used as threshold levels for the analysis of exceedance are reported in Table 3 (annual means) and Table 4 (seasonal means). The Guidelines trigger values for Enclosed coastal for CHL is 2.0 µg L^{-1} for the whole GBR, while for TSS varies across regions. A value of 5 mg L^{-1} was applied to Cape York, Wet Tropics and Mackay Whitsundays, while a value of 15 mg L^{-1} was applied to the Burdekin, Fitzroy and Burnett-Mary Regions (Table 3 page 26 of the Guidelines and K. Martin & C. Honchin, pers comm. 18/3/2013).

Table 3 Trigger values from the Great Barrier Reef Marine Park Authority Water Quality Guidelines (GBRMPA 2009). Guideline values for the assessment of the annual mean values. *: Geographical adjustment: Cape York, Wet Tropics and Mackay Whitsunday/ Burdekin, Fitzroy and Burnett Mary.

Parameter	Enclosed Coastal	Open Coastal	Midshelf	Offshore
Chlorophyll-a (µg L^{-1})	2.0	0.45	0.45	0.40
Secchi Depth (m)	1.0/1.5*	10	10	17
Total Suspended Solids	5.0/15*	2.0	2.0	0.7

Table 4 Trigger values from the Great Barrier Reef Marine Park Authority Water Quality Guidelines (GBRMPA 2009). Seasonally adjusted Guideline values for the assessment of seasonal mean values in dry/wet seasons.

	Water body			
Parameter	Enclosed Coastal	Open Coastal	Midshelf	Offshore
Chlorophyll-a (µg L^{-1})	2.8/1.4	0.32/0.63	0.32/0.63	0.28/0.56
Secchi Depth (m)	1.0/1.5	10	10	17
Total Suspended Solids (mg L^{-1})	6.0/4.0 18/12	1.6/2.4	1.6/2.4	0.6/0.8

The maps are accompanied by tables summarising the exceedance results for each variable and each reporting region. The summary of the exceedance extent in each map provides the relative surface area where mean or median concentration exceeded the trigger values for the year (or seasons), expressed as relative area (%) of the water body. In this report these two quantities will be referred to as REEG (relative extent of exceedance of the Guidelines, i.e. when the mean is used for the assessment) and REEF50 (relative extent of exceedance frequency greater than 0.50, i.e. when the median is used for the assessment). In this report, the REEG values for CHL and TSS (REEG_CHL, REEG_TSS) are presented within each reporting region as separate values for the Enclosed Coastal, Open Coastal, Midshelf, and Offshore water bodies. To compute the REEG values for the whole Inshore water body (i.e. the Enclosed Coastal and the Open Coastal waters calculated together), pixels in the enclosed coastal areas are compared to the guidelines values for Enclosed coastal waters and only the pixels lying in the Open Coastal are compared with the guideline values for Open coastal waters.

The summary of exceedance is also provided for each water body for each season by computing the mean and median concentrations from all valid observations independently of the spatial location, along with the EF for that period. The summaries of the exceedance results are based on a large number of observations (ranging from thousands of valid observations for the Enclosed Coastal waters in the wet season to millions of valid observations for the Offshore area in the dry season).

2.2.4 Calculating metrics for the P2R reporting for marine water quality

The metrics for the P2R reporting for marine water quality are based on the assessment of the exceedance of water quality guidelines for Chlorophyll-a and Total Suspended Solid (RWQPP 2011, RWQPP 2011). In P2R reporting, the two indicators for marine water quality are based on the summary of the exceedance of annual mean values of Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for each reporting period for the inshore water body. Hence the indicator data considered for the P2R metric calculations are the REEG values for CHL and TSS (REEG_CHL, REEG_TSS) for the Inshore water body (i.e. the Enclosed Coastal and the Open Coastal waters calculated together) (RWQPP 2011, RWQPP 2011).

Consistently with the marine water quality P2R reporting scheme, in this report the metric scores are expressed the percent area that does NOT exceed the Guidelines value for the Inshore water body (i.e. the Enclosed Coastal and the Open Coastal waters), hence the REEG values are simply subtracted from 100% to calculate the metric score (i.e. P2R_CHL=100- REEG_CHL and P2R_TSS=100-REEG_TSS). The rationale for this metric calculation method is to provide consistency with other P2R metrics, as all final metrics are standardized to a range from 0 to 100 such that zero is the lowest score and 100 is the highest i.e. ranging from the worst to the best possible environmental condition (RWQPP 2011, RWQPP 2011).

The overall GBR score is calculated by linearly combining the regional scores weighting them by the relative contribution to the GBR. The area weighting is used to prevent overweighting of scores from reporting regions that represent a small area in relation to the total area of GBR. As limited field information was used for the parameterization and validation on the remote sensing retrievals for these two regions (see section 2.1 and Appendix 1), the regional scores for Cape York and Burnett Mary are excluded from the area weighting calculations (RWQPP 2011, RWQPP 2011). The four reporting regions (Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy) contribute 13%, 21% ,27% and 39% to the overall GBR score for each metric (RWQPP 2011, RWQPP 2011).

The P2R marine water quality index (P2R_WQI) is then calculated for each region, as well for the whole GBR, as the average value of the metric scores for the two component indicators, i.e. P2R_WQI=(P2R_CHL+P2R_TSS)/2 (RWQPP 2011, RWQPP 2011).

The estimate of the P2R_WQI and the metric scores for the two component indicators (P2R_CHL and P2R_TSS) does not include an assessment of associated uncertainty. Such assessment would account for the uncertainty associated with the retrieval of CHL and TSS from MODIS data with the coupled physics-based inversion algorithms. The uncertainty associated to the P2R metric score could be estimated following the approach proposed by Schroeder et al. (2012) to assess the uncertainty associated to the estimates of freshwater extent, where the uncertainty associated with the retrieval of CDOM was accounted for when setting the CDOM thresholds. Future work will extend this method to also assess the uncertainty associated to the two component indicators of the marine water quality index from the spatial extent of non-compliance in the Enclosed Coastal and Open Coastal waters.

2.2.5 Guide to interpreting the maps

All maps presented in section 4 have a consistent presentation: land is represented as dark gray; the coastal boundary is based on a standard coastline vector; main rivers are represented by blue lines; and coral reefs including a 1 km buffer zone (to avoid mixed land or reef and water pixels) are depicted as white. The maps of mean, median or maximum values will present data for all the pixels in the bounding box, while the maps of freshwater extent for the wet season, exceedance of the Guidelines and EF present data only for the reporting region of interest. The areas outside the reporting region are depicted in light gray.

Several boundary lines are overlayed onto the maps to enable the identification of water bodies identified by the Guidelines (Enclosed Coastal, Open Coastal, Midshelf, and Offshore). The boundaries for the reporting region are presented in each map as defined by GBRMPA in accordance with the NRM boundaries for the catchment and marine extensions (Figure 2). The cross shelf boundaries were defined by GBRMPA to implement the Guidelines: the thick pink line delineates the Enclosed Coastal waters, the thick white line defines the Open Coastal waters; the thin pink line separates the Midshelf from the Offshore waters while the thick gray line to the East in all images represents the limit of the marine park.

In the maps of freshwater extent for the wet season, pixels in the reporting region of interest are mapped in dark red when the maximum values for the wet season exceed the CDOM threshold for freshwater mapping (0.24 m^{-1} $\Leftrightarrow$ 30±4 salinity). The surface area (km^2) of the freshwater plume extent in the wet season for each region can then be estimated by tallying the number of the 1 km^2 pixels exceeding the CDOM threshold in each map.

In the maps of EG, pixels in the reporting region of interest are mapped in dark red when the annual (and seasonal) mean concentrations exceed the appropriate thresholds reported in Table 3 and Table 4. Pixels are mapped in light gray if they did not exceed the thresholds. The maps of EF report in a continuous colour scale the EF values ranging from 0-0.50 so that the pixels are mapped in dark red (EF>= 0.50) when the annual (and seasonal) median concentrations exceed the thresholds. The spatial patterns in the exceedance maps are a function of the coastal to offshore gradients that can be observed in the median maps of CHL and TSS as well as changes in thresholds between the Midshelf and Offshore areas. Hence most often the exceedance in the Offshore areas is present in clusters to the East of the thin pink line delineating the ‘Offshore’ waters.

3 DELINEATION OF THE ENCLOSED COASTAL WATERS FOR THE GBRWHA REPORTING REGIONS: A CASE-STUDY.

3.1 Objective of this study

In previous MMP reports the assessment of the Guidelines was carried out only on three of the four water bodies identified by the Guidelines (Open Coastal, Midshelf, and Offshore). As the guideline values for CHL and TSS for the Enclosed Coastal waters are higher than those for the Open Coastal water body, the delineation of the Enclosed Coastal water body is needed to reduce over-estimation of the relative area of non-compliance for the Inshore waters.

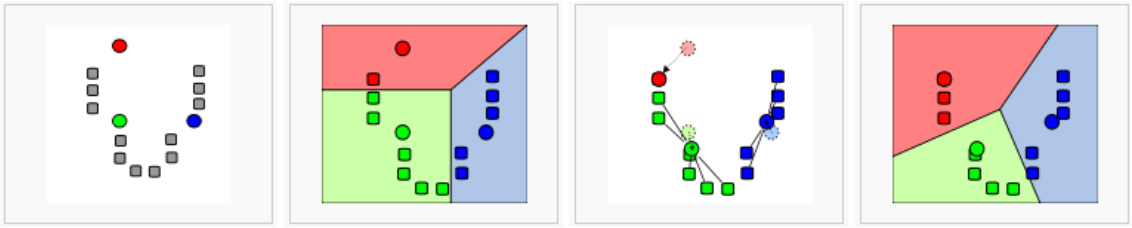
The cross shelf boundaries between the water bodies were delineated by GBRMPA by implementing in a GIS environment the "Approximate water body delineations of the Open Coastal, Midshelf and Offshore marine water bodies in the six NRM regions" (Table 1, GBRMPA 2009). In the Guidelines the seaward limit of the enclosed coastal water body is defined as "cut-off between shallow, enclosed waters near the estuary mouth and deeper, more oceanic waters". The Enclosed Coastal water body was not delineated by GBRMPA in 2009 as the Guidelines state the seaward limit of the enclosed coastal water body should be determined by site-specific studies to determine where the effective limit of freshwater mixing extends.

This section of the report aims to provide GBRMPA with a consistent delineation of the seaward limit of the enclosed coastal water body across the GBRWHA using a statistical analysis of a decade of satellite derived water quality data. This follows the results of the case study on the Burdekin region presented in the 2010/11 MMP Report (Brando et al. 2011) where large differences in the CHL signal were observed when the Open Coastal waters was compared to merged nearshore-coastal water, thus quantifying the effects of a delineation the Enclosed Coastal water body on the estimate of median values for the Burdekin coastal waters.

3.2 The clustering of the water masses

In the 2010/11 MMP report we presented a case study analysing the temporal patterns in the CHL variability across the shelf in the Burdekin region in ten years of MODIS data(Brando et al. 2011). To this aim biogeographical zones within which CHL concentrations display similar magnitude over time and space were statistically defined using the K-means clustering technique. The K-means clustering of the Burdekin waters resulted in five biogeographical clusters: nearshore, coastal, midshelf, lagoon and reef waters. The delineation of the five biogeographical clusters was rather different from the water bodies delineation based on the Guidelines, as they were derived using different water quality variables. In this section we will use the cluster analysis on 11 years of MODIS data to delineate the seaward limit of the enclosed coastal water body in the six NRM reporting regions.

The K-means clustering technique is an unsupervised, non-hierarchical clustering approach that groups pixels into a user-defined number of clusters *k*, usually determined from trial or expert knowledge (Wilks 2006). The K-means algorithm recalculates the group means of each cluster *k* through an iterative process and reassigns each pixel value until it reaches the minimum squared Euclidean distance with respect to the new means (Figure 3).



Step 1:

Select *k* different data points at random. These will be the centres of the initial clusters.

Step 2:

Assign all data points to the cluster with the closest mean value.

Step 3:

The centroid of each cluster becomes the new mean.

Step 4:

Step 2,3 are repeated until convergence is reached or other stopping criteria are met.

Figure 3 Illustration of the K-means clustering technique (modified from Wikipedia).

For this study, the K-means classification was based on twelve multi-annual monthly median CHL maps of each of the MMP reporting regions. Consistently with the analysis performed in the previous report for the Burdekin region (Brando et al. 2011), we constrained the clustering to a maximum number of 8 to 12 classes determined from a maximum number of 20 iterations and a change threshold of 5%. The final number of classes was selected also based on local knowledge, so these areas match with areas having most of the the physical features required to define the enclosed waters. A post-classification technique was performed on the initial clustering results in order to reallocate isolated pixels to a class belonging to the majority of the pixels comprised in a 3x3 pixel kernel.

3.3 Delineation of Enclosed coastal waters

As a result of the delineation of the seaward limit of the enclosed coastal water body for the six NRM reporting regions, the Enclosed Coastal waters account for 15-30% of the inshore water bodies (Table 5). The Enclosed Coastal waters for the six NRM regions are presented in Figures 4-9:

- In the Cape York region (Figure 4), the Enclosed Coastal marine water body accounts for ~30% of the inshore waters used for P2R reporting and for most of the area in Princess Charlotte Bay where the seaward limit of the enclosed coastal waters coincided with the outer boundary for the Open Coastal waters, delineated at 6 km from shore (Table 2)(Table 1, GBRMPA 2009). Also, several enclosed north facing embayments characterized by shallow waters and resuspension such as Shelburne Bay, Temple Bay, Loyds Bay, Bathurst Bay and Ninian Bay were identified.
- In the Wet Tropics region (Figure 5), the Enclosed Coastal marine water body accounts for ~15% of the inshore waters used for P2R reporting (Table 5). The enclosed waters included the Mossman- Daintree, Barron and Herbert River estuary mouths. In Rockingham Bay the seaward limit of the enclosed coastal waters coincides with the outer boundary for the Open Coastal waters in front of the Tully and Murray river mouths.
- In the Burdekin Region (Figure 6), the Enclosed Coastal marine water body accounts for ~15% of the inshore waters used for P2R reporting mostly in front of the mouth of the Burdekin River and in the shallow waters of Cleveland Bay and Bowling Green Bay.

- For the Mackay Whitsunday region (Figure 7), the Enclosed Coastal marine water body accounts for ~20% of the inshore waters used for P2R reporting and for most of the area in Port of Bowen, Repulse Bay and Broad Sound.
- The Enclosed Coastal marine water body of the Fitzroy region (Figure 8) accounts for ~23% of the inshore waters used for P2R reporting and for most of the area in Keppel Bay, Port Curtis and in Broad Sound.
- In the GBRMPA section of the Burnett Mary NRM region (Figure 9), the Enclosed Coastal marine water body accounts for ~21% of the inshore waters used for P2R reporting, mostly in Rodds Bay in front of Port Curtis.

Table 5 Summary of surface areas (Km^2) of all water bodies in the six GBR reporting regions. EC/IS is relative area of the Enclosed Coastal waters compared to the surface of the Coastal waters.

	Enclosed Coastal	Open Coastal	Inshore	Midshelf	Offshore	*EC/IS*
Cape York	1291	3004	4295	10544	62344	*30%*
Wet Tropics	307	1737	2044	5859	19906	*15%*
Burdekin	608	3363	3971	11065	26560	*15%*
Mackay Whitsundays	925	3651	4576	11389	25580	*20%*
Fitzroy	1336	4583	5919	18421	48664	*23%*
Burnett Mary	154	599	753	3401	33928	*20%*
GBR	4621	16937	21558	60679	216982	21%

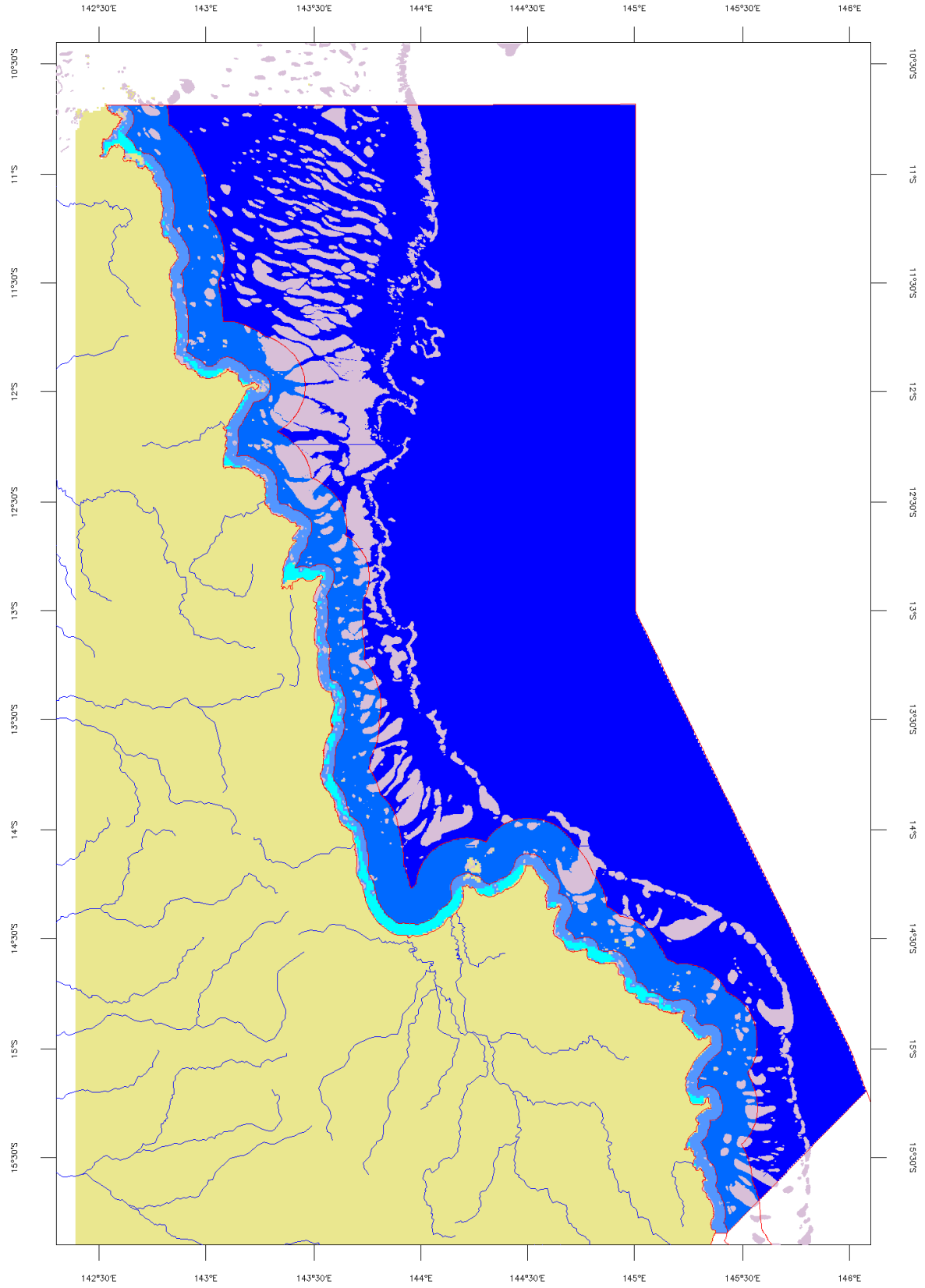


Figure 4. Delineation of the seaward limit of Enclosed Coastal waters for the Cape York region (light blue areas). Regional and cross shelf boundaries as defined by GBRMPA for the MMP 2008/09 reporting are presented as red lines.

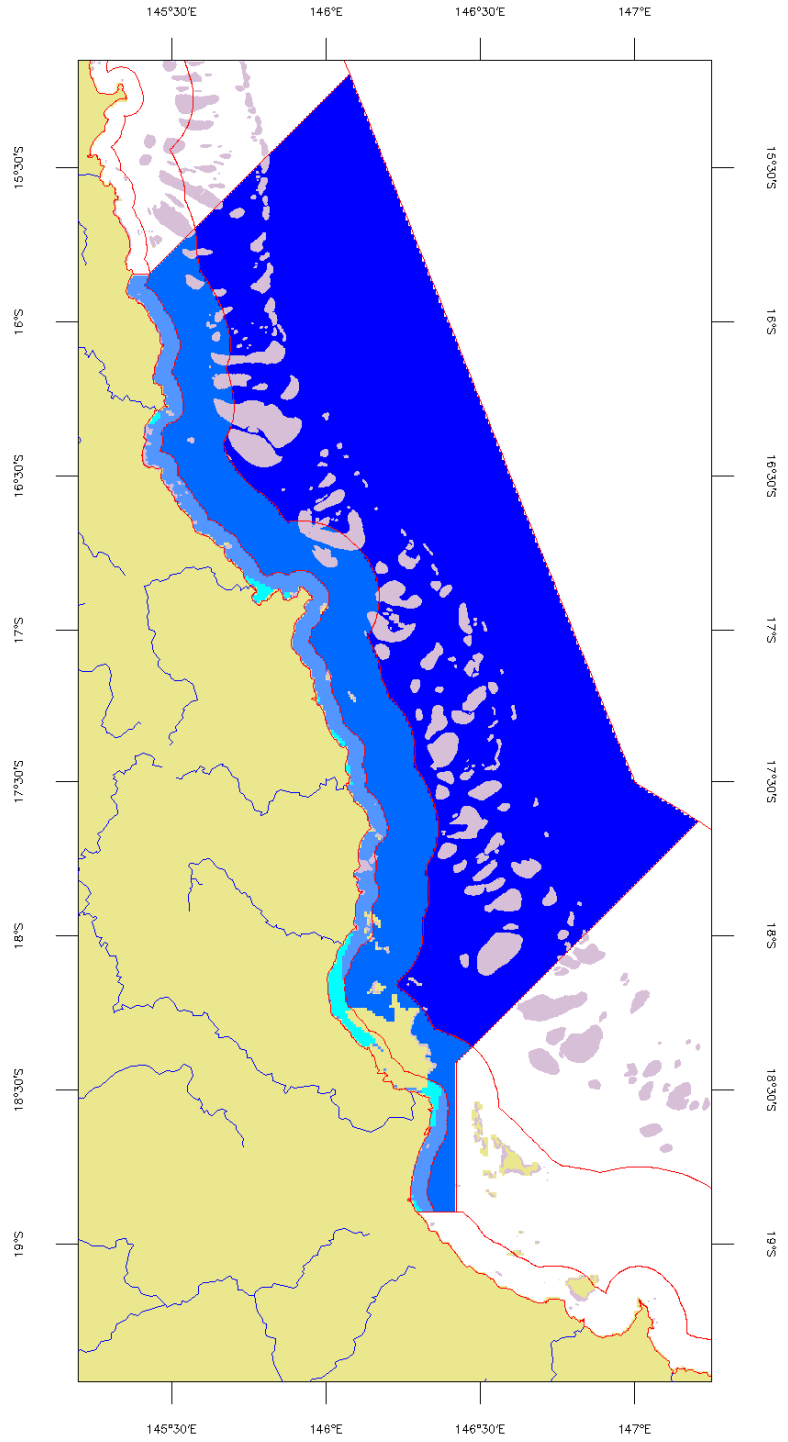


Figure 5. Delineation of the seaward limit of Enclosed Coastal waters for the Wet Tropics region (light blue areas). Regional and cross shelf boundaries as defined by GBRMPA for the MMP 2008/09 reporting are presented as red lines.

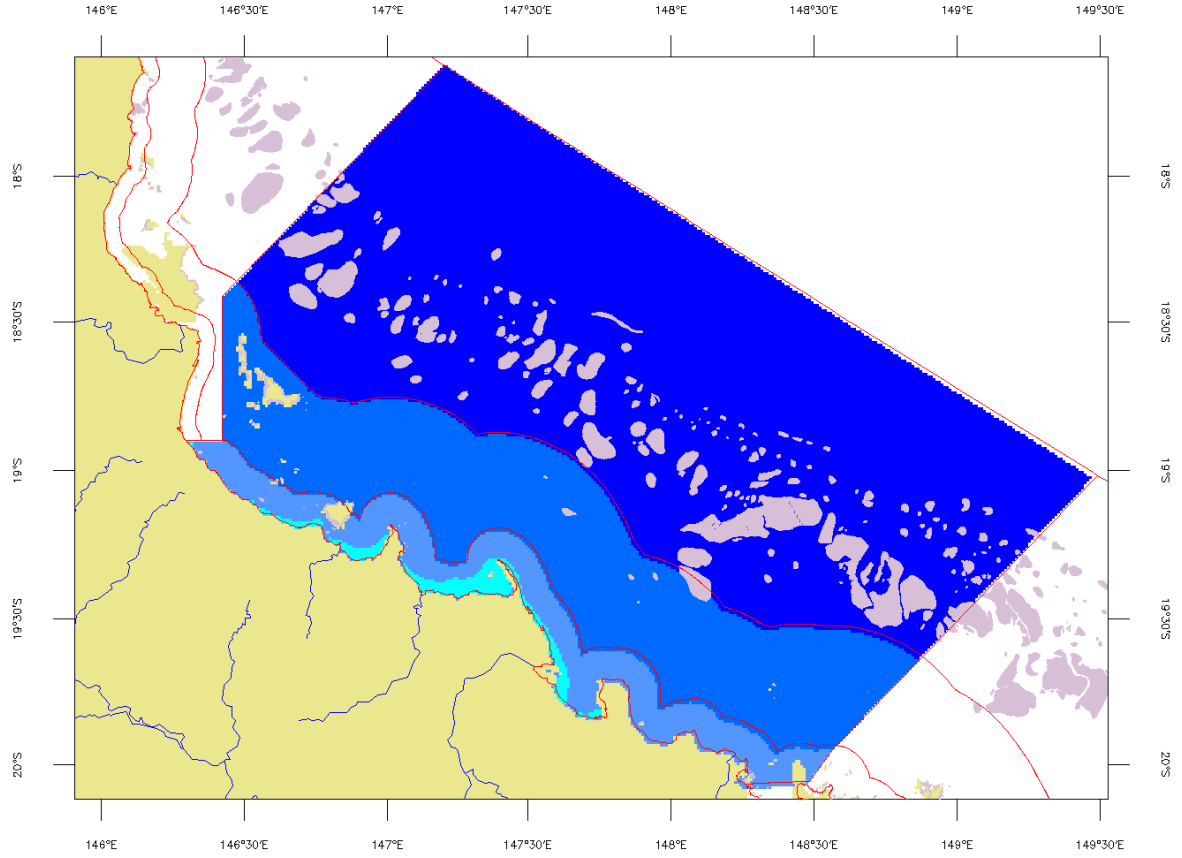


Figure 6. Delineation of the seaward limit of Enclosed Coastal waters for the Burdekin region (light blue areas). Regional and cross shelf boundaries as defined by GBRMPA for the MMP 2008/09 reporting are presented as red lines.

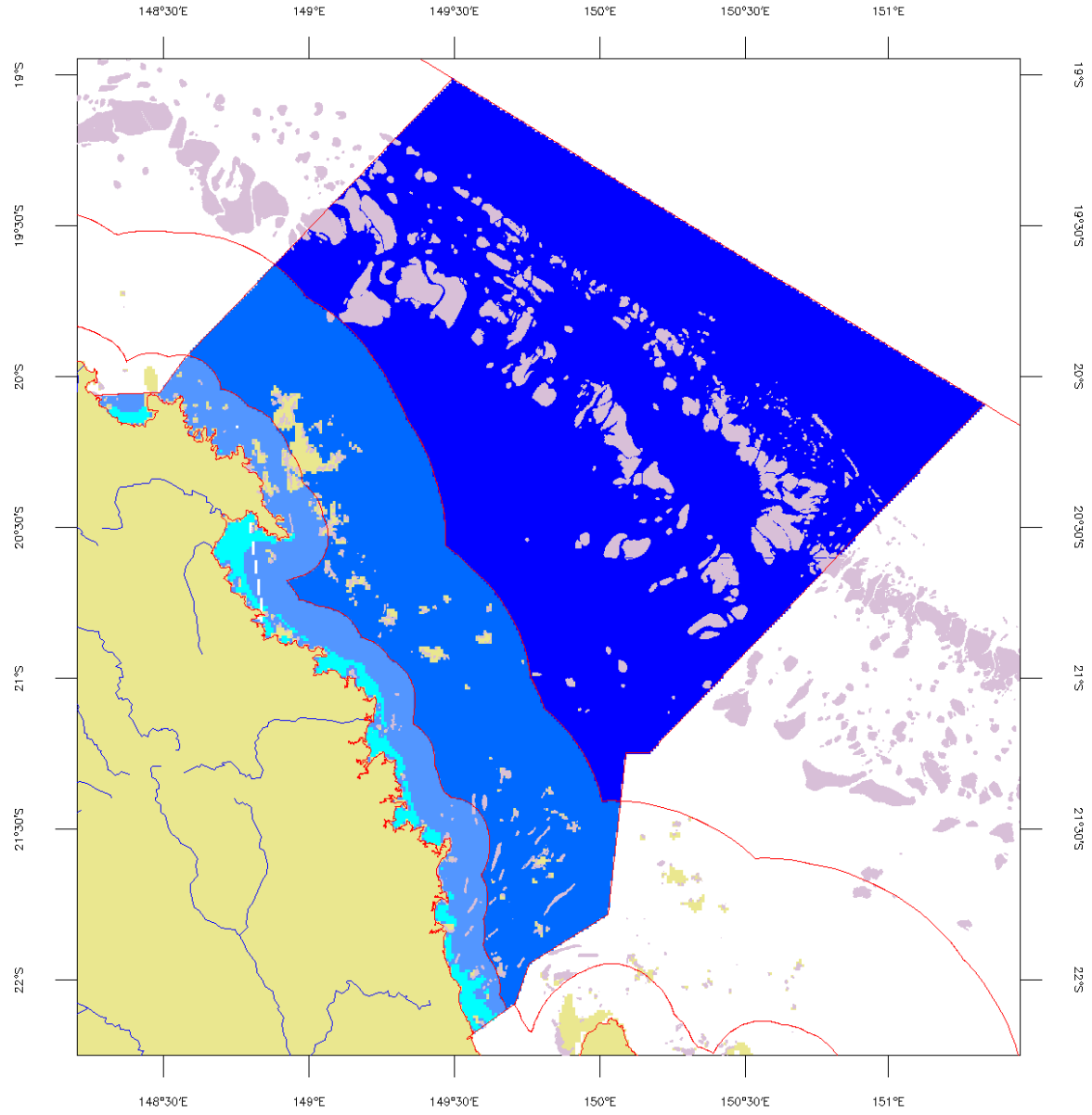


Figure 7. Delineation of the seaward limit of Enclosed Coastal waters for the Mackay Whitsunday region (light blue areas). Regional and cross shelf boundaries as defined by GBRMPA for the MMP 2008/09 reporting are presented as red lines.

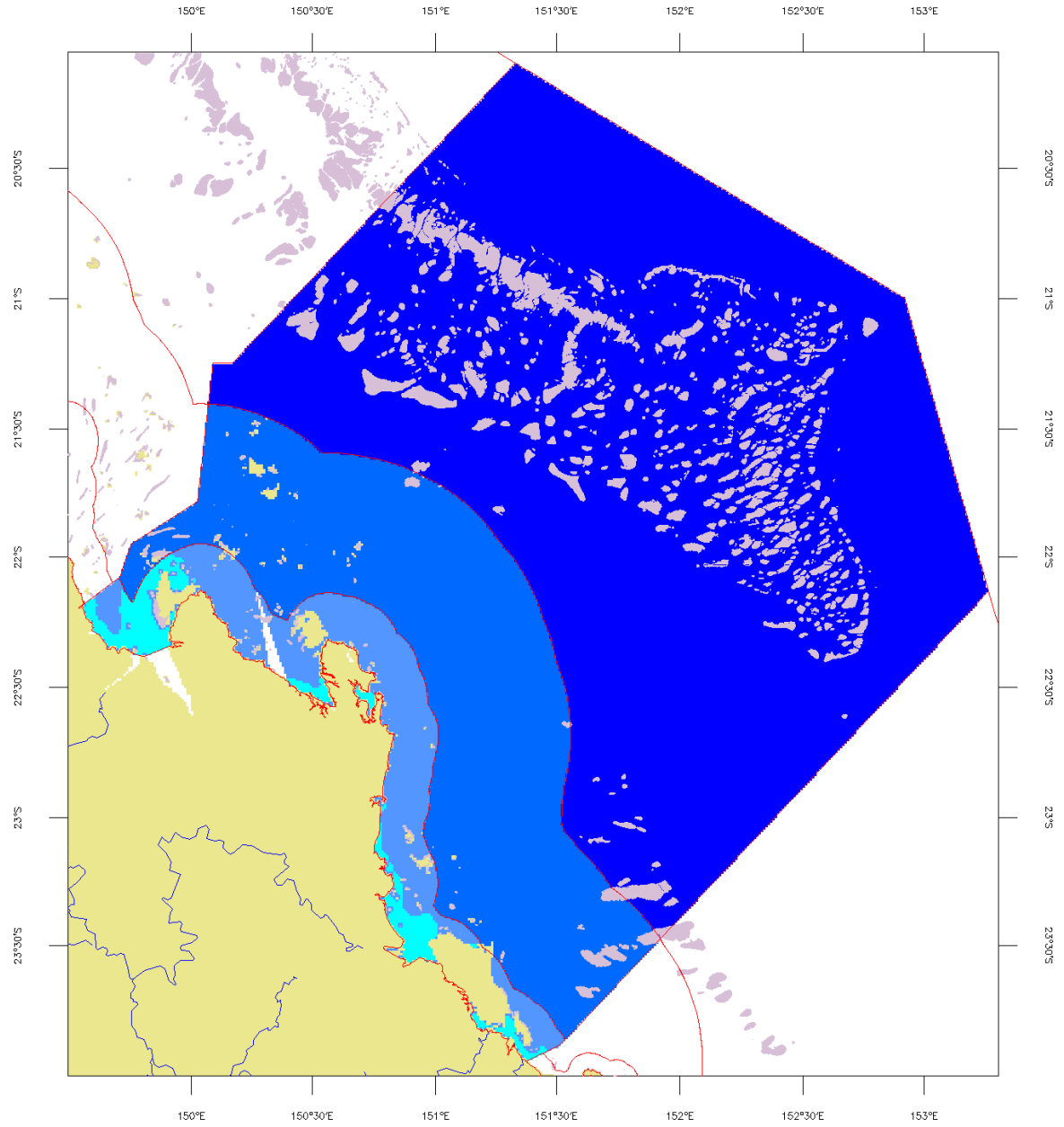


Figure 8. Delineation of the seaward limit of Enclosed Coastal waters for the Fitzroy region (light blue areas). Regional and cross shelf boundaries as defined by GBRMPA for the MMP 2008/09 reporting are presented as red lines.

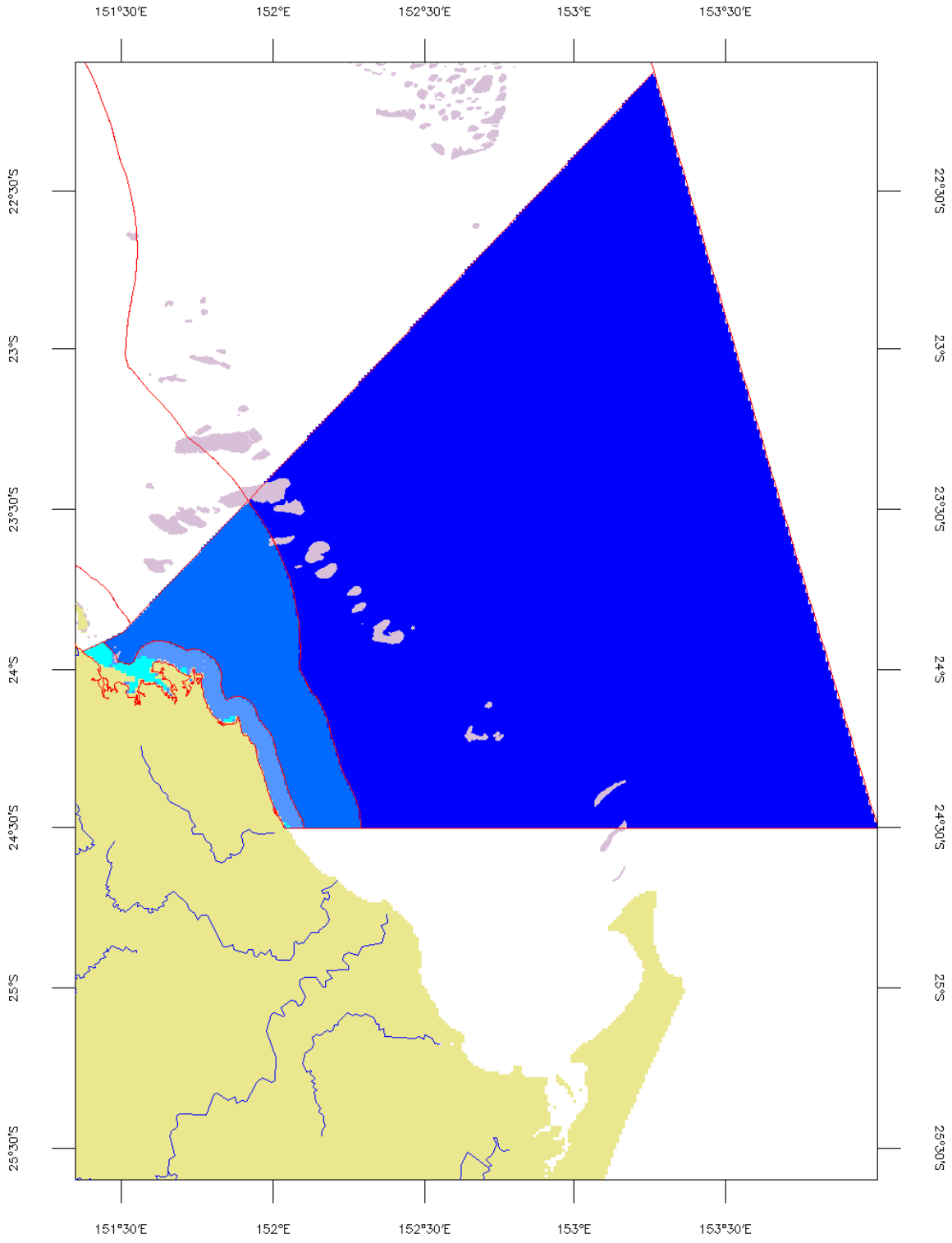


Figure 9. Delineation of the seaward limit of Enclosed Coastal waters for the Wet Tropics region (light blue areas). Regional and cross shelf boundaries as defined by GBRMPA for the MMP 2008/09 reporting are presented as red lines.

3.4 Effect of proposed delineation of the Enclosed Coastal waters assessment of compliance to the Guidelines

To quantify the effect of the proposed delineation of the Enclosed Coastal waters on assessment of compliance to the Guidelines, for each of the six reporting region two graphs with the time series of the Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) are presented in Figures 10 to 15. The top graph presents the calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. This is consistent with the previous MMP reports, and is shaded in Purple. Note these calculations differ from the tables in the previous MMP reports due to the changes in the satellite data processing introduced by NASA in June 2012. The bottom graph presents the calculation performed taking in account the delineation of the Enclosed Coastal waters. The percentage of compliance is still reported as the relative area over the surface area of the whole Inshore region, but pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for Enclosed coastal and only the pixels lying in the Open Coastal are compared with the guideline values for Open coastal waters.

The Guideline trigger values used as threshold levels for the analysis of exceedance in the Enclosed Coastal and Open Costal waters are substantially different (Table 3) The Guidelines trigger values for CHL are 0.45 µg L^{-1} for Open Coastal waters and 2.0 µg L^{-1} for the Enclosed Coastal waters across the whole GBR. For TSS the Guidelines trigger values for Open Coastal waters is 2 mg L^{-1}, while for the Enclosed Coastal waters varies between regions. A value of 5 mg L^{-1} was applied to Cape York, Wet Tropics and Mackay Whitsundays, while a value of 15 mg L^{-1} was applied to the Burdekin, Fitzroy and Burnett-Mary Regions (Table 3 page 26 of the Guidelines and K. Martin & C. Honchin, pers comm. 18/3/2013).

The time series of compliance to the Guidelines are also summarized in the three couples of color-coded tables for Paddock to Reef component scores and the marine water quality index. The top and bottom parts of Tables 6-8 provide the summary for top and bottom graphs in Figures 10 to 15.

For CHL, the changes introduced by adoption of the delineation of the enclosed coastal waters were substantial for the Cape York Regions (~+22%) and for Mackay and Mary Burnett (~+15%) while were minimal for Wet tropics, Burdekin and Fitzroy Regions (+2 - 7%) (Table 6). A marked difference between reporting years 2002/07 and 2007/2012 is still evident, confirming the trends identified in previous MMP reports where P2R_CHL for the whole GBR transitioned from "moderate" to "moderate/poor" as an effect of the "wetter" wet seasons (Figure 15). For TSS, all regions showed substantial increases in compliances (+10 – 30%), particularly the Cape York, Burdekin and Mackay Regions (~+25% in average). This leads to a change of status from "moderate" to "good" for P2R_TSS consistently for all regions for most of the decade (

Table 7).

As effect of delineation of the Enclosed Coastal waters on assessment of compliance to the Guidelines, the Paddock to Reef marine water quality index (P2R_WQI) for the GBR overall varied from "poor/moderate" scores when assessing the compliance without accounting for the Enclosed coastal waters to "moderate-good" scores due a variation of 10-15% in the REEG values (Table 8). Nevertheless, reporting season 2010/11 and 2011/12 show lower scores in both assessments, responding consistently to the two very wet seasons. At regional level, the most notable effect of the delineation of the Enclosed Coastal waters was observed for the Cape York region (Figure 10): the

P2R_WQI scores increased of ~20% on average leading to a change from "poor/moderate" to "moderate-good" for the whole decade.

The proposed delineation of the Enclosed Coastal waters should be taken in consideration by GBRMPA together with other data sources including the Queensland Wetlands 2009 data, depth contours, hydrodynamics and sources of freshwater input to the coast prior to selecting the final water body delineation for formal implementation in the Guidelines and for Paddock to Reef reporting.

Table 6 Summary table for Paddock to Reef marine water quality component score based on CHL compliance (P2R_CHL). Percentage of compliance is reported over the surface area of the whole coastal region. Cells are shaded to reflect the colour coding of the P2R reporting scheme from red to green in steps of 20%. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal.

Without EC delineation	P2R_CHL	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
	CPYK	44	29	40	21	18	33	28	33	16	23
	CNRS	25	11	21	18	8	18	11	13	5	6
	BDKN	38	38	37	40	38	32	27	27	27	30
	MCKY	61	60	67	67	58	57	52	56	35	46
	FITZ	37	44	46	46	45	35	35	28	21	18
	MABU	35	42	52	47	48	35	38	16	7	1
	GBR	**42**	**43**	**47**	**47**	**42**	**38**	**35**	**34**	**24**	**27**
With EC delineation	P2R_CHL	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
	CPYK	67	52	65	45	39	57	52	58	39	47
	CNRS	27	14	23	24	10	24	13	17	8	9
	BDKN	46	44	44	46	44	39	32	32	32	34
	MCKY	75	74	81	81	72	70	66	69	44	58
	FITZ	42	48	51	51	49	40	38	30	21	19
	MABU	48	55	67	63	65	50	52	31	21	15
	GBR	**50**	**50**	**54**	**55**	**49**	**46**	**41**	**39**	**28**	**32**

Table 7 Summary table for Paddock to Reef marine water quality component scores based on TSS compliance (P2R_TSS). Percentage of compliance is reported over the surface area of the whole coastal region. Cells are shaded to reflect the colour coding of the P2R reporting scheme from red to green in steps of 20%. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal.

Without EC delineation		P2R_TSS	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
		CPYK	49	35	50	52	41	59	46	60	50	54
		CNRS	45	20	45	41	32	57	48	38	44	48
		BDKN	42	39	39	44	39	44	53	46	55	42

		MCKY	35	35	39	53	42	32	50	48	50	46
		FITZ	53	49	51	51	53	38	49	50	47	46
		MABU	75	76	78	78	79	75	77	77	64	69
		GBR	**45**	**39**	**44**	**49**	**44**	**40**	**50**	**47**	**49**	**45**
With EC delineation		P2R_TSS	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
		CPYK	79	60	76	78	60	83	66	82	68	76
		CNRS	61	42	58	59	46	70	63	62	60	57
		BDKN	72	64	71	69	67	77	74	70	72	65
		MCKY	68	64	75	77	63	75	72	68	59	60
		FITZ	67	62	65	63	64	62	60	64	60	58
		MABU	98	97	99	98	99	97	98	98	93	92
		GBR	**68**	**60**	**68**	**68**	**62**	**70**	**67**	**66**	**62**	**60**

Table 8 Summary table for Paddock to Reef marine water quality index (P2R_WQI). Percentage of compliance is reported over the surface area of the whole coastal region. Cells are shaded to reflect the colour coding of the P2R reporting scheme from red to green in steps of 20%. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal.

Without EC delineation	P2R_WQI	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
	CPYK	47	32	45	37	29	46	37	47	33	39
	CNRS	35	15	33	30	20	38	29	25	24	27
	BDKN	40	39	38	42	39	38	40	36	41	36
	MCKY	48	48	53	60	50	44	51	52	42	46
	FITZ	45	46	48	48	49	37	42	39	34	32
	MABU	55	59	65	63	64	55	57	47	36	35
	GBR	**43**	**41**	**46**	**48**	**43**	**39**	**42**	**40**	**37**	**36**
With EC delineation	P2R_WQI	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
	CPYK	73	56	70	62	50	70	59	70	53	62
	CNRS	44	28	41	42	28	47	38	40	34	33
	BDKN	59	54	57	58	56	58	53	51	52	50
	MCKY	72	69	78	79	67	72	69	69	52	59
	FITZ	55	55	58	57	57	51	49	47	41	38
	MABU	73	76	83	81	82	74	75	64	57	53
	GBR	**59**	**55**	**61**	**61**	**56**	**58**	**54**	**53**	**45**	**46**

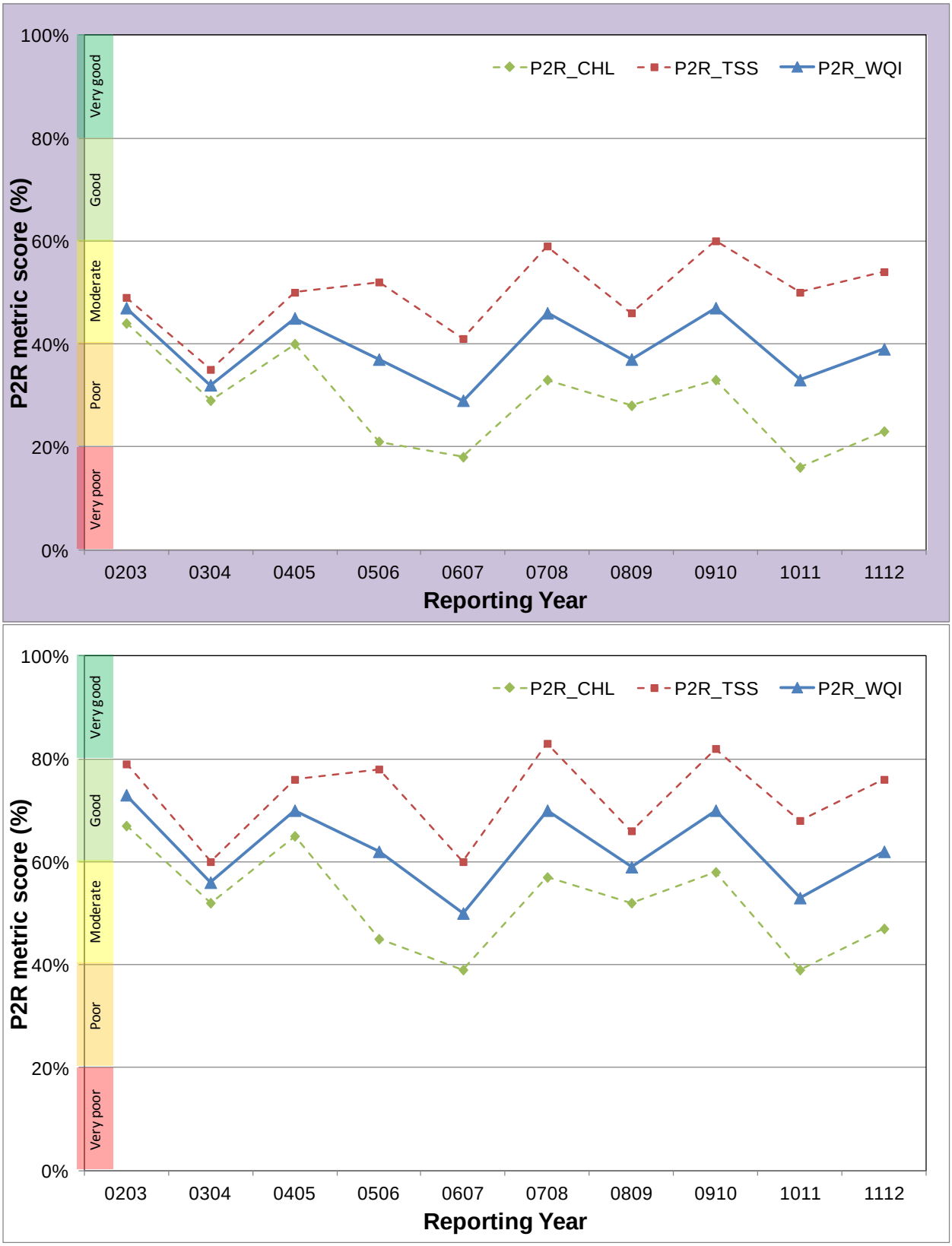


Figure 10. Comparison of P2R trends in Cape York reporting region. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

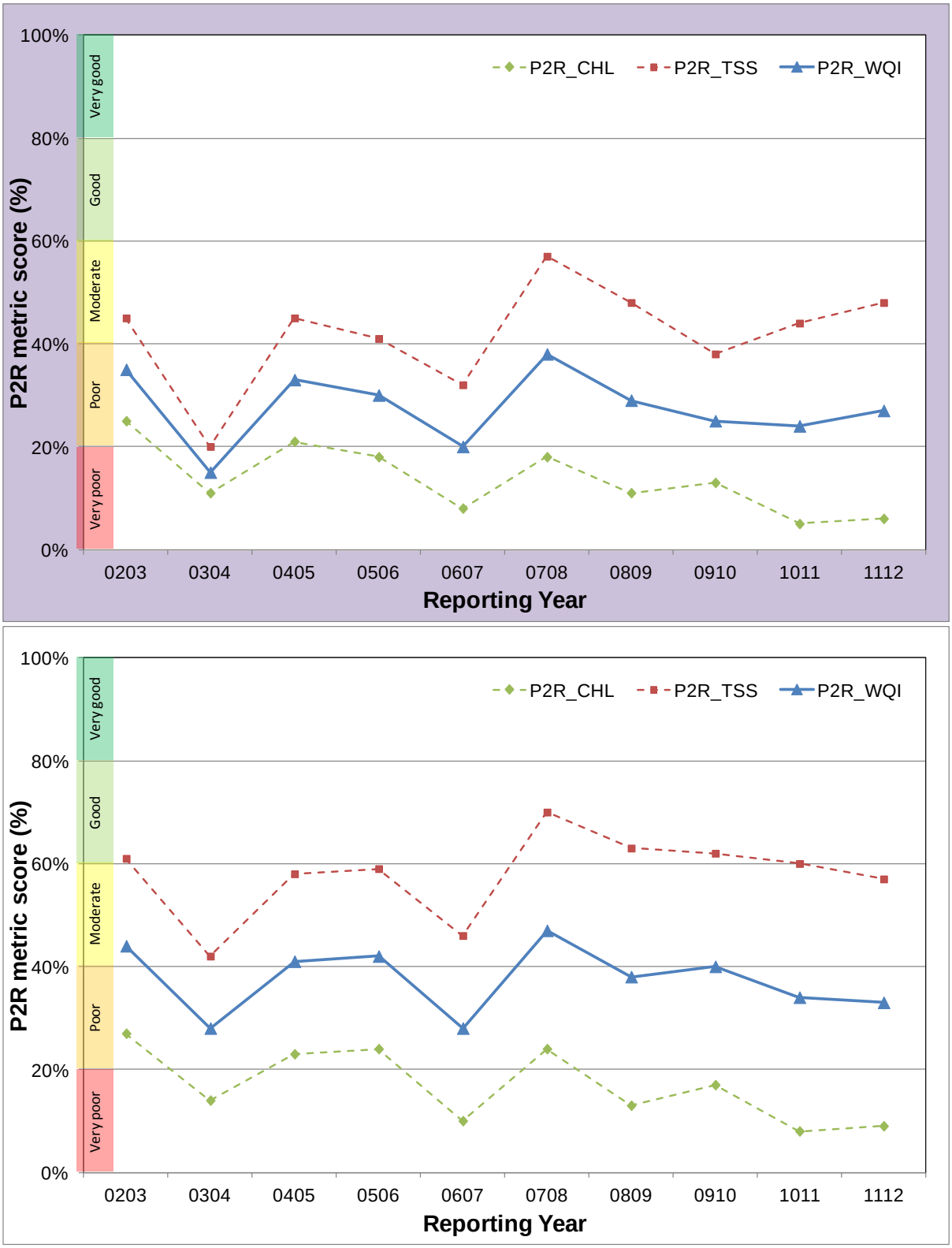


Figure 11. Comparison of P2R trends in Wet Tropics reporting region. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

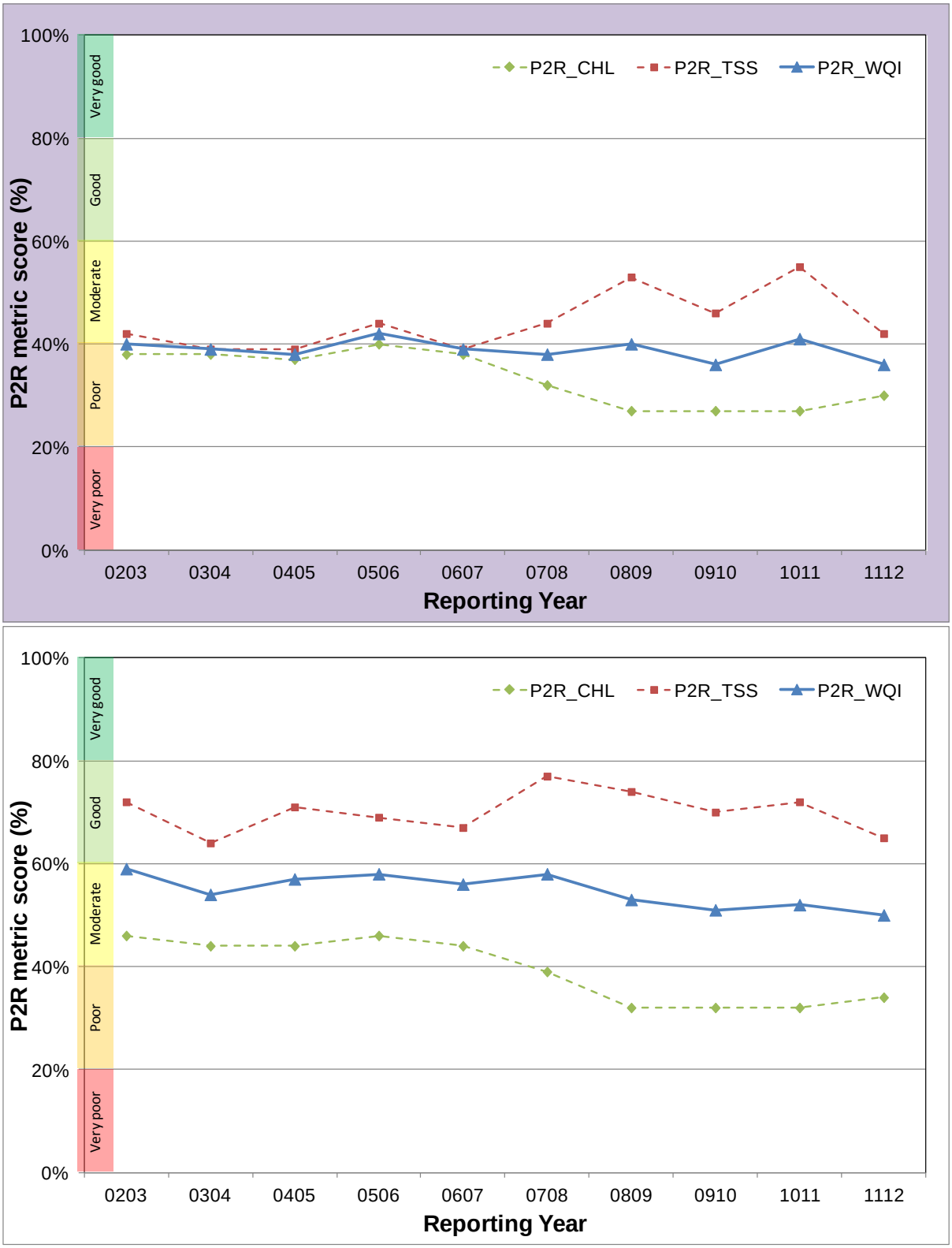


Figure 12. Comparison of P2R trends in Burdekin reporting region. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

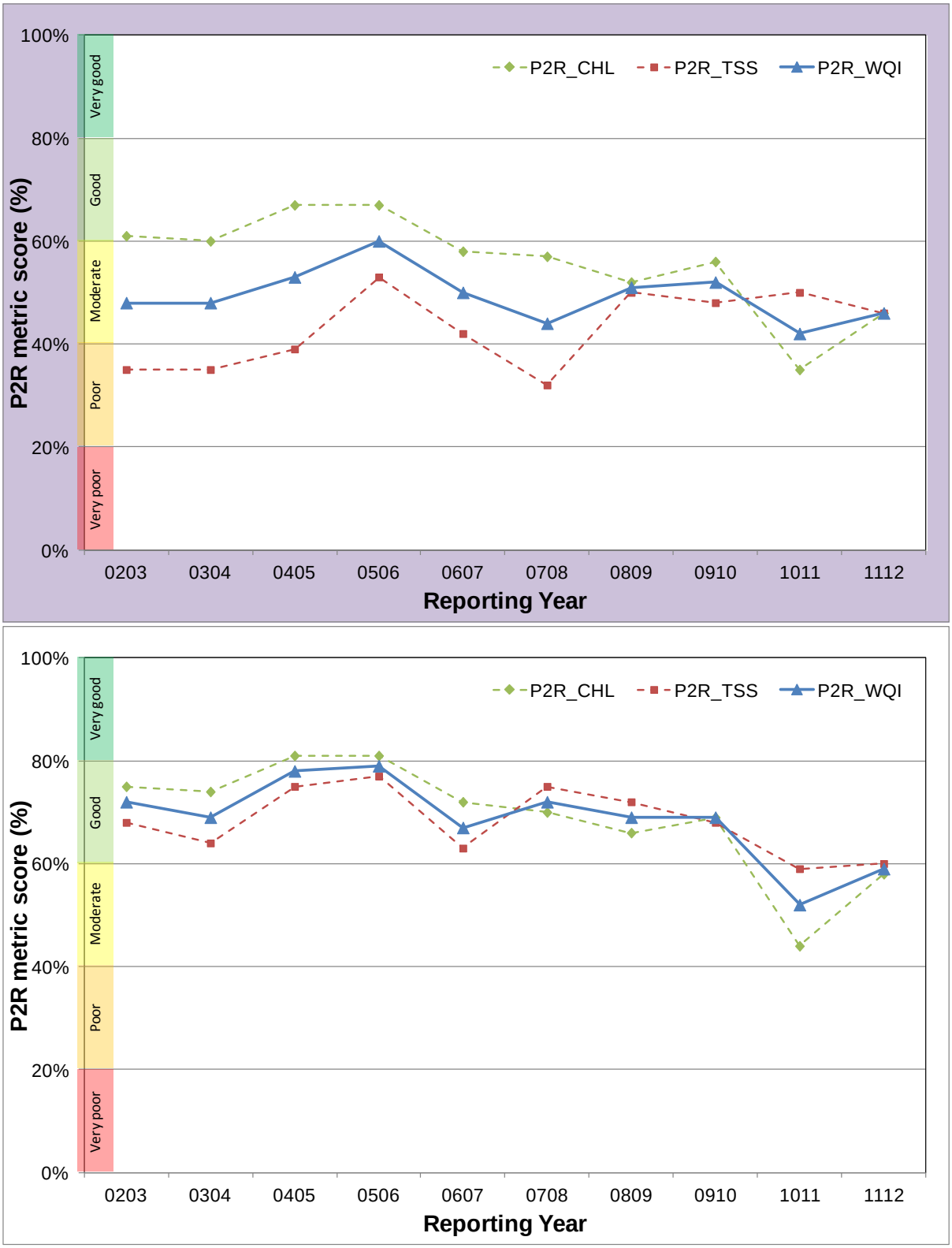


Figure 13. Comparison of P2R trends in Mackay Whitsundays reporting region. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

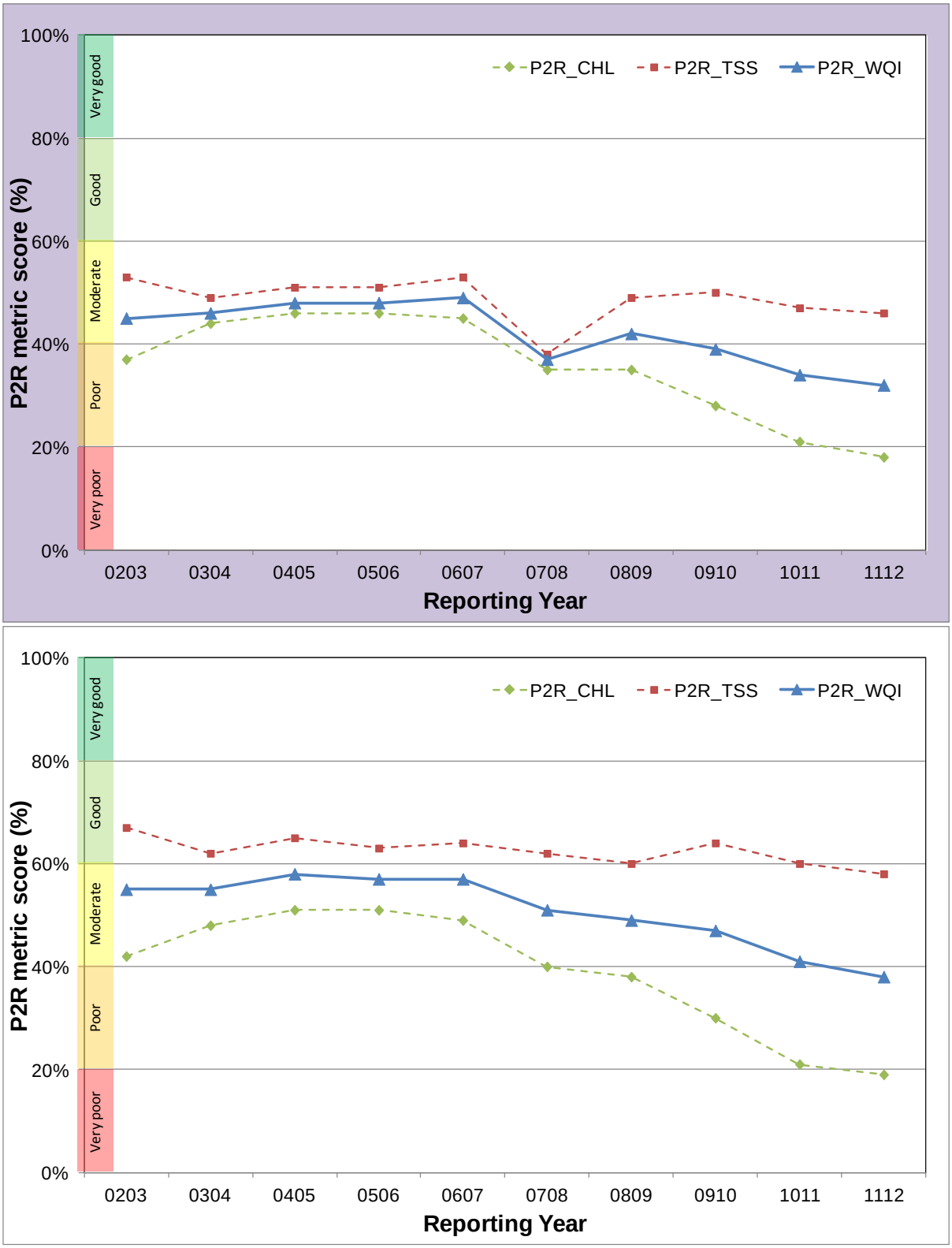


Figure 14. Comparison of P2R trends in Fitzroy reporting region. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

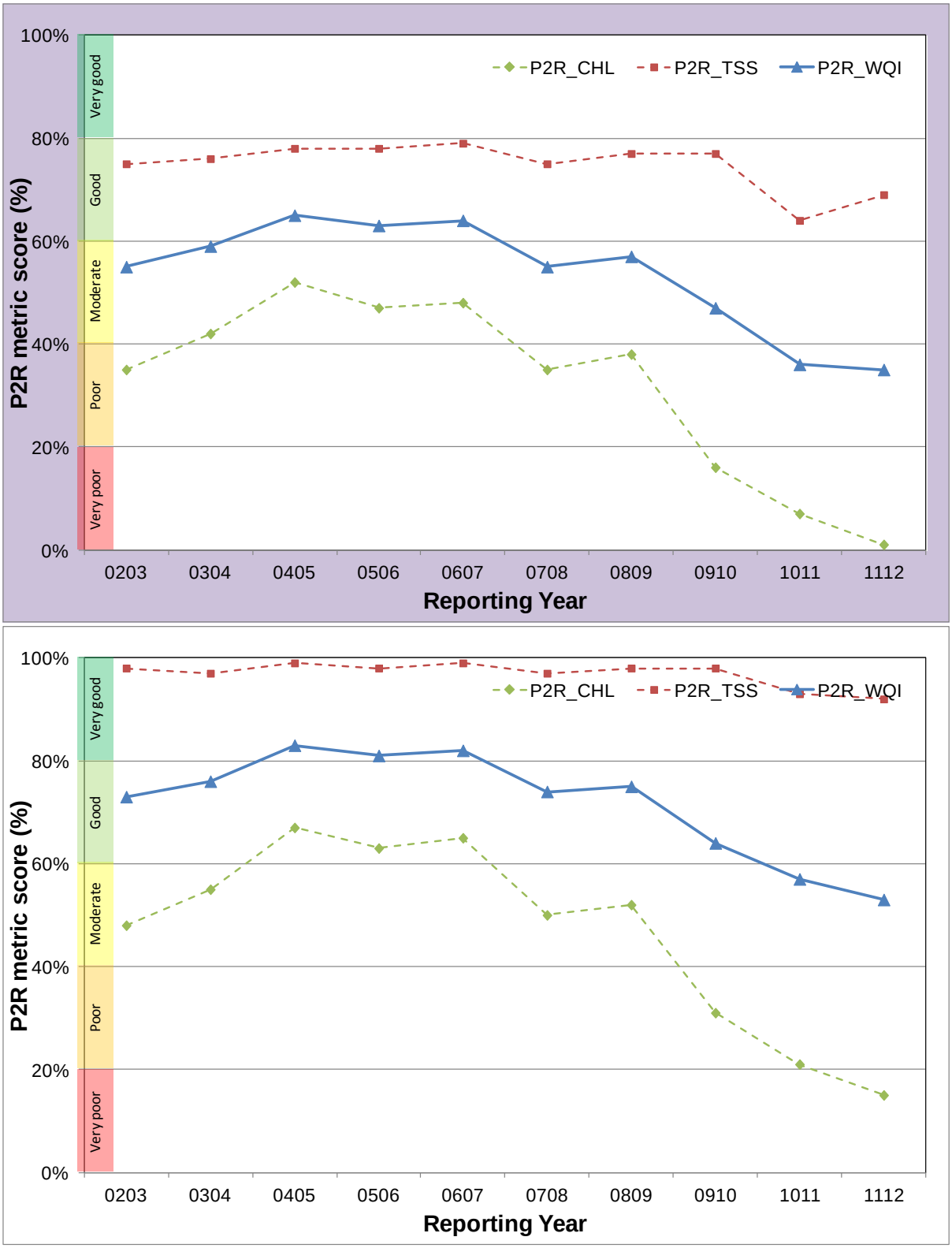


Figure 15. Comparison of P2R trends in Burnett Mary reporting region. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

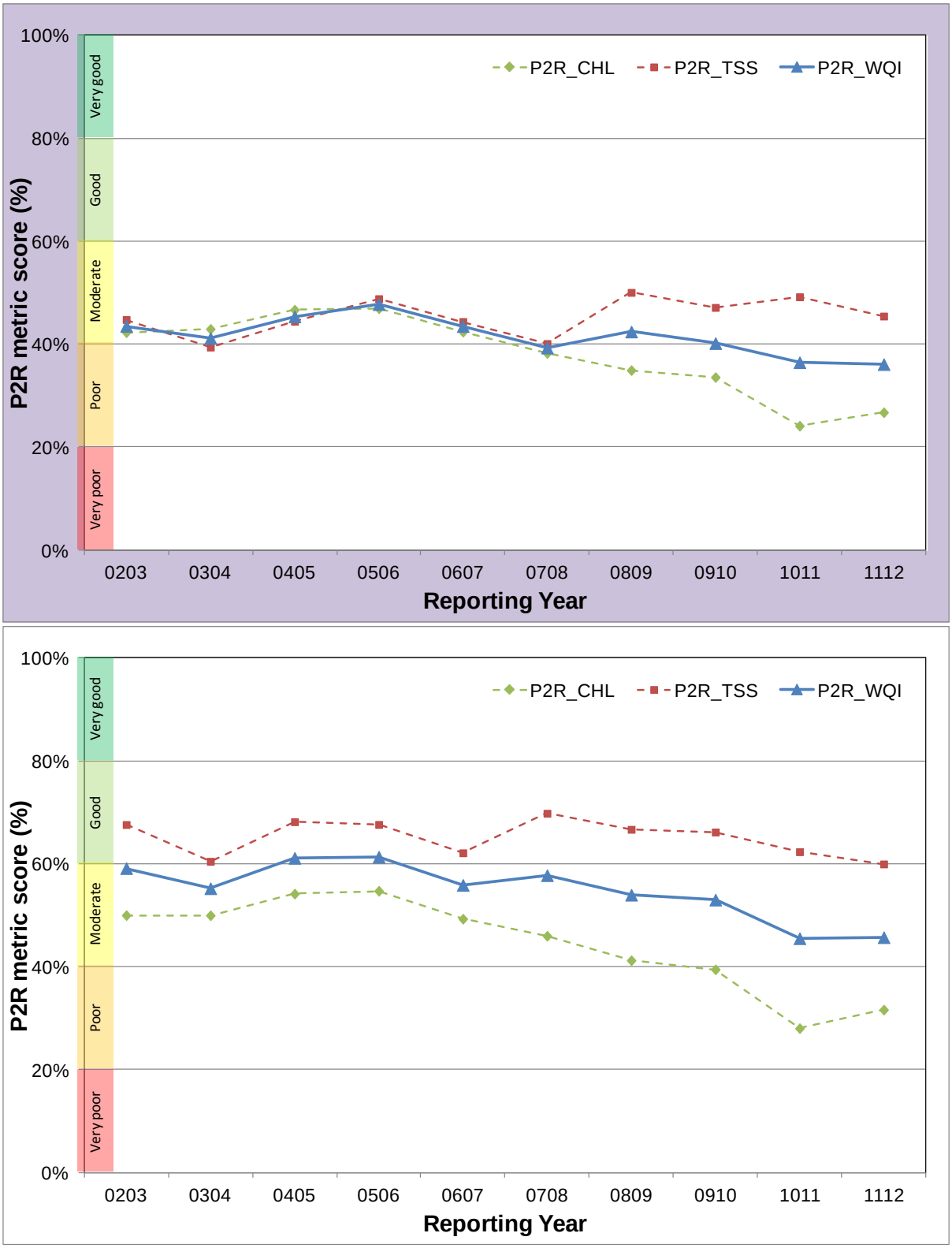


Figure 16. Comparison of P2R trends in the whole GBRWHA. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

4 RESULTS AND DISCUSSION

This section will provide an overview of the satellite- based monitoring results - for the whole Great Barrier Reef World Heritage Area (GBRWHA) followed by a detailed regional report for each of the six reporting regions. For each region the wet season freshwater extent was estimated from CDOM maps is correlated with the river discharges. The wet and dry season median maps are presented for CHL and TSS (as NAP) as well as the maps that show the number of valid observations (i.e. cloud-free and error free image pixels) used for calculating the median values. In addition to the median maps, the exceedance of the Guidelines was assessed for CHL and TSS over the whole year and the wet and dry seasons.

4.1 Great Barrier Reef wide summary

4.1.1 Assessment of freshwater extent during the wet season

Wet season flood plume movements across Great Barrier Reef marine waters are a consequence of the volume and duration of river (flood) flows, wind direction and velocity, as well as the local marine currents and tidal dynamics.

Freshwater discharge from the Great Barrier Reef catchments in 2011/12 was overall higher than the annual median flow. The flow in the Burdekin and Fitzroy Rivers was almost 3 times above the long term median flow(Schaffelke et al. 2012). Most of the rivers in the Wet tropics (Daintree, Barron, Mulgrave, South Johnstone, Tully and Herbert rivers) were just above the median flows. In the Mackay Whitsunday region, the freshwater discharge of the Pioneer Rivers was more than four times above median flows while the discharge for the Proserpine, O'Connell Rivers were more than double than the median flows (Figure 17). The Burnett and Mary Rivers flooded over December and January reaching record peak and flow levels (Schaffelke et al. 2011).

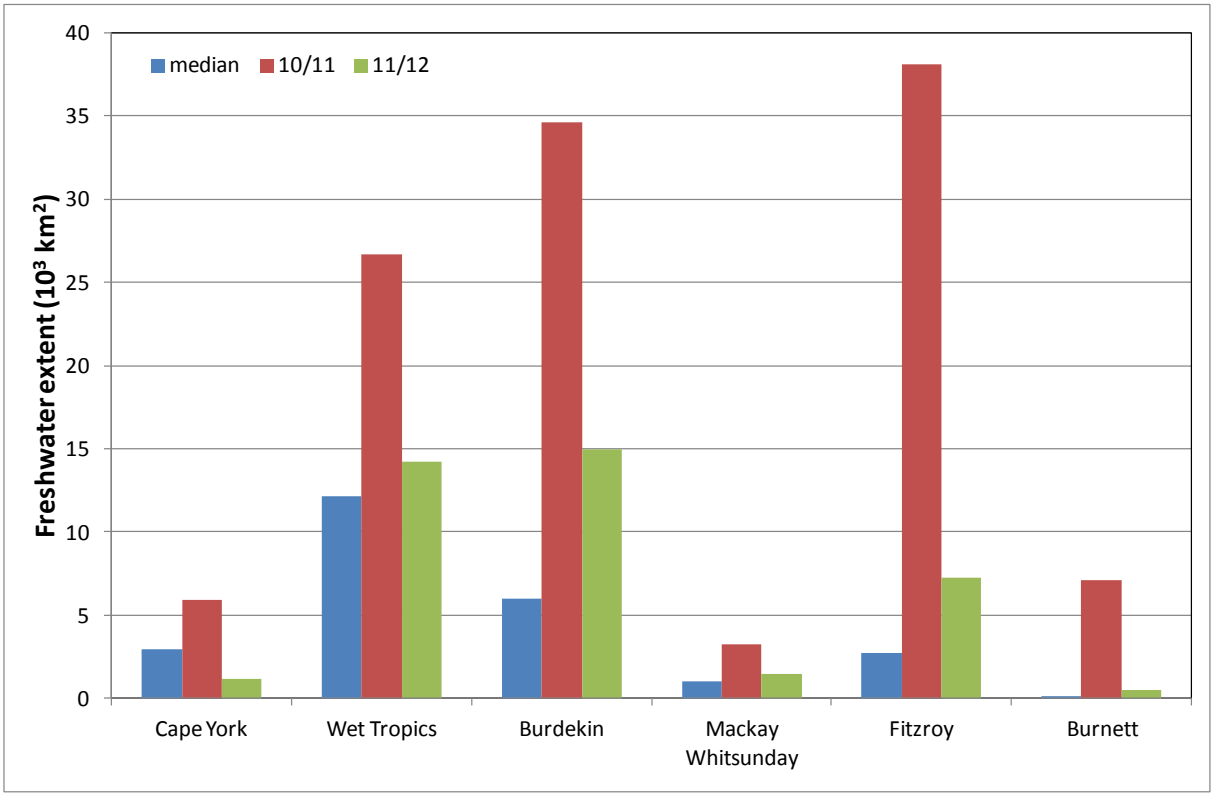


Figure 17. Comparison of fresh water discharge for 2011/2012 compared to 2010/2011 and the long term median for each reporting region of the GBRWHA. Data are aggregated to the reporting regions from table A1-3 of (Schaffelke et al. 2011) presenting data supplied by the Queensland Department of the Environment and Resource Management for each river. Long-term medians were estimated from annual total flows (October to October), long-term medians are not available for the Cape York and Burnett Mary regions (Schaffelke et al. 2011).

Figure 18 provides an overview of the freshwater extent for wet season 2011/2012 (November 2011-April 2012) for the whole GBRWHA. The freshwater extent was estimated by applying a threshold of 0.24 m^{-1} for the CDOM seasonal maximum. Detailed maps for each region are presented in the regional reporting sections (Figure 29, Figure 40, Figure 51, Figure 62, Figure 73, Figure 84). Flood plumes extended across inshore waters of the southern and northern Great Barrier Reef, but had a more limited influence on far northern Great Barrier Reef waters. The freshwater extent based on the CDOM maximum provides a conservative estimate of the extent as the flood plumes could have extended further in cloudy or overcast days and hence may not been captured with the satellite imagery. The estimated freshwater extent for the whole GBRWHA was highly correlated to the total freshwater discharges (R^2=0.835, Figure 19), the freshwater extent for 2011/2012 was similar in magnitude to 2007-2010 period as observed with the MODIS time series. The estimated freshwater extent for 2011/2012 was larger than in 2010/2011 only for the Burdekin and Burnett Mary regions, while for Fitzroy and the Wet Tropics it was higher than the median extents observed with the MODIS time series (Figure 20). The spatial variability of freshwater extents across the regions reflects the variability in flow conditions across the regions for the wet season 2011/2012 (Figure 17).

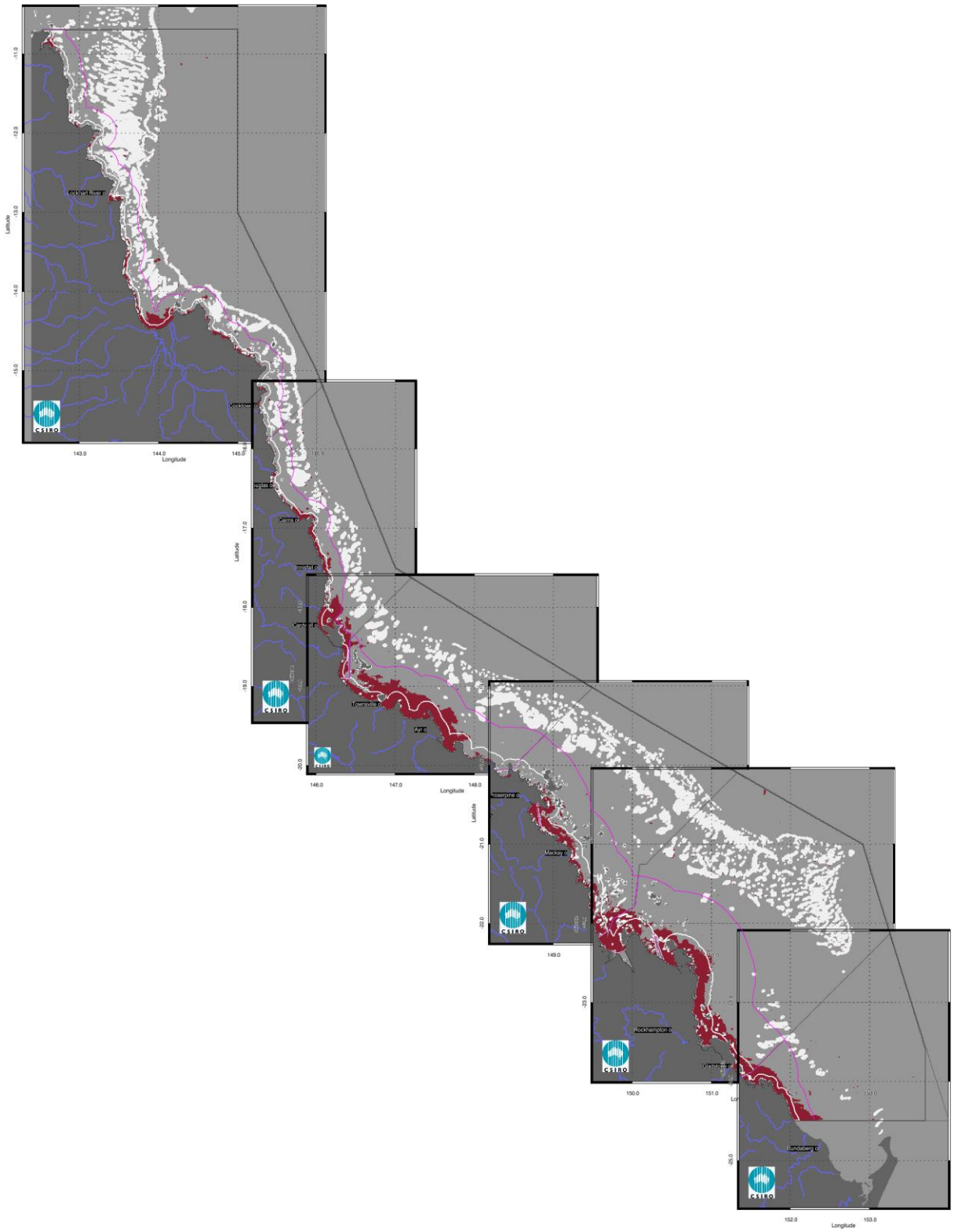


Figure 18. Overview of the freshwater extent for the wet season 2011/2012 (November 2011- April 2012) for the whole Great Barrier Reef World Heritage Area. Detailed maps for each region are presented in the regional reporting sections (Figure 29, Figure 40, Figure 51, Figure 62, Figure 73, Figure 84). Pixels are mapped in dark red when the CDOM seasonal maximum values for the year exceed the threshold of 0.24 m^{-1}.

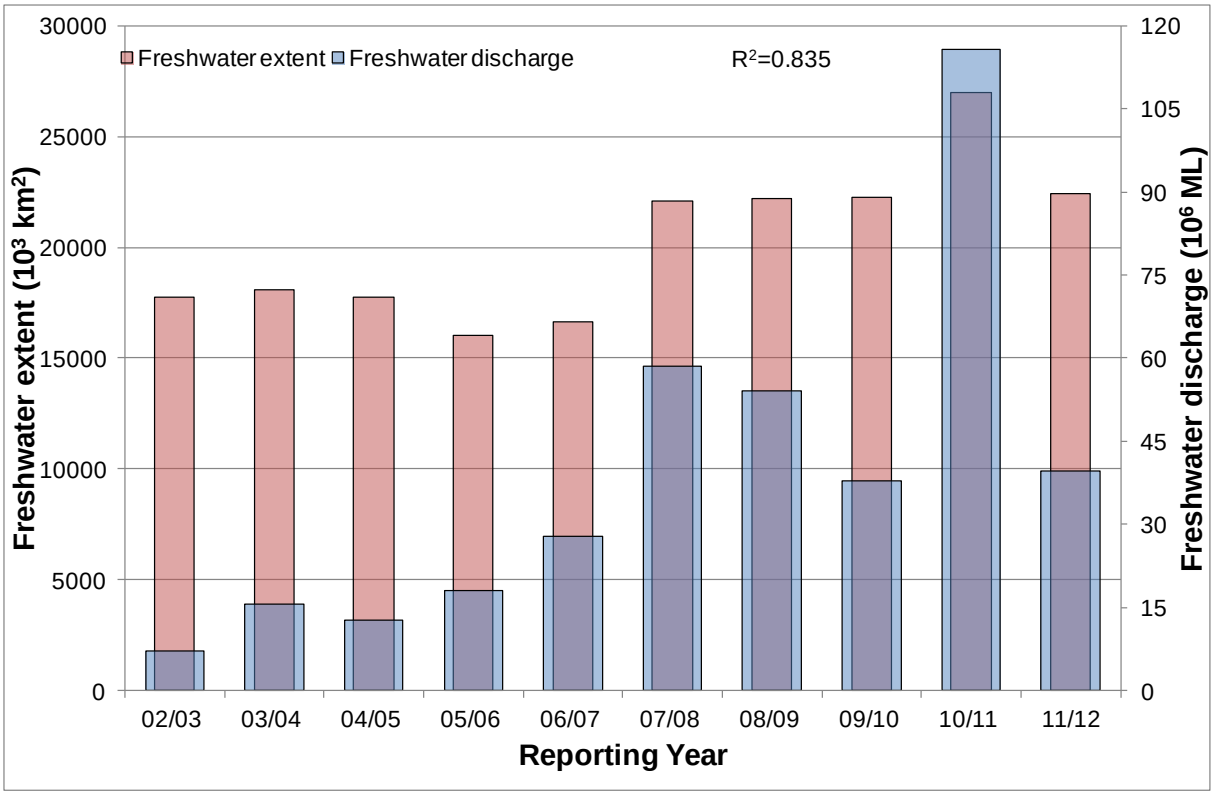


Figure 19. Total freshwater discharge and total estimated freshwater extent for the whole GBRWHA based on the CDOM maximum for the wet seasons.

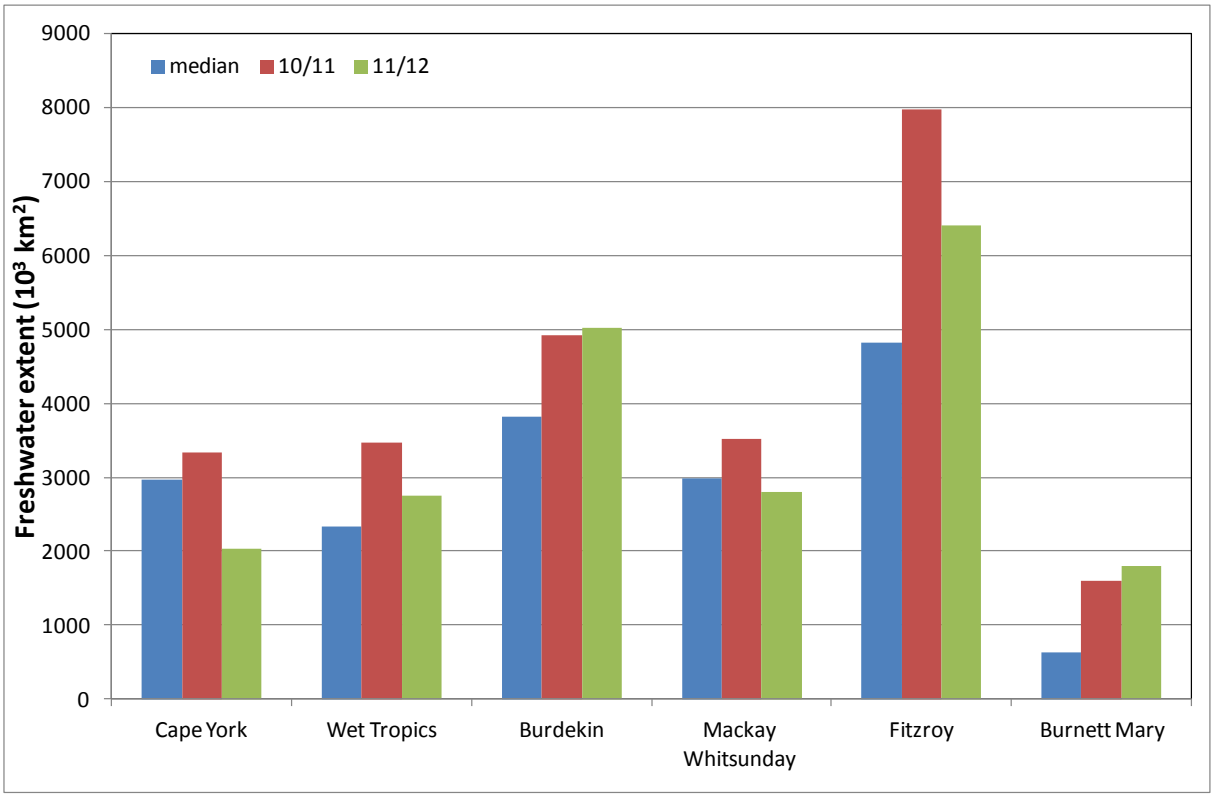


Figure 20. Comparison of estimated freshwater extent based on the CDOM maximum for the wet seasons 2010/2011 (November 2010- April 2011), 2011/2012 (November 2011- April 2012) and the median extent for the decade for each reporting region of GBRWHA.

4.1.2 Assessment of the exceedance of water quality guidelines

The annual median values maps for CHL an TSS for 2010/2011 (1 May 2010 – 30 April 2011) for the whole GBRWHA are presented in Figure 21 and Figure 22. A coastal to offshore gradient in CHL and TSS concentration can be observed, with the inshore waters in the Wet Tropics and Burdekin Regions having elevated concentrations of CHL and TSS over the monitoring period (Figure 21 and Figure 22). The Guideline annual threshold values for CHL are 2.0 µg L^{-1} for Enclosed Coastal, 0.45 µg L^{-1} for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore , while for TSS are 5.0 (or 15.0) mg $L^{-1}$for Enclosed Coastal, 2.0 mg $L^{-1}$for Open Coastal and Midshelf and 0.7 mg L^{-1} for Offshore. Detailed maps for the wet and dry season for each region are presented in the regional reporting sections.

Figure 23 and Figure 24 show the map of EG (i.e. exceedance of the mean annual values) for CHL and TSS for the 2011/12 reporting period (1 May 2011 – 30 April 2012) for the whole GBRWHA. The REEG values for CHL and TSS (REEG_CHL, REEG_TSS) within each reporting region are presented in Table 9 separately for the Enclosed Coastal, Open Coastal, Midshelf, and Offshore water bodies. For P2R reporting only the REEG values for the Inshore water body (i.e. the combined Enclosed Coastal and the Open Coastal waters) are considered for the metric calculations.

The Enclosed Coastal water body shows high areas of CHL EG (REEG_CHL = 68-89% of relative area of the water body, Table 9) for the Wet Tropics, Burdekin and Fitzroy reporting regions, while the REEG_CHL for Cape York, Mackay Whitsunday and Burnett Mary ranged 17-29%. For all reporting regions (with the exception of Mackay Whitsunday) the Open Coastal water body shows high areas of CHL EG (REEG_CHL = 68-99% of relative area of the water body, Table 9). Hence the CHL EG for the Inshore water bodies shows high areas of CHL EG for the Wet Tropics, Fitzroy and Burnett Mary regions (REEG_CHL = 81-91%), while Cape York, Mackay Whitsunday and Burdekin ranged 41-66%. These values were overall comparable to the previous reporting year (Table 10)

For all reporting regions Open Coastal water body shows areas of TSS EG (REEG_TSS=10-38% of relative area of the water body, Table 9) comparably to the previous reporting year (REEG_TSS=9-37 % for 2009/10, Table 10). In Both years the Enclosed Coastal waters showed high values (REEG_TSS=56-72% of relative area of the water body) for the Wet Tropics, Mackay Whitsunday and Fitzroy region. Some areas of TSS EG (TSS_REEG 5-7%) occurred also in Offshore areas, particularly in the Cape York and Mackay-Whitsunday reporting regions, consistently with the previous reporting years. These large areas of exceedance of the mean annual TSS values may be due to an over-estimate of the mean TSS concentrations in Offshore waters or to a low guideline threshold value. Also, exceedance of the Guidelines in these offshore waters may not be directly related to the land influence on these waters as for large portions of the Offshore areas other oceanographic processes, e.g. upwelling events, influence the TSS concentrations during the year (Wooldridge et al. 2006, Brodie et al. 2008).

For Figure 21 and all subsequent CHL maps the median values were presented instead of the mean values, as medians values are closer to the modal values the arithmetic mean for GBR waters (Section 3 Brando et al 2011(Brando et al. 2011)). For all the regional reporting the exceedance to both the mean and median values are reported as maps as well as tables. For sake of simplicity and to adhere to the letter of the Guidelines, in Figure 23, Figure 24, Table 9 and Table 10) only the exceedance to mean values of CHL and TSS are reported. These values are then used to calculate the P2R marine water quality index (P2R_WQI) and the metric scores for the two component indicators, i.e. P2R_CHL and P2R_TSS (Table 11), following the method outlined in section 2.2.4.

The marine water quality for this reporting year for the whole GBR was scored as “moderate”, reflecting the one “poor” and three “moderate” scores for P2R_WQI in the four reporting regions that contribute the whole of GBR score (Table 11, the regional scores for Cape York and Burnett Mary are excluded from calculations of the overall GBR score for the metrics). The scores for the two component indicators for the whole GBR were “poor” for P2R_CHL and “moderate” for P2R_TSS, reflecting the “very poor” to “moderate” regional scores for P2R_CHL and “moderate” to “good” regional scores from P2R_TSS. The marine water quality index was similar to the reporting year 2010/11 and lower than for the previous reporting years for all regions, as well as the whole GBR (Figure 25), reflecting the high freshwater discharges from the GBR catchments in 2010/11 and 2011/12 and the associated estimated freshwater plume extent (Figure 20).

The assessment of the P2R marine water quality index and the exceedance of the Guidelines is described in detail in the regional reporting sections with maps and tables summarising the exceedance results for CHL and TSS.

As all the results presented in this report supersede the exceedance assessments and the P2R scores presented previous reports, Appendix 3 provides the REEG values for CHL and TSS (REEG_CHL, REEG_TSS) presented within each reporting region as separate values for the newly delineated Enclosed Coastal, as well as the Open Coastal, Inshore (encompassing both Enclosed Coastal and Open Coastal), Midshelf, and Offshore water bodies for all reporting years. Also a summary of all P2R scores for all reporting year is provided, based on the REEG values for the Inshore water body (i.e. the Enclosed Coastal and the Open Coastal waters).

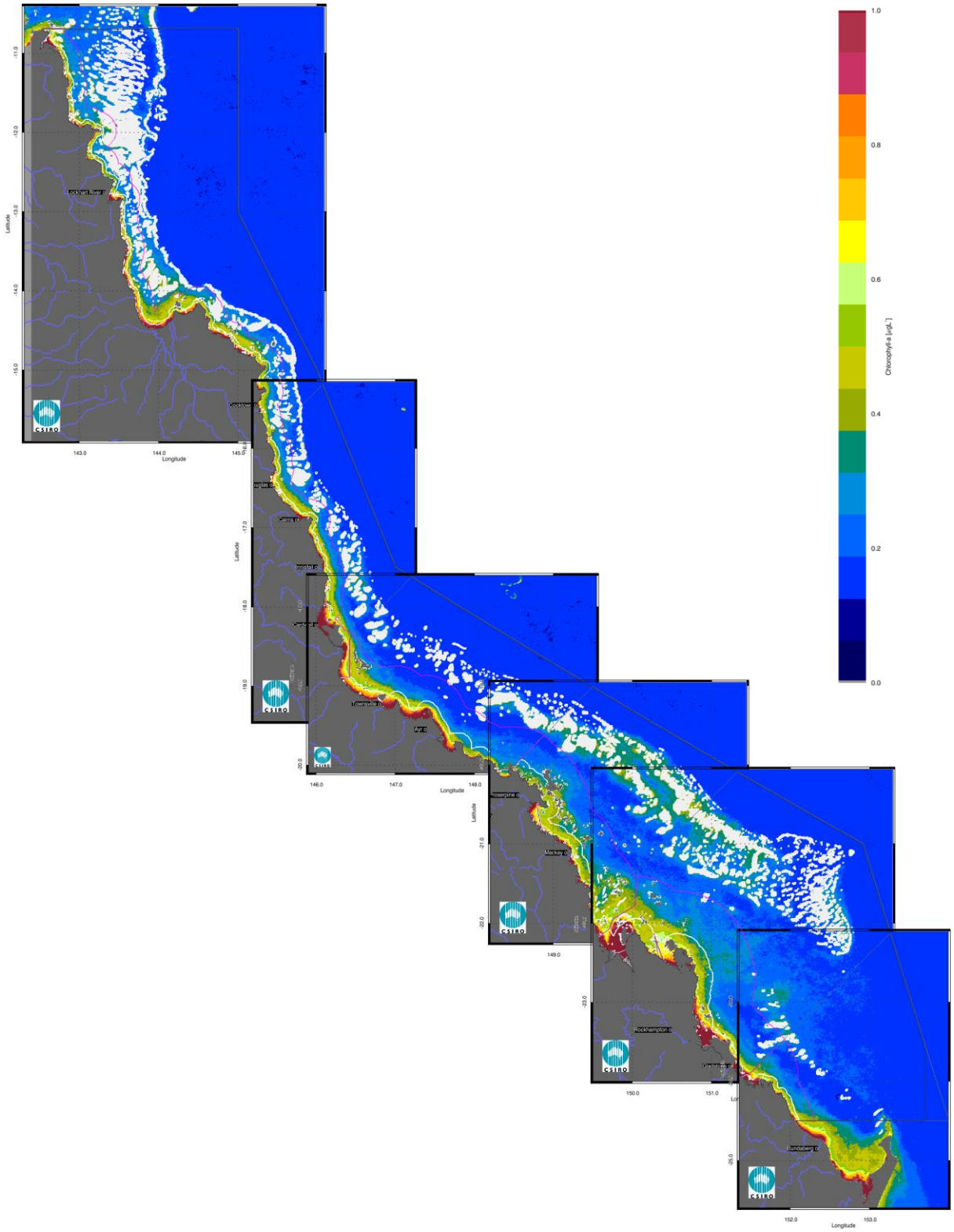


Figure 21. Map of the Chlorophyll-a annual median values for the 2010/2011 reporting period (May 2010 – April 2011) for the whole of the Great Barrier Reef World Heritage Area. The Guideline values for annual means of Chlorophyll –a are 2.0 µg L-1 for Enclosed Coastal, 0.45 µg L-1 for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore.

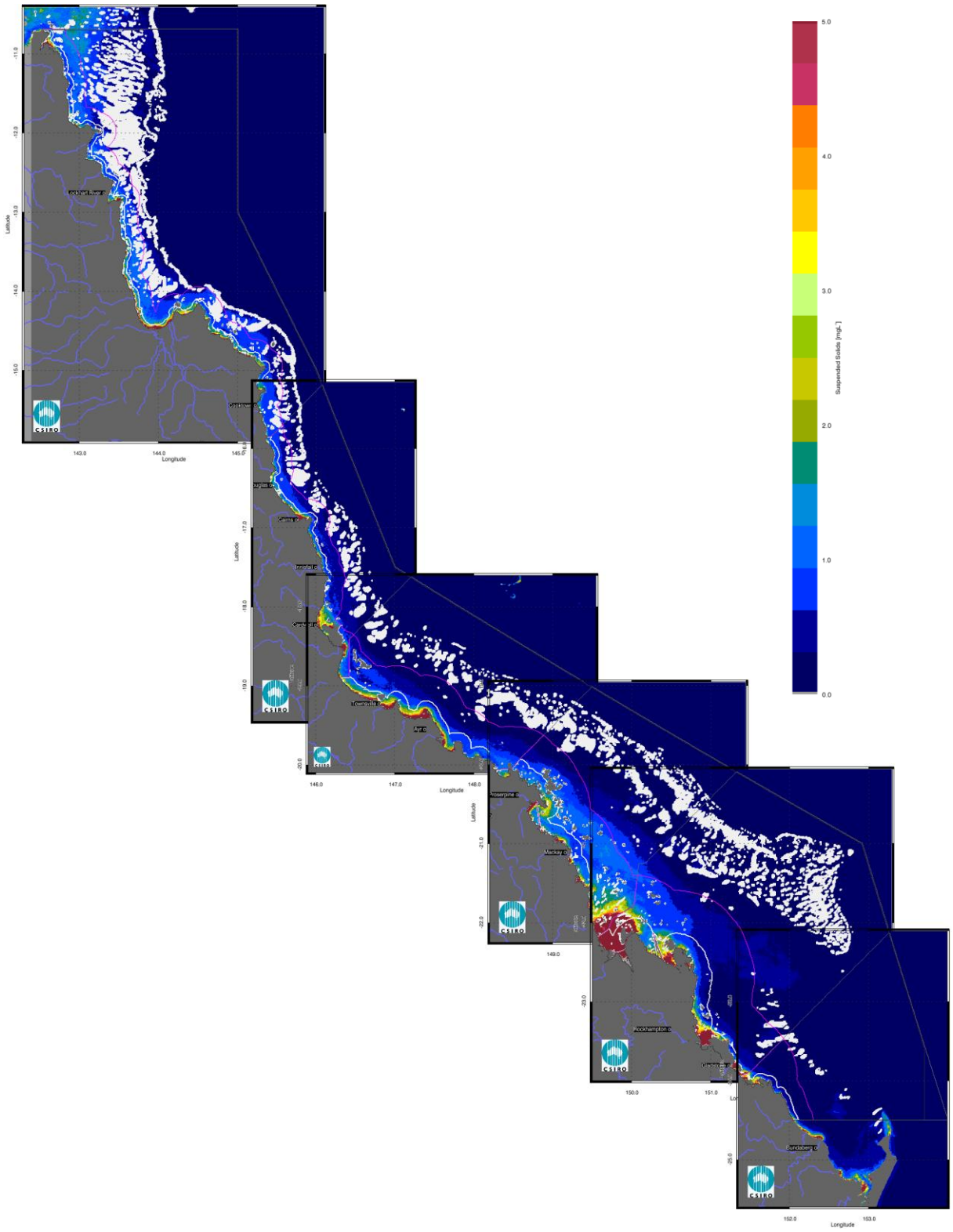


Figure 22. Map of annual median values of non-algal particulate matter (as a measure of Total Suspended Solids) for the 2010/2011 reporting period (May 2010 – April 2011) for the whole of the Great Barrier Reef World Heritage Area. The Guideline values for annual means of Total Suspended Solids are 5.0 (or 15.0) mg $L^{-1}$for Enclosed Coastal, 2.0 mg $L^{-1}$for Open Coastal and Midshelf and 0.7 mg L^{-1} for Offshore.

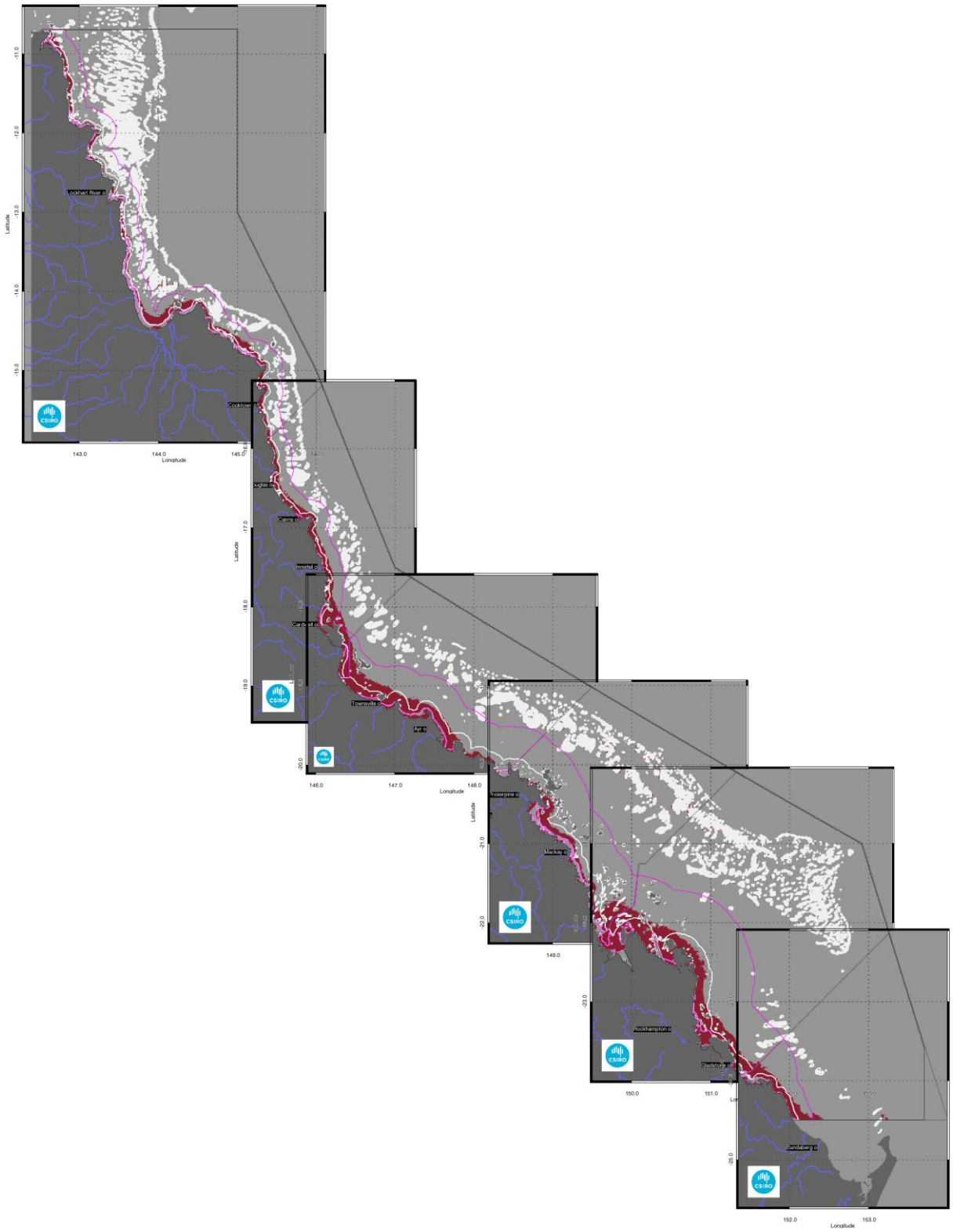


Figure 23. Collation of the exceedance maps of mean annual Chlorophyll-a for the 2010/2011 reporting period (May 2010 – April 2011) for the whole of the Great Barrier Reef World Heritage Area. Pixels are mapped in dark red when mean values for the year exceed the thresholds. Detailed maps are reported in the regional reporting sections (Figure 33, Figure 44, Figure 55, Figure 66, Figure 77 and Figure 88).

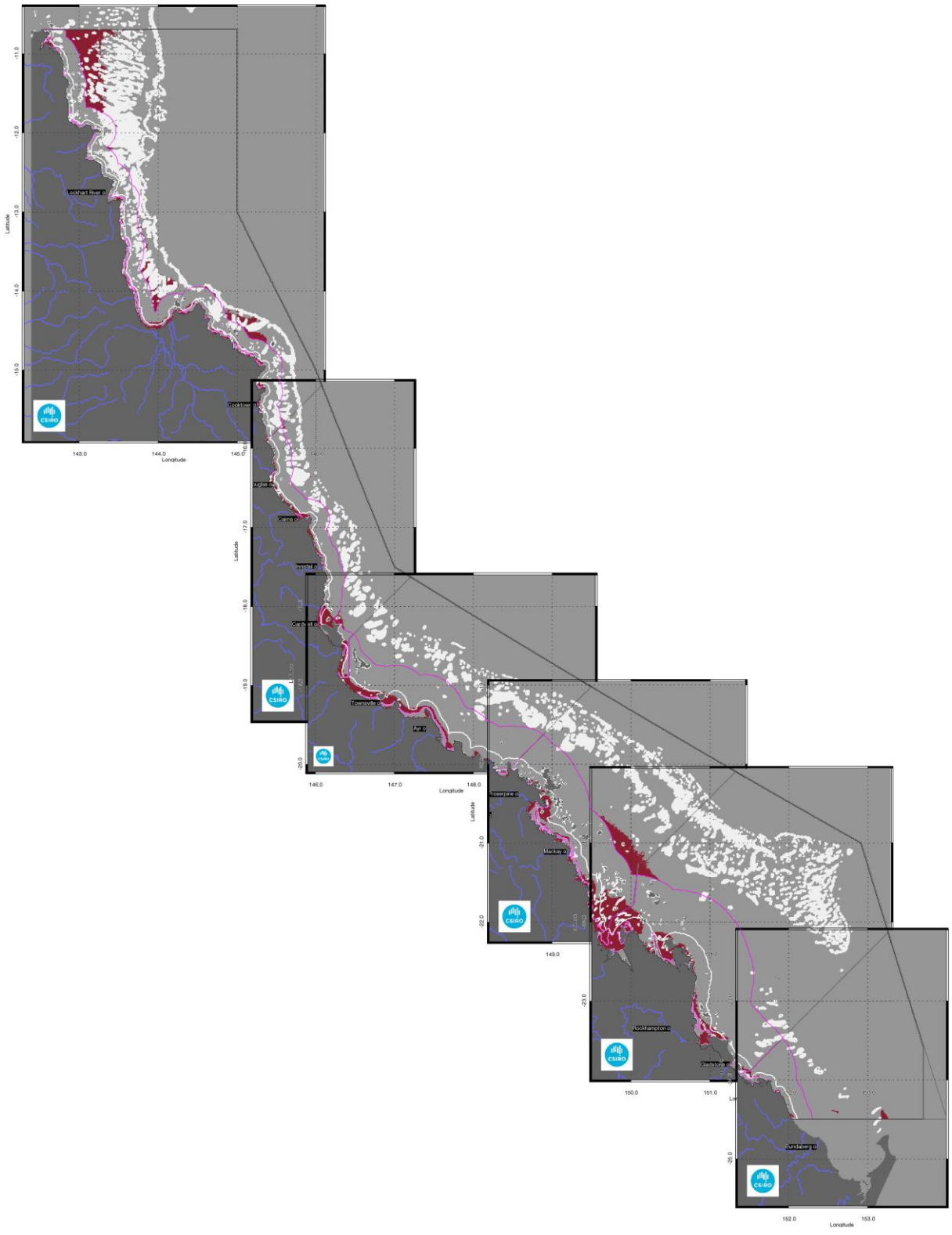


Figure 24. Collation of the exceedance maps of mean annual Total Suspended Solids for the 2010/2011 reporting period (May 2010 – April 2011) for the whole of the Great Barrier Reef World Heritage Area. Pixels are mapped in dark red when mean values for the year exceed the thresholds. Detailed maps are reported in the regional reporting sections (Figure 33, Figure 44, Figure 55, Figure 66, Figure 77 and Figure 88).

Table 9. Summary of the exceedance of annual mean values of Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for this reporting period (1 May 2011 – 30 April 2012) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
1112	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	17	68	52	14	0	34	18	23	1	6
Wet Tropics	78	93	91	30	0	69	38	43	7	0
Burdekin	68	65	66	12	0	16	38	34	0	0
Mackay Whitsunday	25	45	41	5	1	56	35	39	8	5
Fitzroy	89	79	81	8	0	66	35	42	3	0
Burnett Mary *	29	99	84	20	0	0	10	8	1	0

Table 10. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the previous reporting period (1 May 2010 – 30 April 2011) for the Open Coastal, Mid-shelf and Offshore water bodies. Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
1011	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	5	78	61	25	0	45	26	32	5	6
Wet Tropics	76	94	92	32	1	72	34	39	4	0
Burdekin	63	69	68	12	0	11	30	27	0	0
Mackay Whitsunday	27	63	56	10	0	56	37	40	8	7
Fitzroy	86	76	78	8	0	65	32	40	2	1
Burnett Mary *	24	92	78	8	0	0	9	7	1	0

Table 11. Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) for this reporting period (1 May 2011 – 30 April 2012). Cells are shaded to reflect the colour coding of the P2R reporting scheme from red to green in steps of 20%.* Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals. The regional scores for Cape York and Burnett Mary are excluded from calculations of the overall GBR score for each metric.

	P2R_CHL	P2R_TSS	P2R_WQI
Cape York*	Moderate (47)	Good (76)	**Good (62)**
Wet Tropics	Very poor (9)	Moderate (57)	**Poor (33)**
Burdekin	Poor (34)	Good (65)	**Moderate (50)**
Mackay Whitsunday	Moderate (58)	Moderate (60)	**Moderate (59)**
Fitzroy	Very poor (19)	Moderate (58)	**Poor (38)**
Burnett Mary *	Very poor (15)	Very Good (92)	**Moderate (53)**
GBR	**Poor (32)**	**Moderate (60)**	**Moderate (46)**

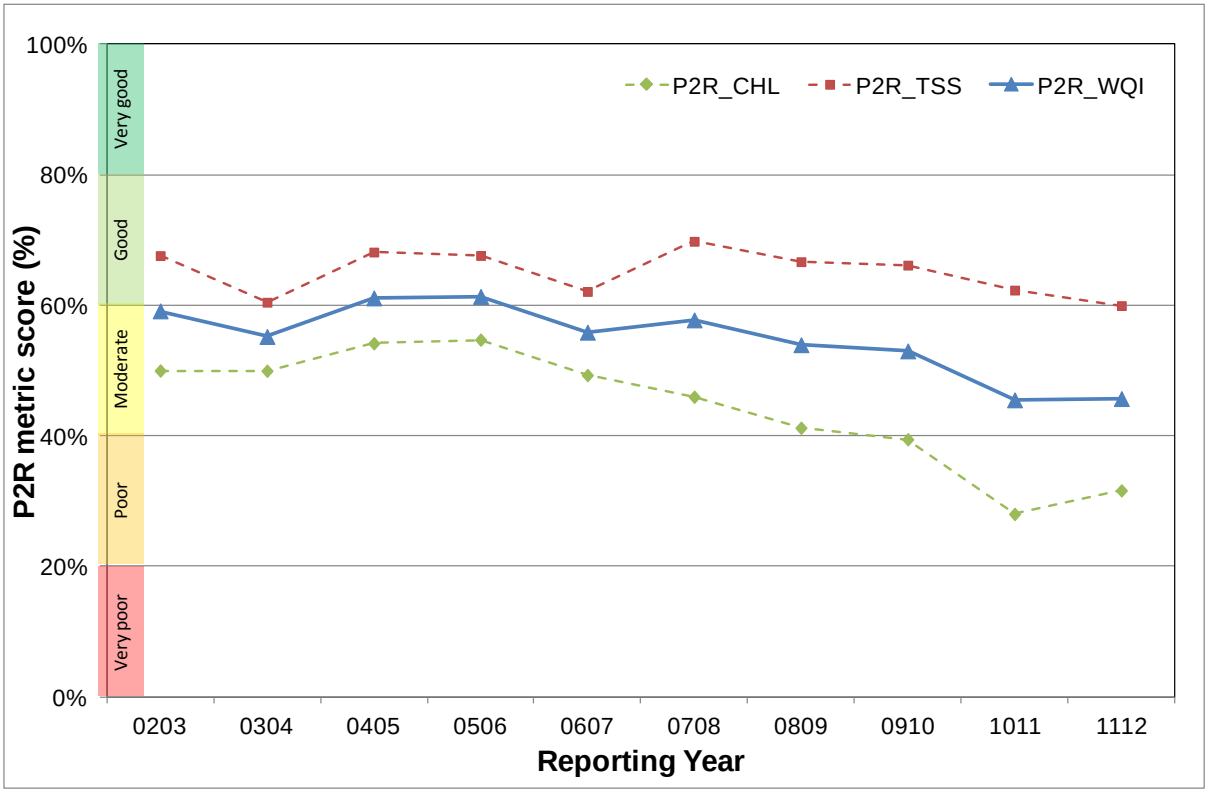


Figure 25. Trends in the Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) aggregated for the whole GBR. The regional scores for Cape York and Burnett Mary are excluded from calculations of the overall GBR score for the metrics.

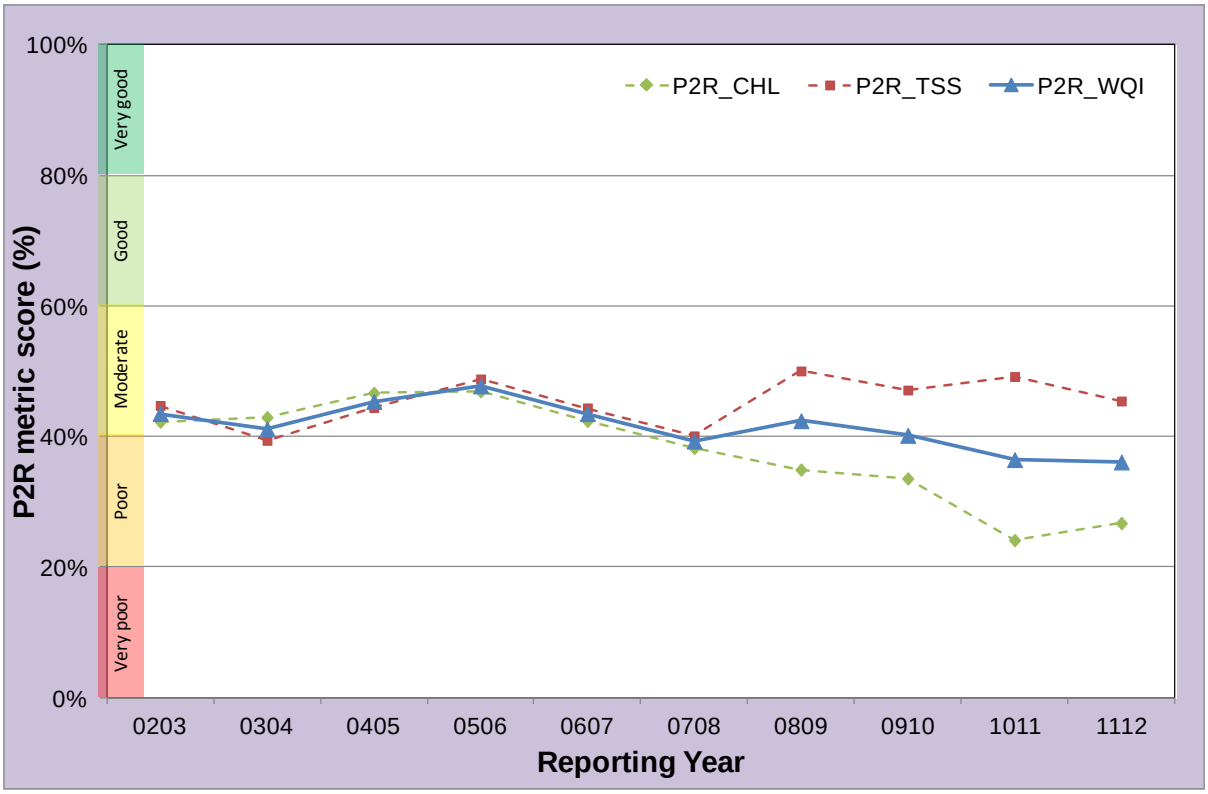


Figure 26. Comparison of P2R trends in the whole GBRWHA. Top: calculation without the delineation of enclosed coastal waters, i.e. using the same threshold value across the whole coastal region. Bottom calculation performed taking in account the delineation of the enclosed coastal waters, i.e. pixels in the newly delineated enclosed coastal areas are now compared to the guidelines values for enclosed coastal, and only the pixels in the open coastal are compared with the guideline values for open coastal. Percentage of compliance is reported over the surface area of the whole coastal region.

4.2 Regional reports: Cape York region

Cape York Peninsula is the northernmost extremity of Australia. From its tip at Cape York it extends southward in Queensland for about 800km, widening to its base, which spans 650km from Cairns in the east to the Gilbert River in the west. The largest rivers in the Cape flow into the Gulf of Carpentaria, however there are several large catchments that drain into the GBR. The region has a monsoonal climate with distinct wet and dry seasons with mean annual rainfall ranging from 1715mm in the Starke region to 2159mm near the Lockhart River airport. Most rain falls between December and April (Johnson et al. 2011). The Cape is an area of exceptional conservation value and has cultural value of great significance to both Indigenous and non-Indigenous communities. The majority of the land is relatively undeveloped, therefore water entering the lagoon is perceived to be of a high quality (Johnson et al. 2011).

This system is characterized by shallow and turbid waters (e.g. in Princess Charlotte Bay) and a relatively narrow coastal water body. The outer boundary for the Open Coastal marine water body approximate delineation in the Guidelines for this NRM region is only 6 km from shore (Table 1 at page 12 of GBRMPA 2009). The Enclosed Coastal marine water body accounts for ~30% of the inshore waters used for P2R reporting and for most of the area in Princess Charlotte Bay as well as Shelburne Bay, Temple Bay, Loyds Bay, Bathurst Bay and Ninian Bay (Table 5,Figure 2). Caution should be used when interpreting the results for this region as limited field information was used for the parameterization and validation on the remote sensing retrievals.

4.2.1 Assessment of freshwater extent during the wet season

Figure 29 reports the freshwater extent for wet season 2011/2012 (November 2011- April 2012) for the Cape York region. The freshwater extent was estimated by applying a threshold of 0.24 m^{-1} for the CDOM seasonal maximum. For the Cape York region the freshwater extent in 2011/2012 was (2038 km^2) below the median value of the last decade (Figure 27). The annual flow data for the Normanby River for this year was the lowest since the current record started in 2006/07.

4.2.2 The wet and dry season median maps for Chlorophyll-a and Total Suspended Solids.

The wet and dry season CHL median maps of (Figure 30) for the Cape York region show high CHL levels near the coast and in the estuary to lower concentrations towards the East. Median CHL values of 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The median values in the Offshore region in the reef matrix ranged from ~0.15-0.5 μgL^{-1}.

The wet and dry season median maps of NAP (as a measure of TSS) (Figure 31) show values higher than 5 mg/L in Princess Charlotte Bay in both seasons.

The maps in Figure 32 depict the number of observations available for calculating the median values for each season on each pixel in the map. The maps show that this amount varies from 15 to 30 observations (out of 180) for the wet season and about 50 (out of 180) for the dry season for each pixel location.

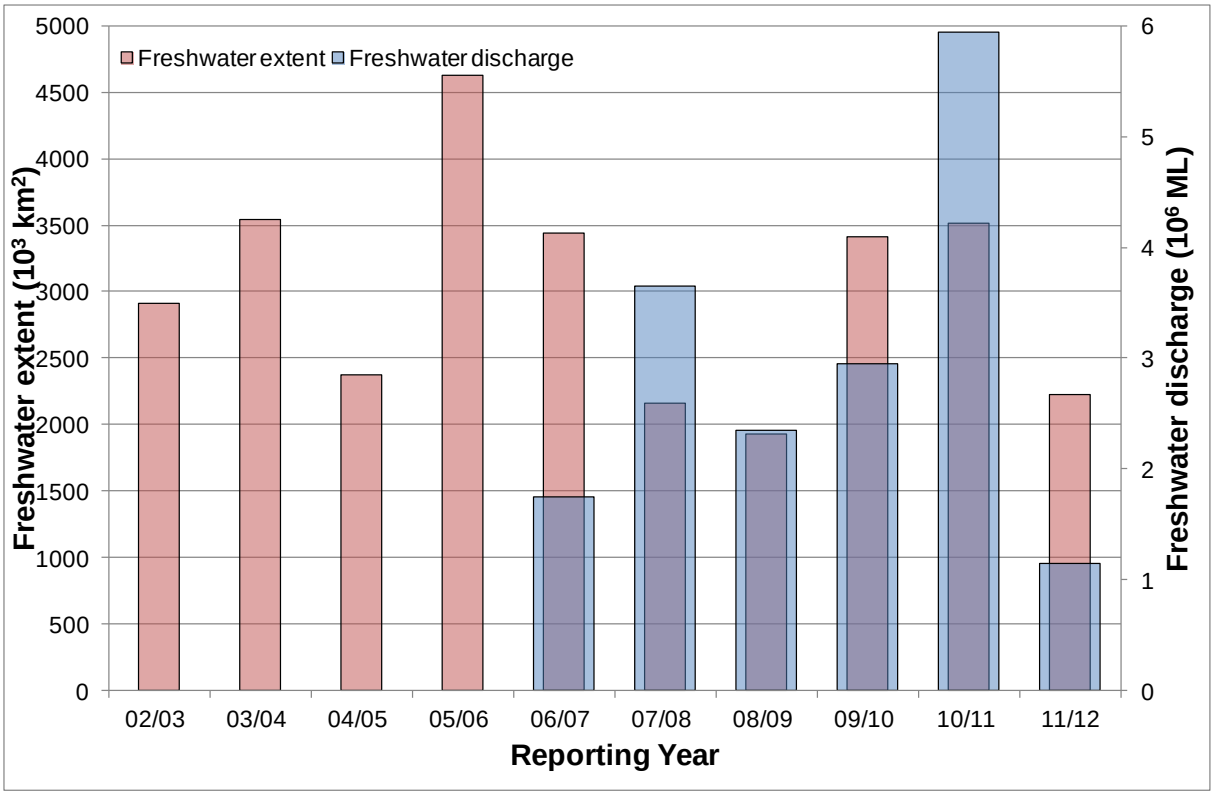


Figure 27. Freshwater discharge and estimated freshwater extent for the Cape York region based on the CDOM maximum for the wet seasons.

4.2.3 Assessment of the marine water quality index and the exceedance of water quality guidelines

The marine water quality for this reporting year for the Cape York region was scored as "good", reflecting a "moderate" score for P2R_CHL and "good" for P2R_TSS (Figure 28). The marine water quality index and the component scores have been oscillating between "moderate" and "good" since the 2003/04 reporting season, showing no clear correlation with the high freshwater discharges from the Cape York catchments and the associated estimated freshwater plume extents (Figure 27).

The exceedance of the Guidelines was assessed for CHL and TSS retrieved from MODIS Aqua using CSIRO's algorithm. For the Cape York region the annual mean CHL values of exceeded the Guidelines threshold values for 17% of the Enclosed Coastal area, 68% of the Open Coastal area, 13% of the Midshelf and none of the Offshore areas (Figure 33, Table 12). The mean CHL values of exceeded the Guidelines thresholds for 93% of the Open Coastal area in the dry season and 27% in the wet season. In the dry season CHL exceeded the Guidelines for 79% of the Midshelf and 17% of the Offshore areas (Figure 34, Table 13). Similar exceedance values were obtained if the median was used for the assessment (i.e. when EF was higher than 0.50, Figure 35, Table 13). The EG maps for CHL show that the mean CHL values of exceeded the Guidelines thresholds in the wet season and over the whole year only in river mouths and embayments (Figure 33, Figure 34). In the dry season the mean CHL values exceed in most of the reef matrix and Offshore waters (Figure 34), while the EF ranged between 10-25 %, indicating that median CHL values did not exceed the Guidelines (Figure 35).

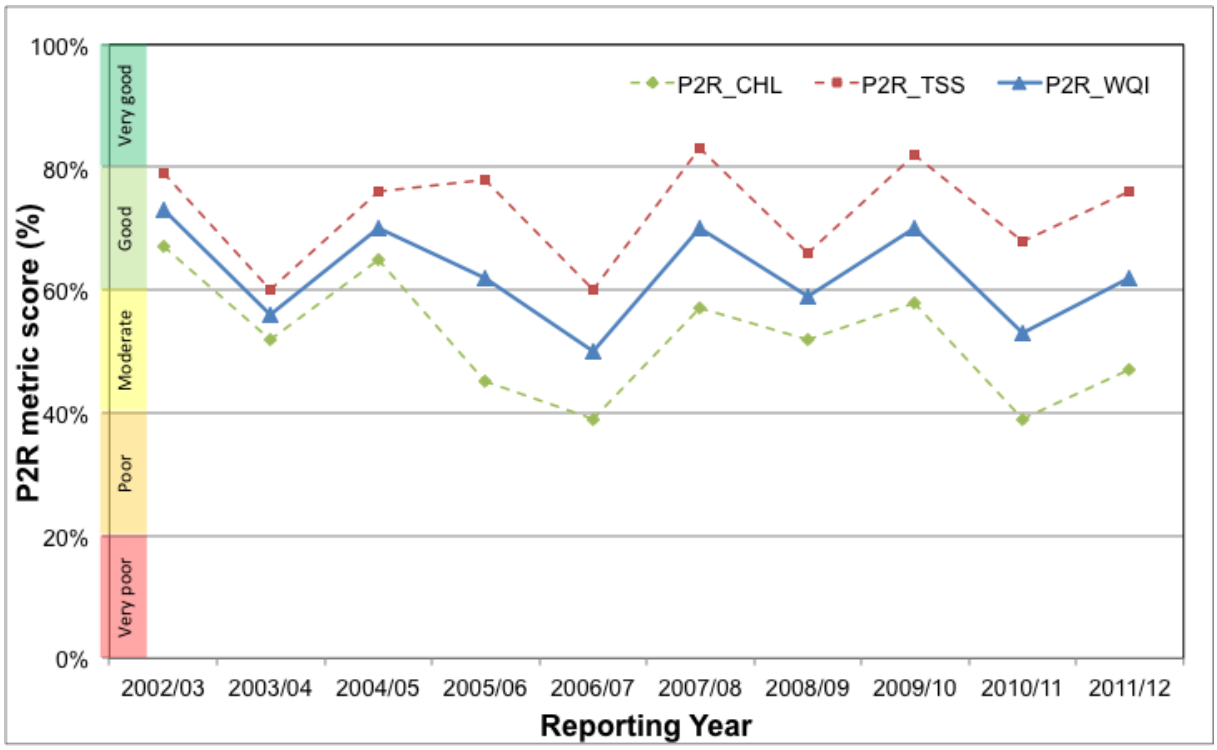


Figure 28. Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) for the Cape York region based on the assessment of exceedance to the Guidelines.

Over the whole year, exceedance of TSS Guideline values was recorded in 58% of Open Coastal, 57% of Midshelf and 21% of Offshore areas (Figure 33, Table 12). The mean values of TSS exceeded the Guidelines values for 76 % of the Open Coastal Area in the dry season and 20 % in the wet season, in the dry season the mean values of TSS also exceeded the Guidelines for 74 % of the Midshelf and 26% of the Offshore area. Almost no exceedance was recorded for the Midshelf and Offshore areas in both seasons if the median was used for the assessment, while the exceedance of the median values for the Open Coastal area were significantly lower than those for the mean values (45% for the dry season and 9% for the wet season, Figure 37, and Table 14).

Table 15 and Table 16 report the summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season independently of the location, along with the EF for that period. These metrics are based on a high number of observations (ranging from 22 thousands valid observations for Open Coastal area in the wet season to almost 1 million for the Offshore area in the dry season). According to these metrics in the dry season the mean values of Chlorophyll exceed the Guidelines for the Open Coastal, Inshore and Midshelf waters, while the median values of Chlorophyll-a exceeded the Guidelines values for the Open Coastal and Inshore area. The mean values of TSS exceeded the Guidelines values for the Open Coastal and Inshore area in the dry season. In the wet season only the mean value of Chlorophyll exceed the Guidelines in both seasons.

Table 12 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Cape York region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, IS: Inshore, MS: Midshelf, OS: Offshore), "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2011_30-Apr-2012		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
EC	1291	48142	423448	17%	11%	34%	17%
OC	3004	120868	985312	68%	64%	19%	4%
IS	4295	169010	1408760	53%	48%	24%	8%
MS	10544	540359	3458432	14%	13%	2%	0%
OS	62344	2094250	20448832	0%	0%	6%	5%

Table 13 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Cape York region (Figure 34, Figure 35). Column and row labels are described in the legend of Table 12.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	1291	32449	202687	33%	18%	15693	220761	8%	8%
OC	3004	77801	471628	93%	89%	43067	513684	27%	26%
IS	4295	110250	674315	75%	68%	58760	734445	21%	21%
MS	10544	350984	1655408	43%	37%	189375	1803024	6%	5%
OS	62344	1306456	9788008	2%	2%	787794	10660824	0%	0%

Table 14 Summary of the exceedance maps for Non-algal particulate matter (NAP as a measure of TSS) for the dry and wet season for the Cape York region (Figure 36, Figure 37). Column and row labels are described in the legend of Table 12.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid	Number total	Mean >	Median >	Number valid	Number total obs.	Mean >	Median >

		obs.	obs.	trigger	trigger	obs.		trigger	trigger
EC	1291	32449	202687	55%	31%	15693	220761	18%	11%
OC	3004	77801	471628	31%	18%	43067	513684	5%	3%
IS	4295	110250	674315	39%	22%	58760	734445	9%	6%
MS	10544	350984	1655408	5%	1%	189375	1803024	1%	0%
OS	62344	1306456	9788008	10%	8%	787794	10660824	3%	2%

Table 15. Summary of Chlorophyll-a exceedance for the dry and wet season for the Cape York region. “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels) for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, MS: Midshelf, OS: Offshore), "Number total obs." provides the total number of observations. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for Chlorophyll –a for the dry/wet season are 1.4/2.8 µg L^{-1} for Enclosed Coastal, 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	32449	202687	1.26	0.86	19%	15693	220761	1.34	1.06	7%
OC	77801	471628	**0.54**	**0.47**	78%	43067	513684	**0.57**	0.49	32%
MS	350984	1655408	**0.33**	0.30	48%	189375	1803024	0.44	0.40	11%
OS	1306456	9788008	0.17	0.15	8%	787794	10660824	0.19	0.15	1%

Table 16 Summary of Non-algal particulate matter (NAP as a measure of TSS) exceedance for the dry and wet season for the Cape York region. Column and row labels are described in the legend of Table 15. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for TSS for the dry/wet season means are 4/6 mg L^{-1} for Enclosed Coastal, 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	32449	202687	5.01	2.52	12%	15693	220761	3.26	1.91	2%

OC	77801	471628	**1.65**	0.97	27%	43067	513684	1.21	0.89	7%
MS	350984	1655408	1.05	0.84	12%	189375	1803024	0.99	0.67	7%
OS	1306456	9788008	0.23	0.11	11%	787794	10660824	0.24	0.16	5%

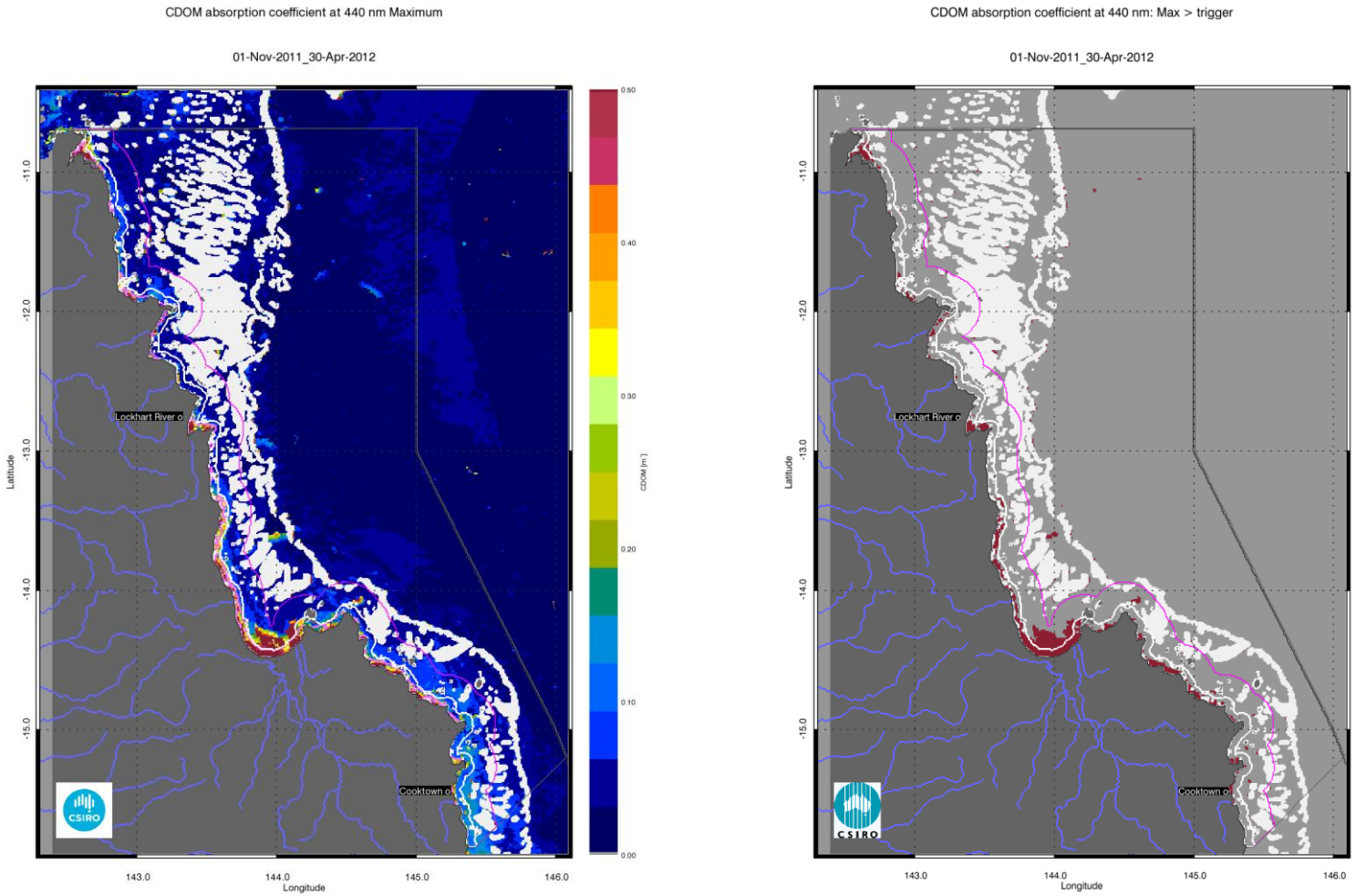


Figure 29. Map of freshwater extent for the wet season for the Cape York region. The first map presents the maximum value of CDOM for the wet season 2011/2012 (November 2011 - April 2012), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.24 m^{-1}.

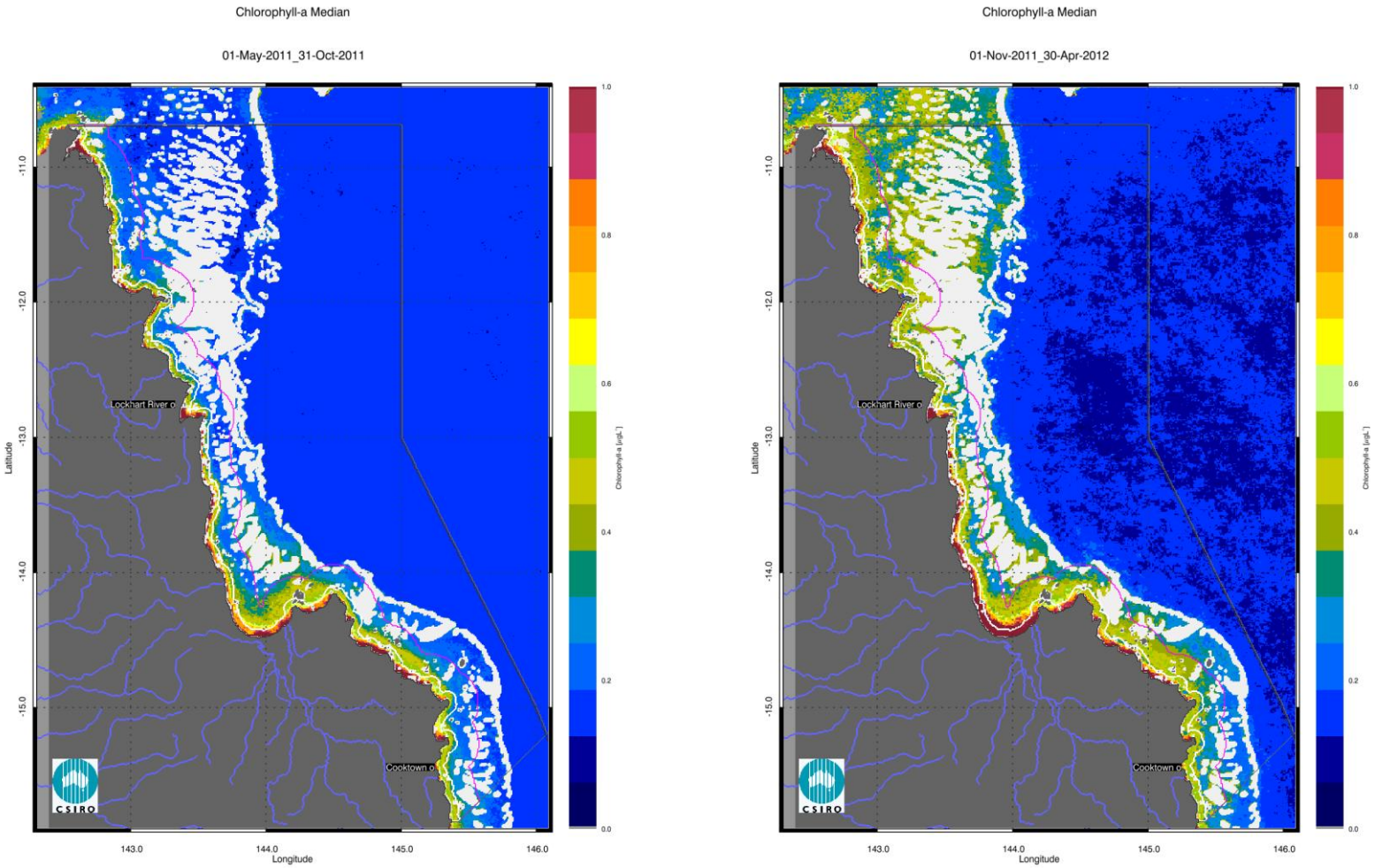


Figure 30. Chlorophyll-a median maps for the dry and wet season for the Cape York region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

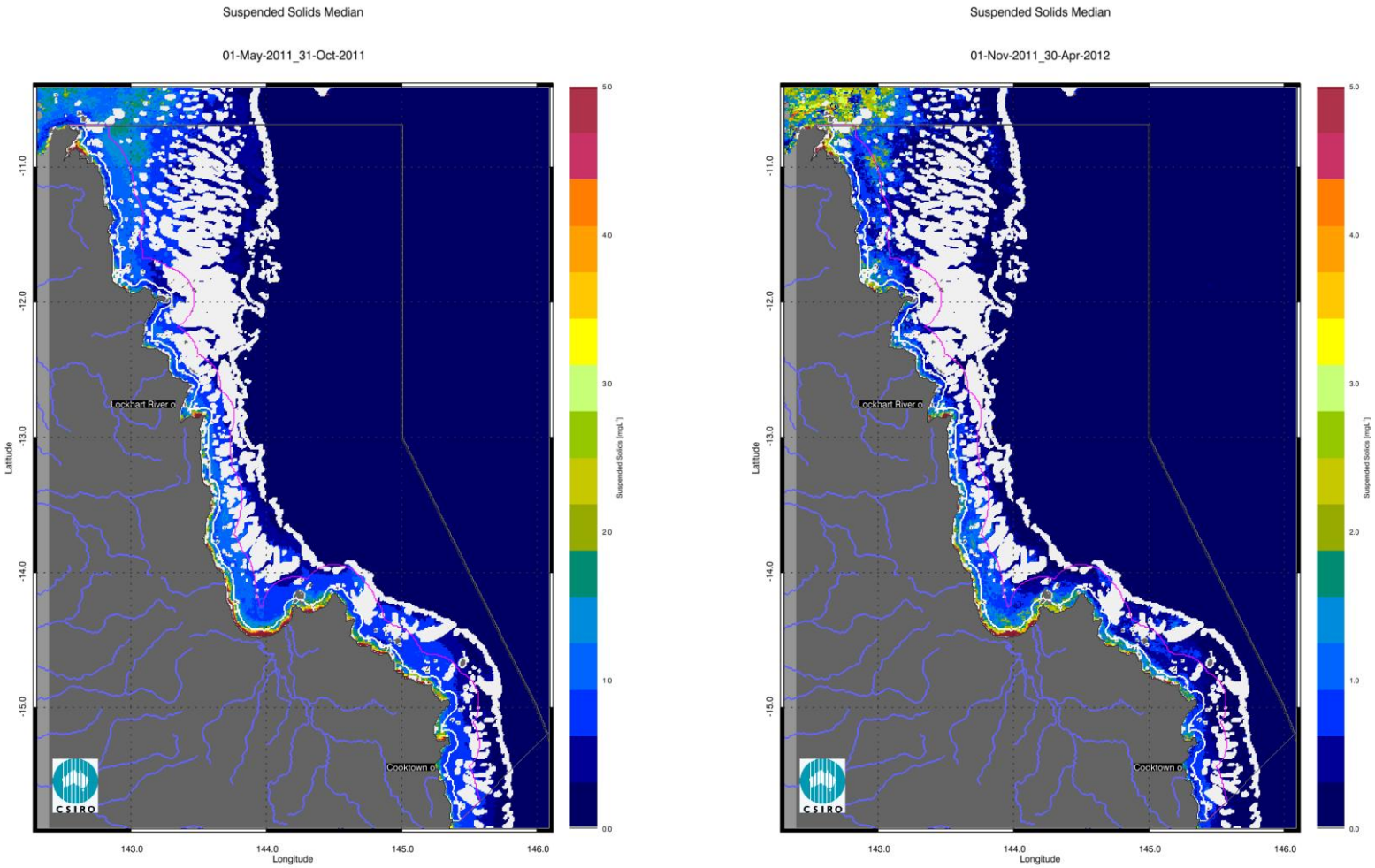


Figure 31. Non-algal particulate matter (NAP as a measure of TSS) median maps for the dry and wet season for the Cape York region. The first map presents the median for the dry season 2010 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

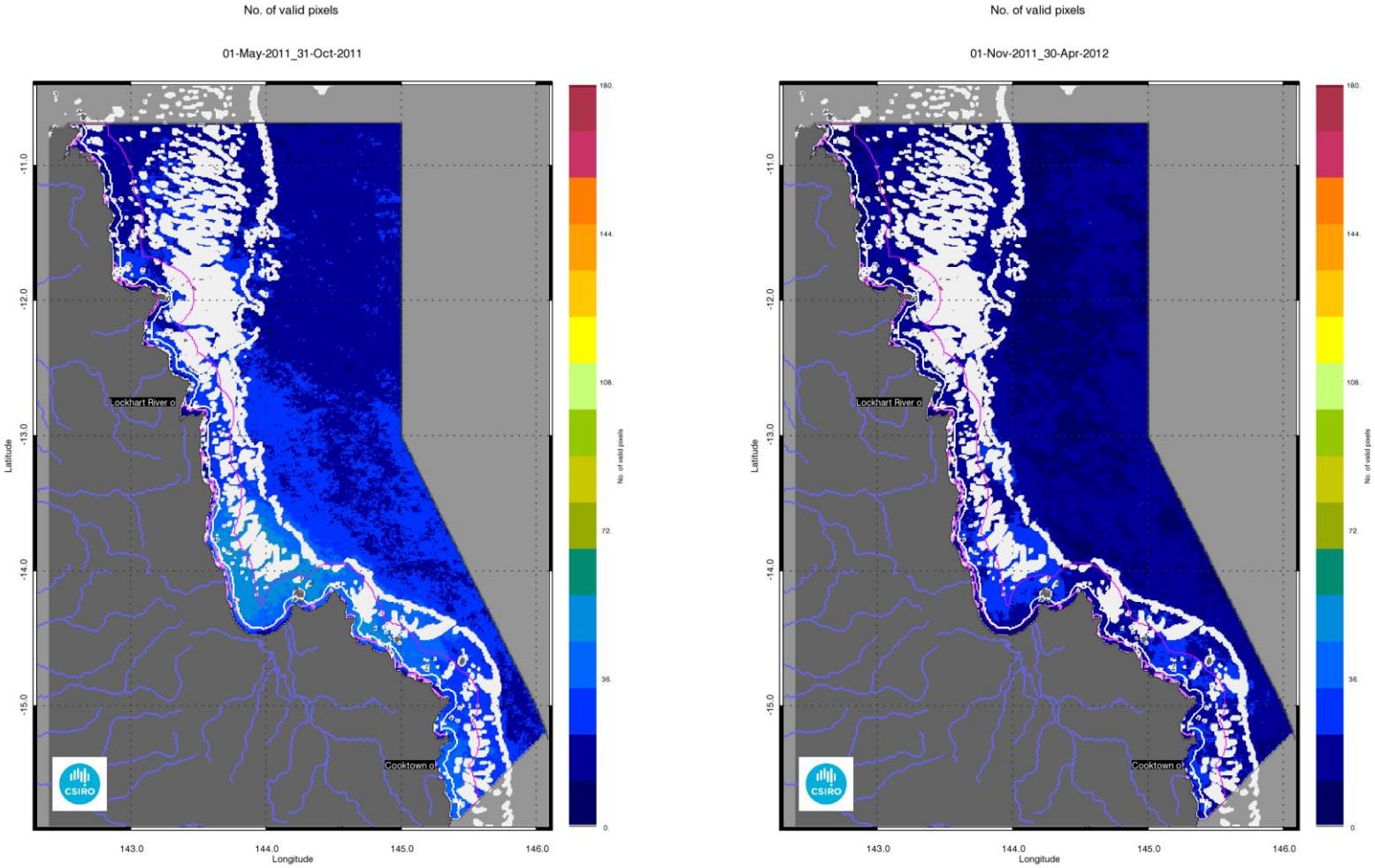


Figure 32. Number of observations used to calculate the median maps (Figure 30 - Figure 31) for the dry and wet season for the Cape York region. The first map presents the number of observations available for analysis in the dry season 2011 (May - October), while the second map presents the number of observations available for analysis in the wet season 2011/2012 (November 2011 - April 2012).

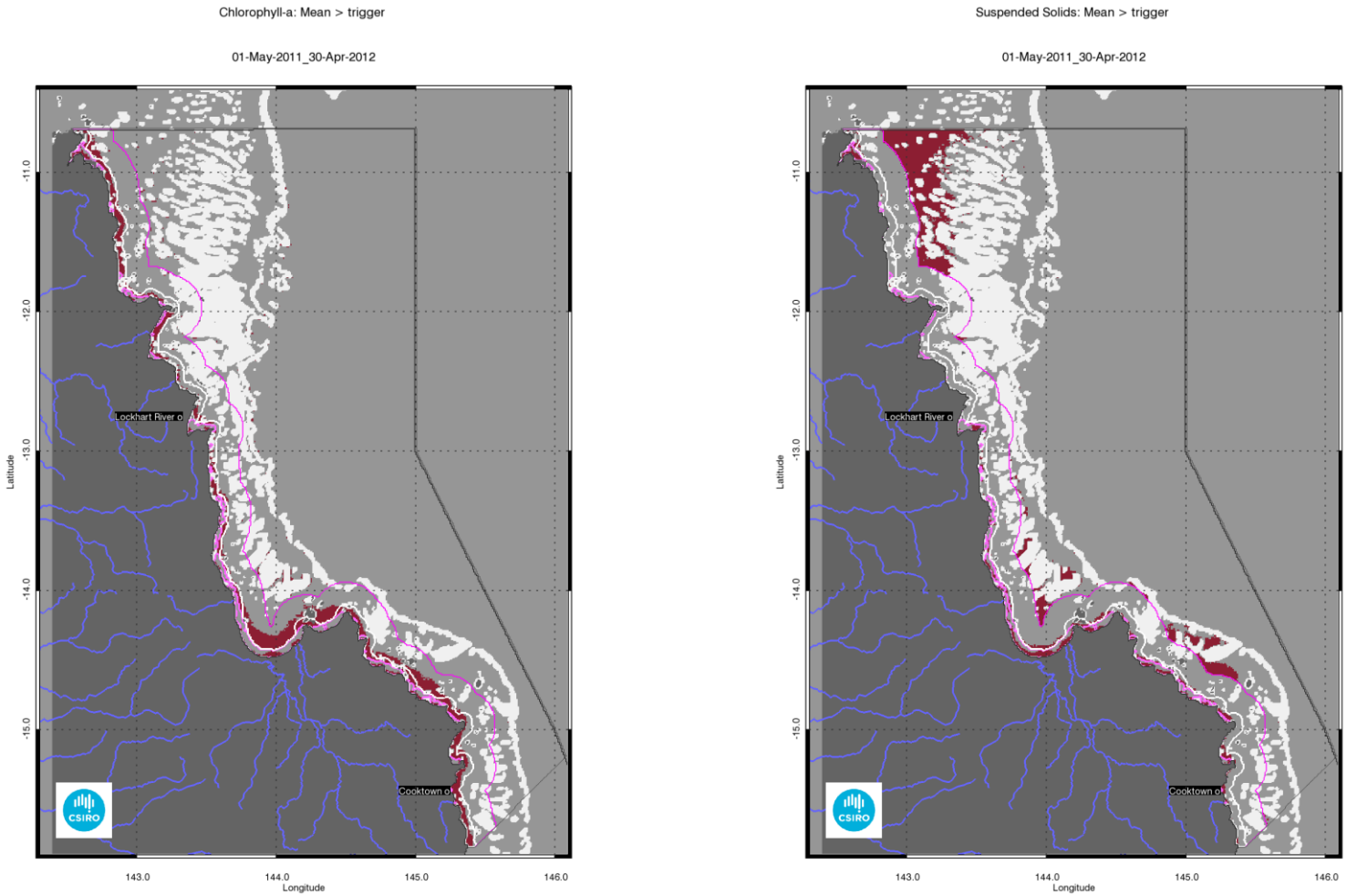


Figure 33. Exceedance maps for the Cape York region for the reporting year 2011/12 (May 2011 –April 2012). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (NAP as a measure of TSS) exceedance map. The Guideline values for annual means of Chlorophyll–a are 0.45 µg L^{-1} for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore, while for TSS are 2.0 and 0.7 mg L^{-1}.

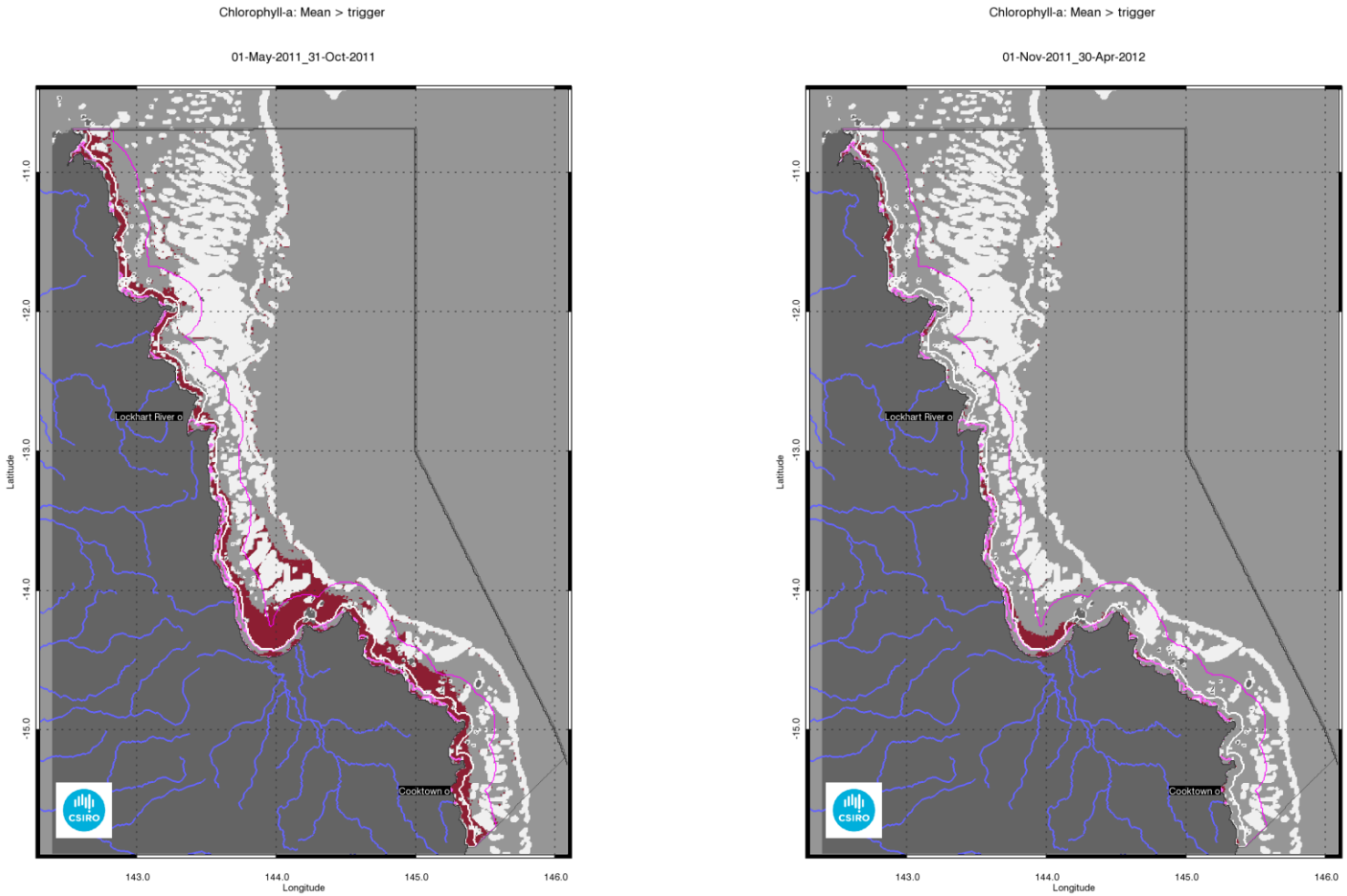


Figure 34. Chlorophyll-a exceedance maps for the dry and wet season for the Cape York region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll–a for the dry/wet season are 0.32/0.63 µg L-1 for Open Coastal and Midshelf and 0.28/0.56 µg L-1 for Offshore.

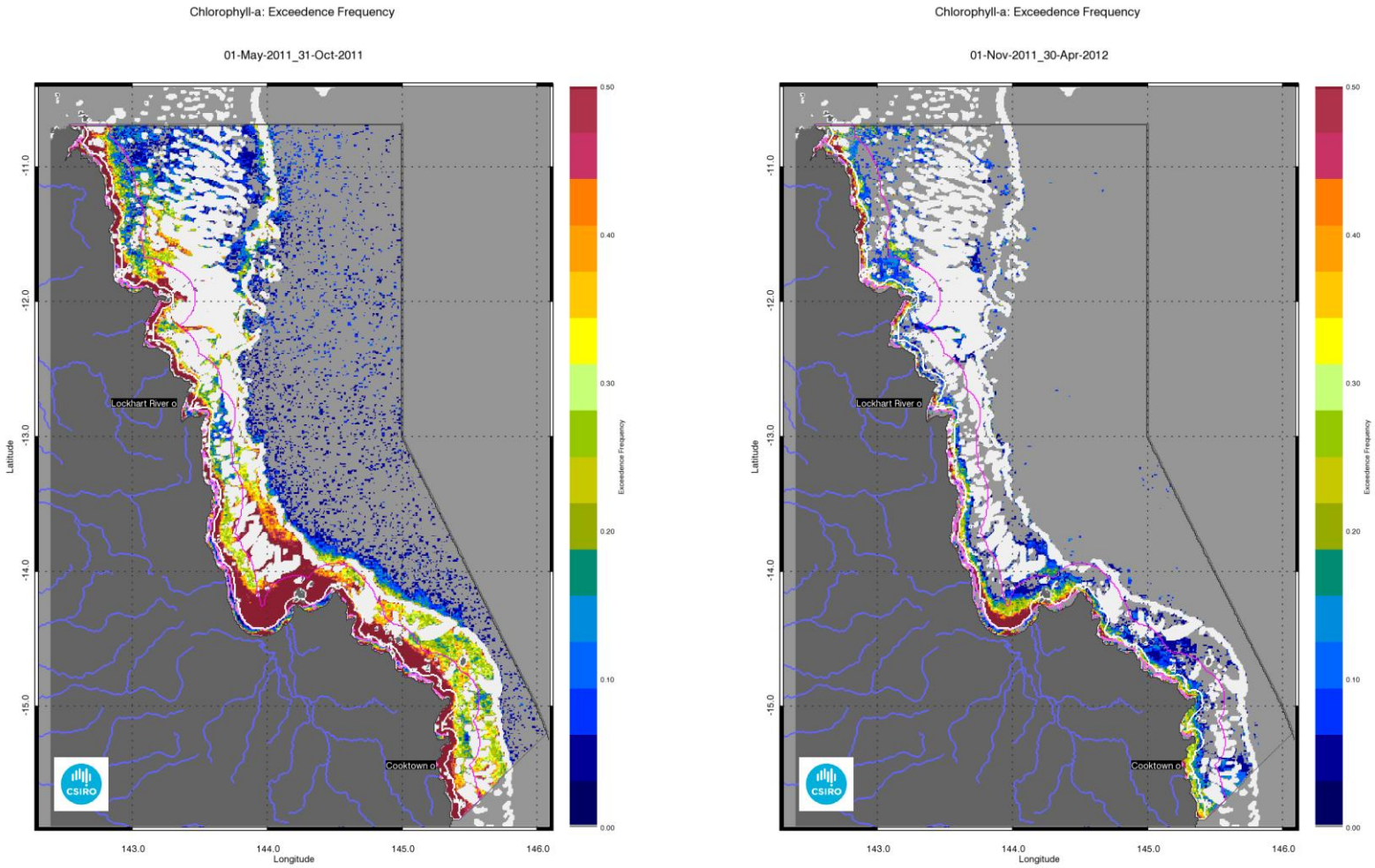


Figure 35. Chlorophyll-a exceedance frequency maps for the dry and wet season for the Cape York region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll –a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

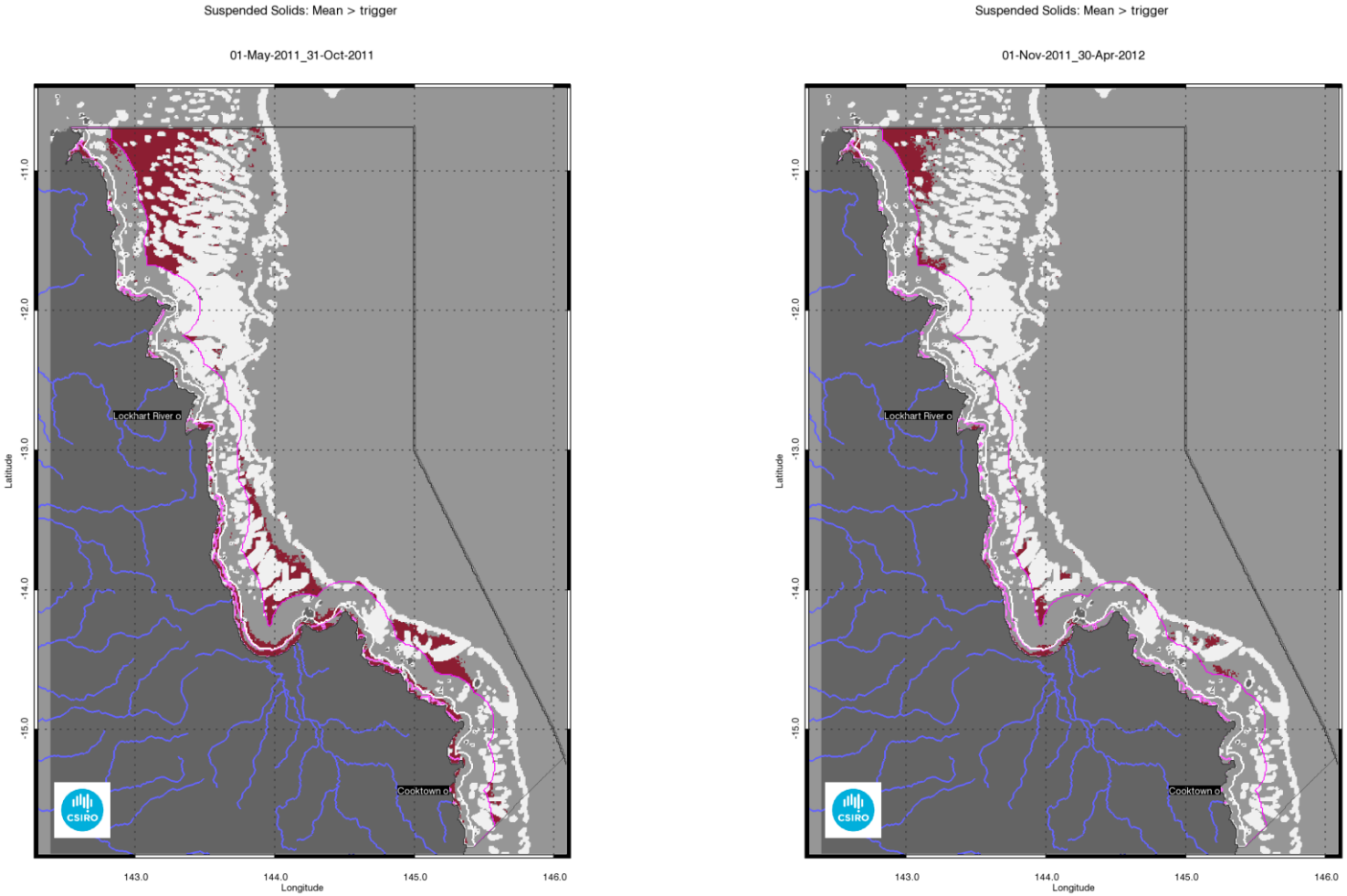


Figure 36. Non-algal particulate matter (NAP as a measure of TSS) exceedance maps for the dry and wet season for the Cape York. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

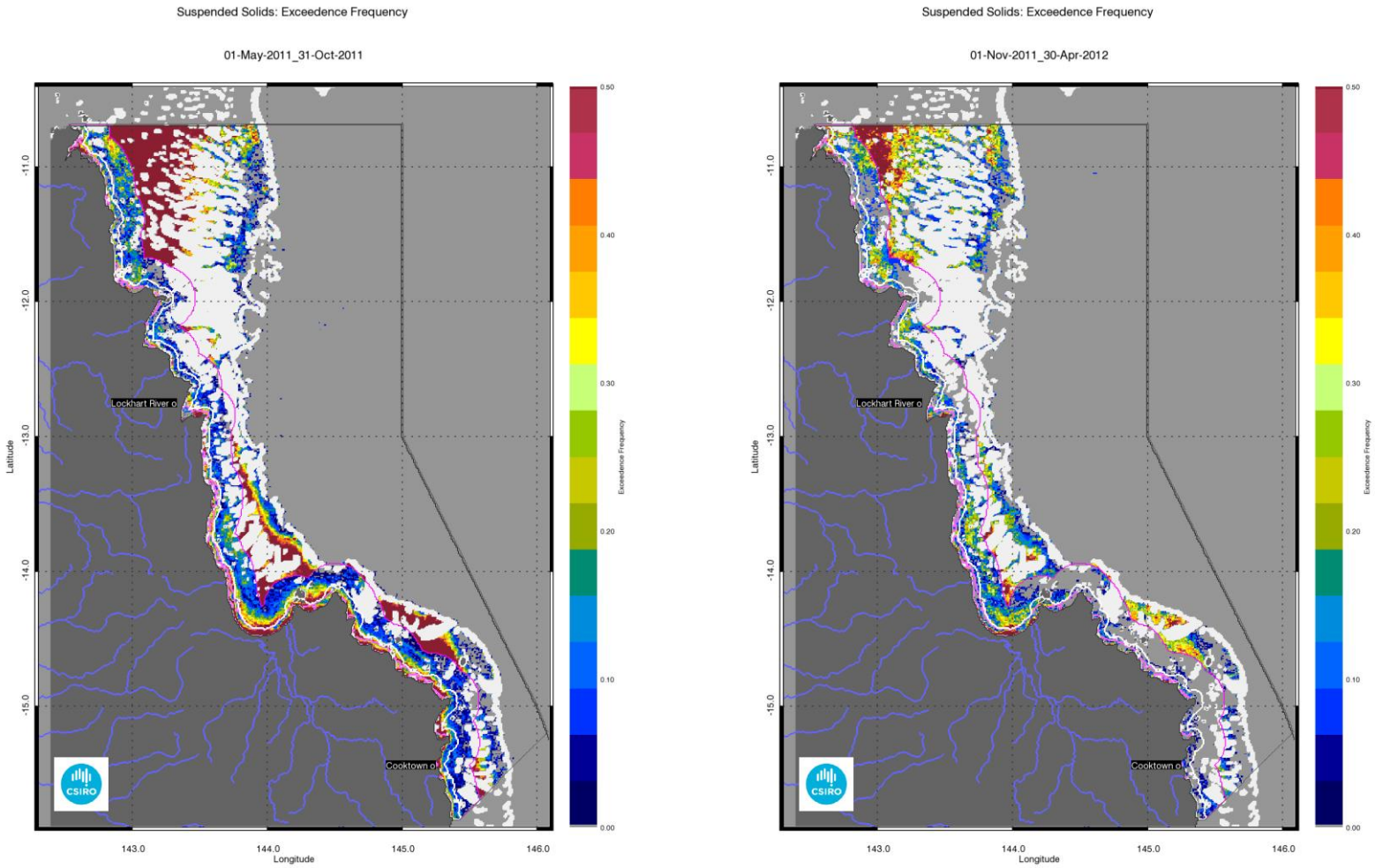


Figure 37. Non-algal particulate matter (NAP as a measure of TSS) exceedance frequency maps for the dry and wet season for the Cape York region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

4.3 Regional reports: Wet Tropics region

Land use practices within the wet tropics catchment include primary production such as sugar cane and banana farming, dairying, beef, cropping and tropical horticulture. Other uses within the region include fisheries, mining, and tourism (Johnson et al. 2011). Declining water quality, due to sedimentation combined with other forms of pollutants, the disturbance of acid sulphate soils, and point source pollution have been identified as a major concern to the health of coastal and marine ecosystems. Major environmental controls on GBR water quality in the wet tropics include pulsed terrigenous runoff, salinity and temperature extremes (Johnson et al. 2011). The Enclosed Coastal marine water body accounts for ~15% of the inshore waters used for P2R reporting. The enclosed waters included the Mossman- Daintree, Barron and Herbert River estuary mouths. In Rockingham Bay the seaward limit of the enclosed coastal waters coincides with the outer boundary for the Open Coastal waters in front of the Tully and Murray river mouths. and for most of the area in Princess Charlotte Bay (Table 5,Figure 2).

4.3.1 Assessment of freshwater extent during the wet season

Figure 40 reports the freshwater extent for wet season 2011/2012 (November 2011- April 2012) for the Wet Tropics region. The freshwater extent was estimated by applying a threshold of 0.24 m^{-1} for the CDOM seasonal maximum. For the Wet Tropics region the freshwater extent for the wet season 2011/2012 (November 2011- April 2012) was 2747 km^2, a value higher than the median extent of the last decade and comparable to the 2779 km^2 of the wet season 2008/2009 (Figure 38). In 2011/12 Most of the rivers in the Wet tropics (Daintree, Barron, Mulgrave, South Johnstone, Tully and Herbert rivers) were just above the median flows. The freshwater extent responded to the freshwater discharge (Figure 38): in 2010/11 the flow conditions in the Daintree and Barron Rivers were more than twice above median levels while the freshwater discharge for the Herbert was more than three times above median flows, as the Wet Tropics region was affected by the impact of the Category 5 Tropical Cyclone Yasi in February 2011 and associated flooding (Figure 17). A lower freshwater extent in 2009/10 (2319 km^2) was due to the to the flow conditions in the Russell, Johnstone, Tully and Herbert Rivers below median levels (0.6 – 0.8 times median levels, Figure 17)..

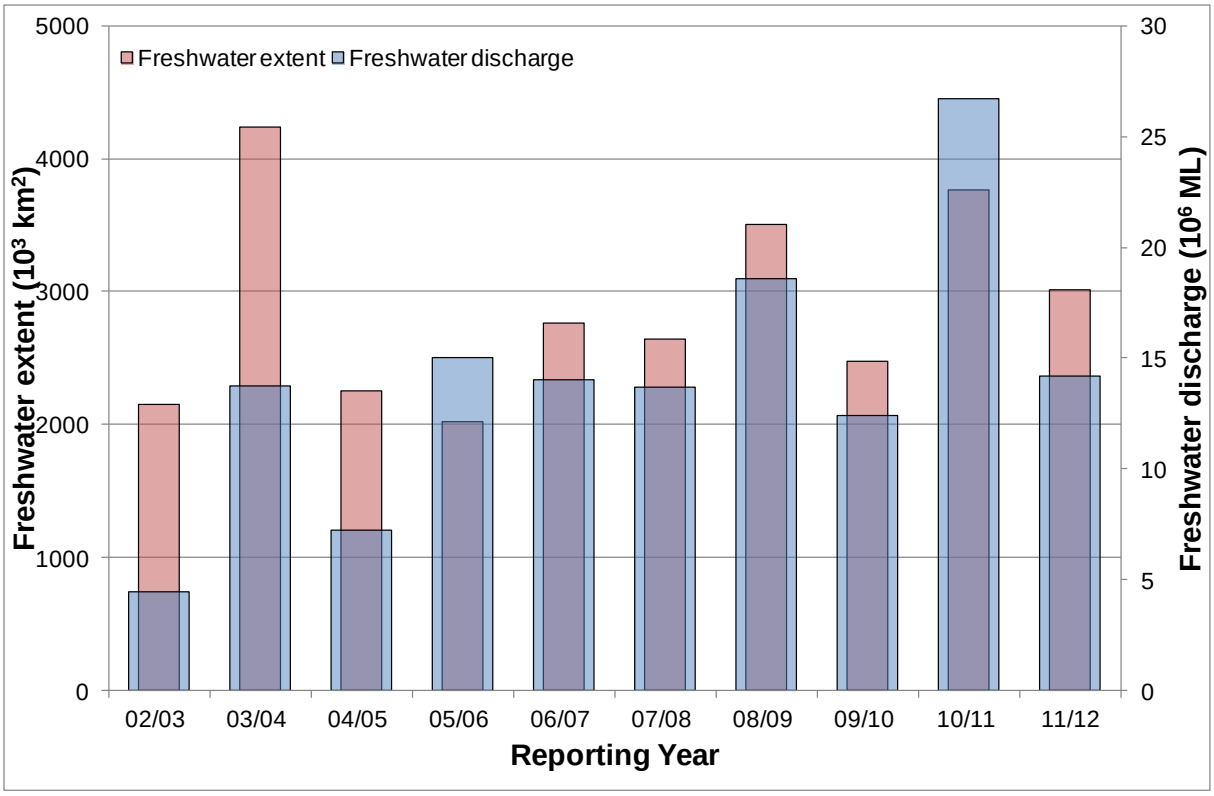


Figure 38. Freshwater discharge and estimated freshwater extent for the Wet Tropics region based on the CDOM maximum for the wet seasons.

The estimated freshwater extended in the Midshelf water bodies reaching the reef matrix to the East of port Douglas and Innisfail (Figure 40). The high concentration of CDOM in these areas is patchy and it provides conservative estimate of the freshwater extent as flood plumes could have extended further in cloudy or overcast days and hence may not been captured with the satellite imagery.

Some of the CDOM and freshwater extent reported for this region (Figure 40), in particular to the East of the Herbert River and Hinchinbrook Island where CDOM absorption were higher than 0.50 m^{-1} are probably associated with the Burdekin River flows and discharge that were more than five times above the median values. Also some of the discharge due to the Herbert River is possibly accounted for in the Burdekin Region. These difficulties in clearly associating the sources of freshwater discharge with the estimated freshwater extent are due to local hydrodynamics, as well as the nature of the marine boundaries for the reporting regions.

4.3.2 The wet and dry season median maps for Chlorophyll-a and Total Suspended Solids.

The wet and dry season CHL median maps of (Figure 41) for the Wet Tropics region show high CHL concentrations near the coast and in the estuary to lower concentrations towards the East. Median CHL values of up-to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for the dry season, while the wet season showed values up to 1.0 μgL^{-1} beyond the coastal to inshore boundary and ranges of 0.4-0.6 μgL^{-1} in the Midshelf. The median CHL values in the offshore region in the reef matrix ranged between 0.15-0.25 μgL^{-1}.

The wet and dry season median maps of non-algal particulate matter (as a measure of TSS) (Figure 42) for the Wet Tropics region show values higher than 3 mgL^{-1} in Rockingham Bay and Halifax Bay.

The number of image observations available for calculating the median values varies from 20 to 30 observations for the wet season and 40-50 for the dry season for each pixel location (Figure 43) .

4.3.3 Assessment of the marine water quality index and the exceedance of water quality guidelines

The marine water quality for this reporting year for the Wet Tropics region was scored as "poor", reflecting a "very poor" score for P2R_CHL and "good" for P2R_TSS (Figure 39). The marine water quality index has been oscillating between "poor" and "moderate" since the 2003/04 reporting season. The component scores show opposite behaviours, with P2R_CHL showing a decline from "poor" to very poor for 2003/04 to-date, while P2R_TSS showing an increase in scores from "moderate" in 2004/05 – 2006/07 to "good" for the previous four reporting years, returning to "moderate" in 2011/12. The P2R_CHL scores seem to respond to the higher freshwater discharges in the last four years and the associated estimated freshwater plume extents (Figure 38).

The Enclosed Coastal marine water body accounts for ~15% of the inshore waters used for P2R reporting, in front of the Barron and Herbert River mouths and for most of the area in Rockingham Bay (Table 5, Figure 2). The annual mean CHL values exceeded the guideline value for 79% of the Enclosed Coastal area, 93% of the Open Coastal area, 31% of the Midshelf and 1% of the Offshore areas (Figure 44, Table 17). The spatial patterns in EG are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 41, Figure 42) and by the changes in trigger values between the Enclosed Coastal and Open Coastal areas as well as between the Midshelf and Offshore areas. The mean CHL values of exceeded the Guidelines values for 98-99% of the Enclosed Coastal and Open Coastal areas in the dry season and 51-60 % in the wet season, in correspondence to the river mouths: Mossman –Daintree, Barron, Russell-Mulgrave, Johnstone, Tully, Murray and Herbert rivers and Hinchinbrook Channel (Figure 45). In the dry season CHL exceeded the Guidelines for 56 % of the Midshelf and 2% of the Offshore areas mainly waters within and around the reef matrix (Figure 45, Table 18). Similar exceedance values were retrieved if the median was used for the assessment (i.e. when EF values were higher than 0.50 in Figure 46, Table 17, Table 18).

The annual REEG for TSS extend reached 69% in the Enclosed Coastal 39% of the Open Coastal, 7% of the Midshelf and 1% of Offshore areas (Figure 44, Table 17). The seasonal mean TSS values exceeded the Guidelines values for 75 % of Enclosed Coastal and 56% of the Open Coastal Area in the dry season and 55% and 9 % in the wet season, in the dry season the mean values of TSS also exceeded the Guidelines for 10 % of the Midshelf and 6% of the Offshore area. Almost no exceedance was recorded for the Midshelf and Offshore areas in both seasons and over the year if the median was used for the assessment (REEF50), while the exceedance of the median values for the inshore area were lower than those for the mean values (15% for the whole year, 31% for the dry season and 10% for the wet season, Figure 48, and Table 19).

The exceedance for the annual mean, as well as in the seasonally adjusted mean values of CHL and TSS in the Offshore water body occurred consistently between the Midshelf to Offshore boundary (particularly to the North-East and South- East of Hinchinbrook Island) and the whole Reef Matrix, due to the steep change in Guidelines trigger values across the Midshelf to Offshore boundary (from 2.0 to 0.7 mg L^{-1} for the annual means and from 1.6/2.4 to 0.6/0.8 mg L^{-1} for the seasonally adjusted values, Table 3 and Table 4).

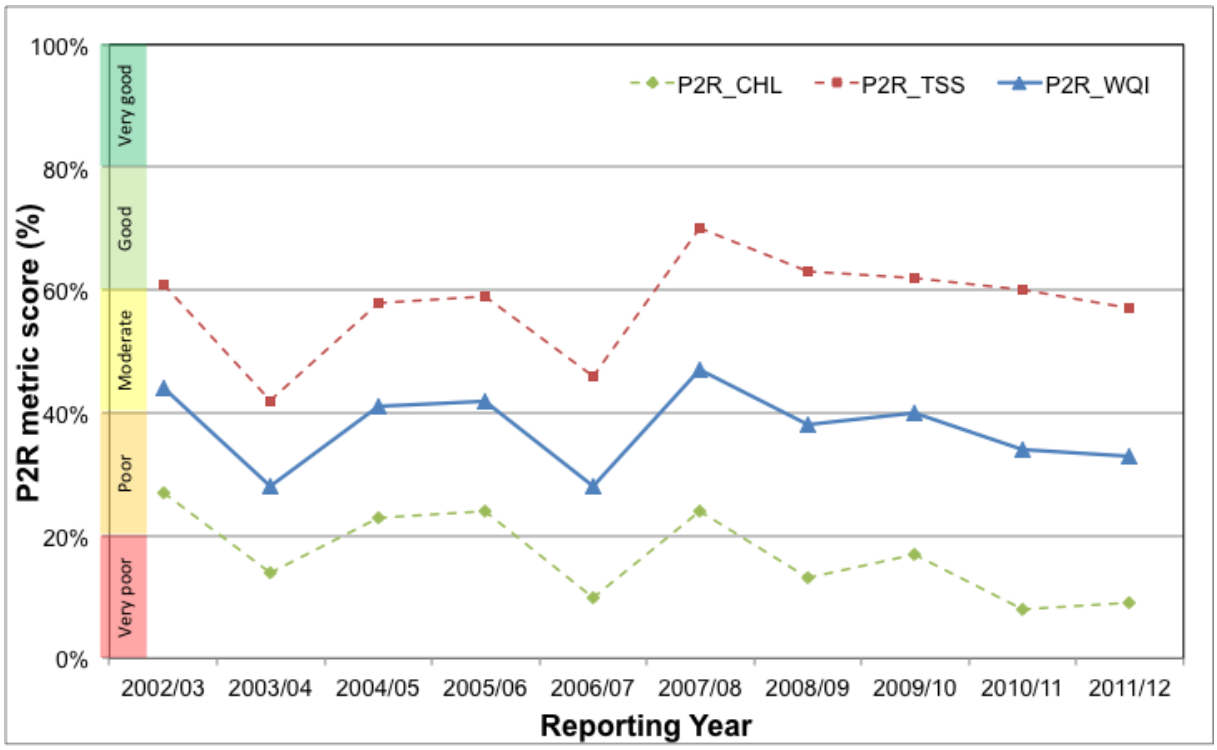


Figure 39. Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) for the Wet Tropics region based on the assessment of exceedance to the Guidelines.

Table 20 and Table 21 report the summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EF for that period. These metrics are based on a high number of observations (ranging from 5 thousand valid observations for Enclosed Coastal area in the wet season to over 460 thousand for the Offshore area in the dry season). According to these metrics the mean and the median CHL values exceeded the Guidelines values for the Enclosed Coastal, Open Coastal areas in both seasons and in Midshelf for the dry season, while the mean TSS values exceeded the Guidelines values only for the Open Coastal area in the dry season. The mean and median values for the TSS concentration differed substantially (for all water bodies and seasons). The mean values were ~ 2-3 times higher than medians.

Table 17 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Wet Tropics region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, IS: Inshore, MS: Midshelf, OS: Offshore), , "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2011_30-Apr-2012		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
EC	307	13558	100389	79%	43%	69%	38%
OC	1737	105009	567999	93%	92%	39%	11%
IS	2044	118567	668388	91%	84%	43%	15%
MS	5859	385403	1915893	31%	28%	7%	3%
OS	19906	909151	6509262	1%	1%	1%	0%

Table 18 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Wet Tropics region (Figure 45, Figure 46). Column and row labels are described in the legend of Table 17.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	307	8922	48199	98%	68%	4636	52190	51%	39%
OC	1737	68006	272709	99%	99%	37003	295290	60%	52%
IS	2044	76928	320908	99%	94%	41639	347480	59%	50%
MS	5859	247415	919863	56%	50%	137988	996030	18%	15%
OS	19906	586618	3125242	2%	2%	322533	3384020	1%	0%

Table 19 Summary of the exceedance maps for Non-algal particulate matter (NAP as a measure of TSS) for the dry and wet season for the Wet Tropics region (Figure 47, Figure 48). Column and row labels are described in the legend of Table 17.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	307	8922	48199	75%	40%	4636	52190	55%	36%
OC	1737	68006	272709	56%	30%	37003	295290	9%	5%
IS	2044	76928	320908	59%	31%	41639	347480	16%	10%
MS	5859	247415	919863	10%	4%	137988	996030	4%	2%
OS	19906	586618	3125242	6%	3%	322533	3384020	0%	0%

Table 20. Summary of Chlorophyll-a exceedance for the dry and wet season for the Wet Tropics region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, MS: Midshelf, OS: Offshore), , "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for Chlorophyll –a for the dry/wet season are 1.4/2.8 µg L^{-1} for Enclosed Coastal, 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	8922	48199	**2.61**	**1.67**	60%	4636	52190	**3.07**	2.09	38%
OC	68006	272709	**0.82**	**0.59**	92%	37003	295290	**0.79**	**0.68**	53%
MS	247415	919863	**0.42**	**0.35**	57%	137988	996030	0.53	0.42	27%
OS	586618	3125242	0.19	0.15	15%	322533	3384020	0.22	0.17	4%

Table 21 Summary of Non-algal particulate matter (NAP as a measure of TSS) exceedance for the dry and wet season for the Wet Tropics region. Column and row labels are described in the legend Table 20. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for TSS for the dry/wet season means are 4/6 mg L^{-1} for Enclosed Coastal, 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	8922	48199	7.13	4.01	21%	4636	52190	7.21	4.50	9%
OC	68006	272709	**2.47**	1.16	38%	37003	295290	1.31	0.83	10%
MS	247415	919863	1.08	0.65	11%	137988	996030	0.82	0.40	4%
OS	586618	3125242	0.24	0.14	9%	322533	3384020	0.20	0.15	3%

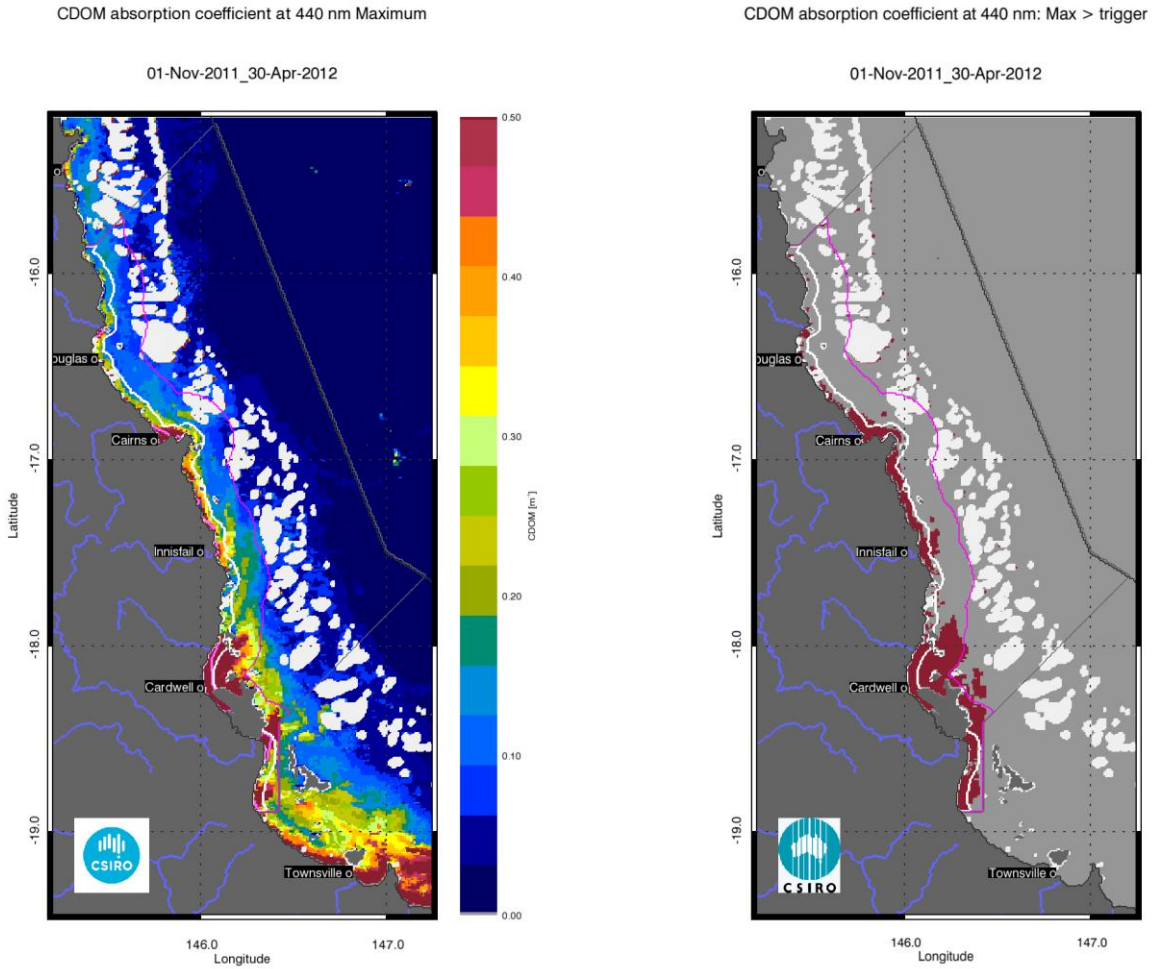


Figure 40. Map of freshwater extent for the wet season for the Wet Tropics region. The first map presents the maximum value of CDOM for the wet season 2011/2012 (November 2011 - April 2012), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.24 m^{-1}.

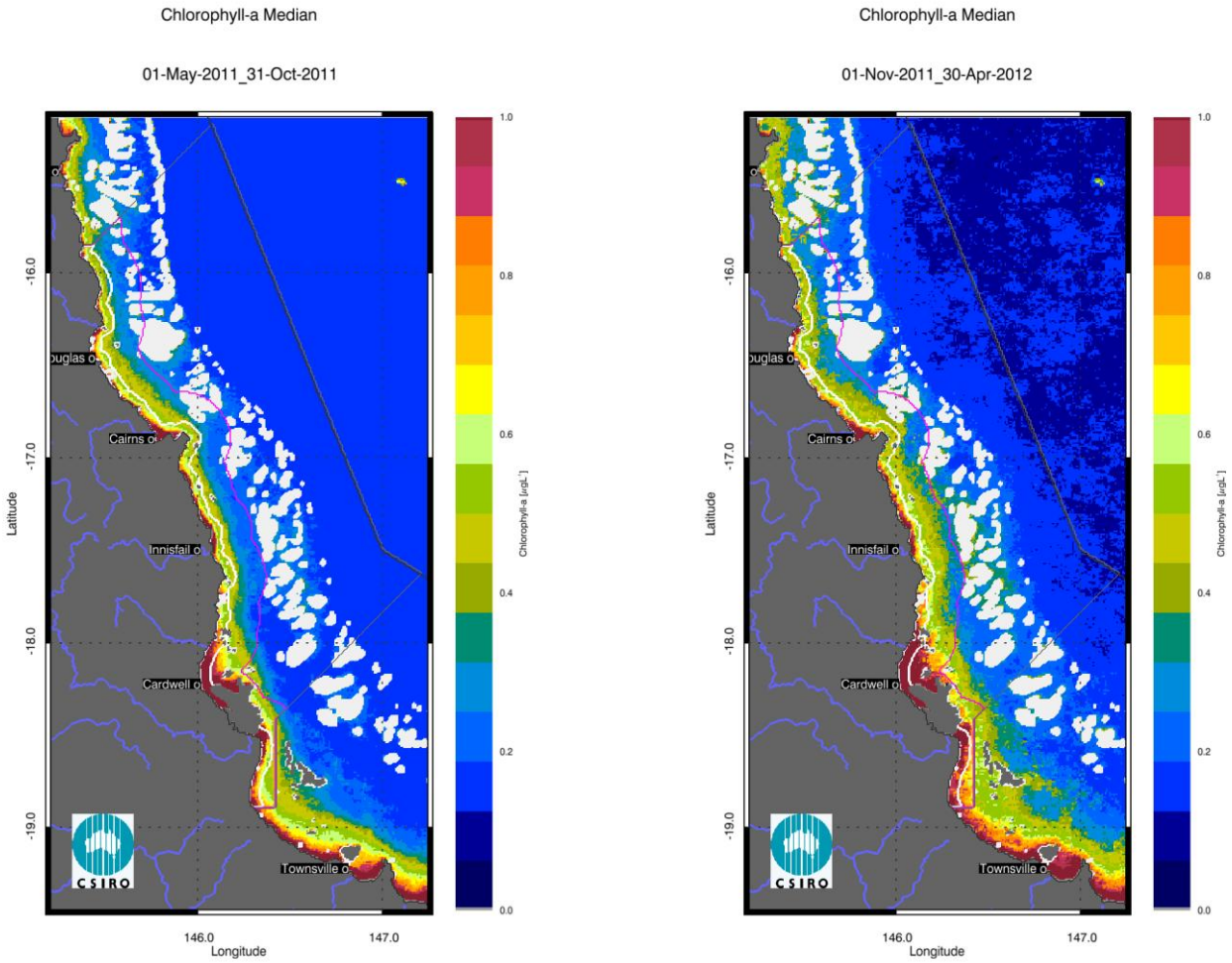


Figure 41. Chlorophyll-a median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

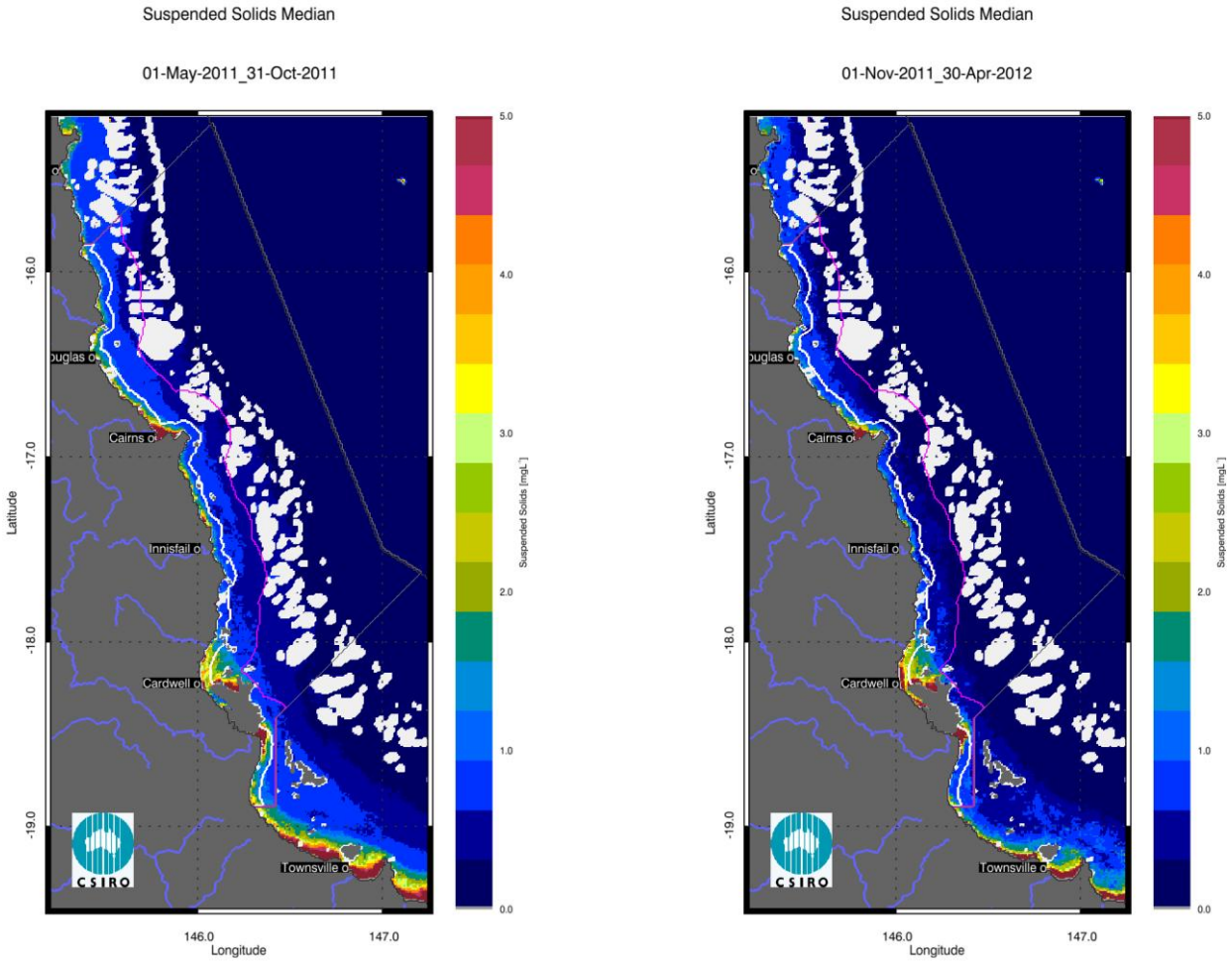


Figure 42. Non-algal particulate matter (NAP as a measure of TSS) median maps for the dry and wet season for the Wet Tropics region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

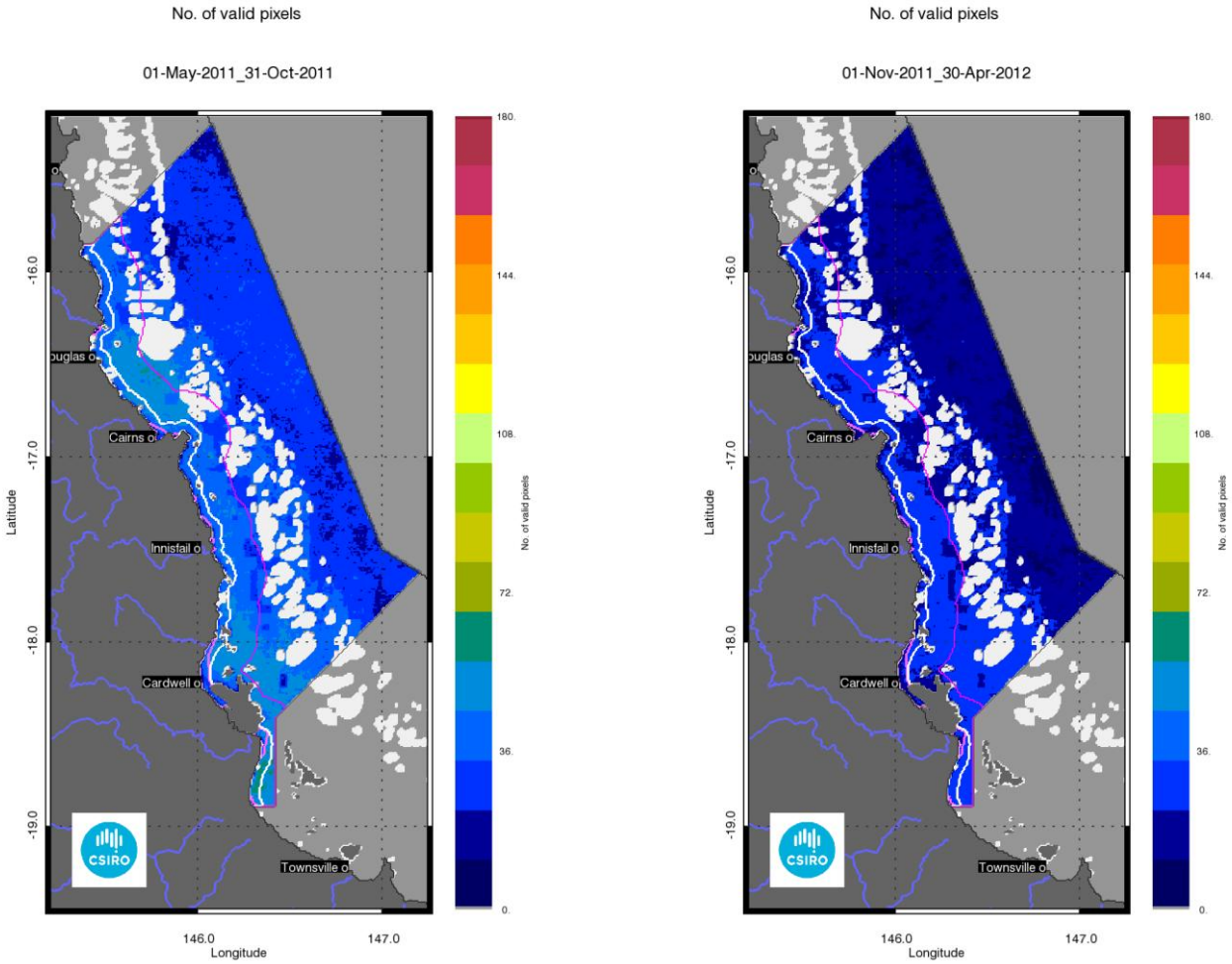


Figure 43. Number of observations used to calculate the median maps (Figure 41 - Figure 42) for the dry and wet season for the Wet Tropics region. The first map presents the number of observations available for analysis in the dry season 2011 (May - October), while the second map presents the number of observations available for analysis in the wet season 2011/2012 (November 2011 - April 2012).

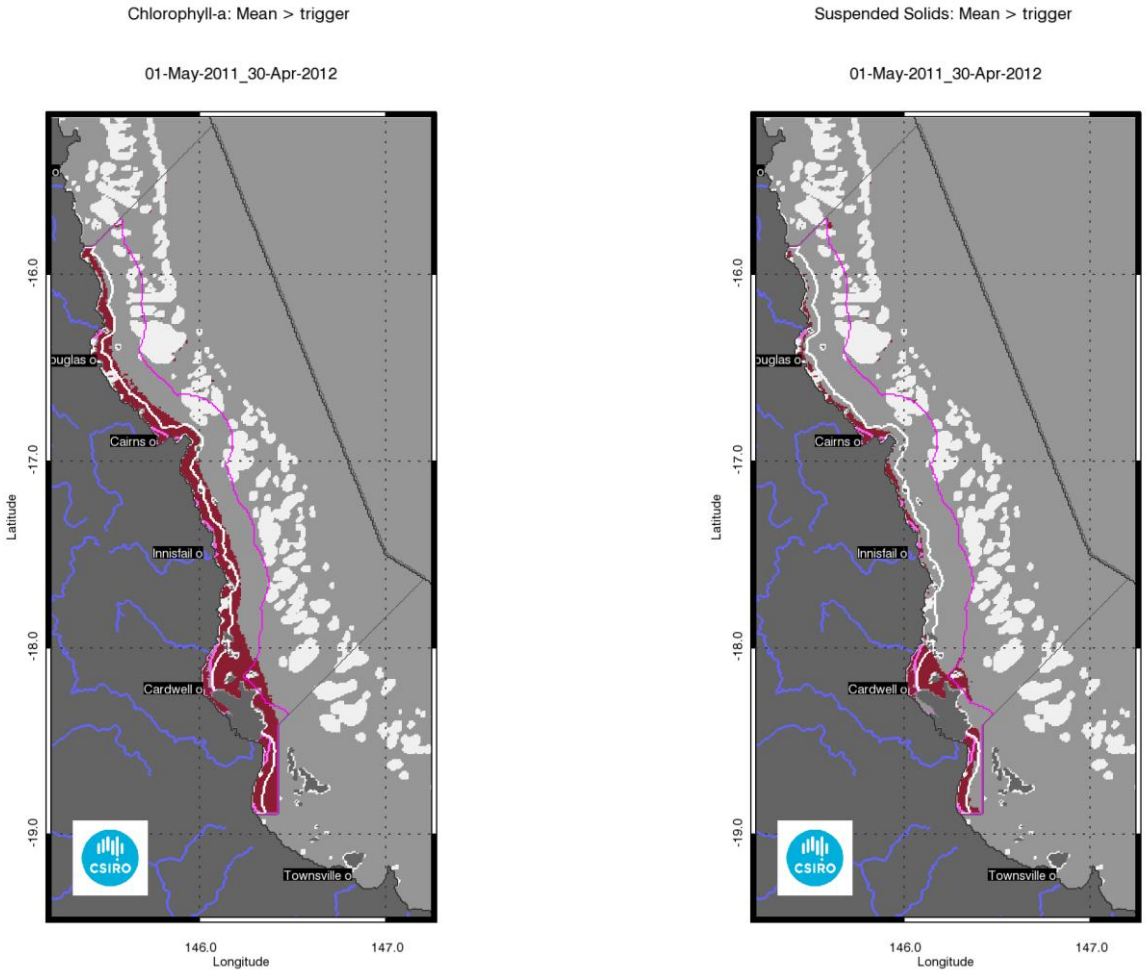


Figure 44. Exceedance maps for the Wet Tropics region for the whole year (May 2011 – April 2012). The first map presents the Chlorophyll-a exceedance map, while the second map presents the non-algal particulate matter (NAP as a measure of TSS) exceedance map. The Guideline values for annual means of Chlorophyll–a are 0.45 µg L^{-1} for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore, while for TSS are 2.0 and 0.7 mg L^{-1}.

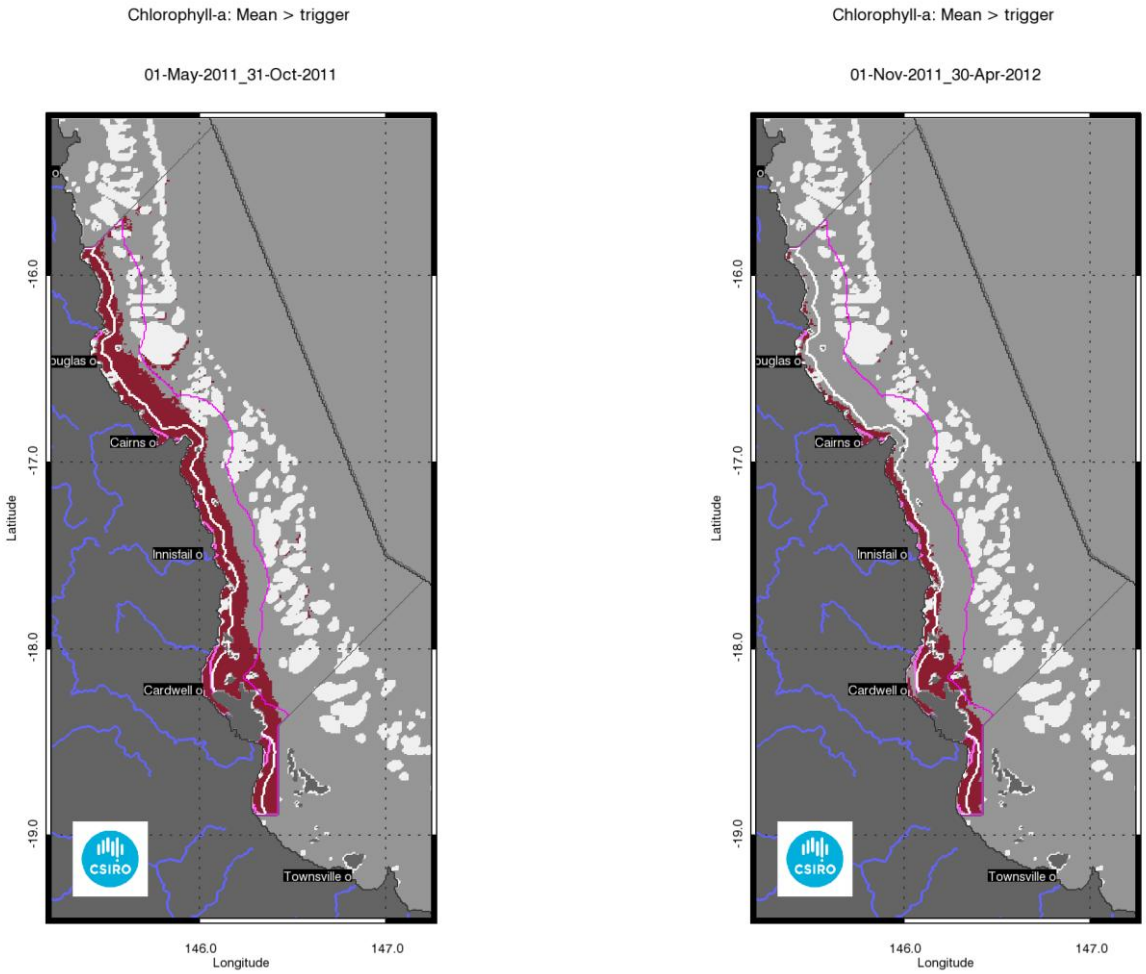


Figure 45. Chlorophyll-a exceedance maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll –a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

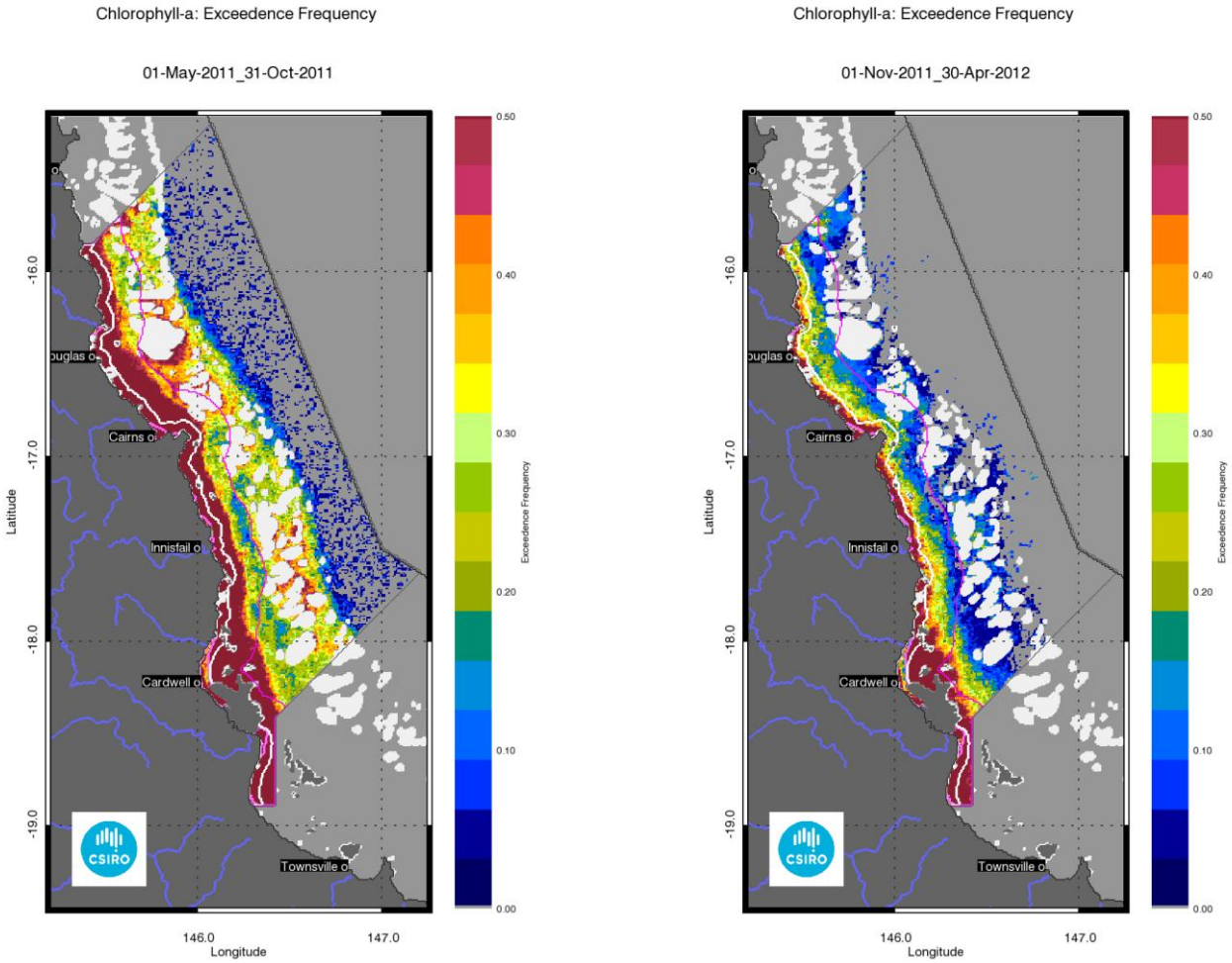


Figure 46. Chlorophyll-a exceedance frequency maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll –a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

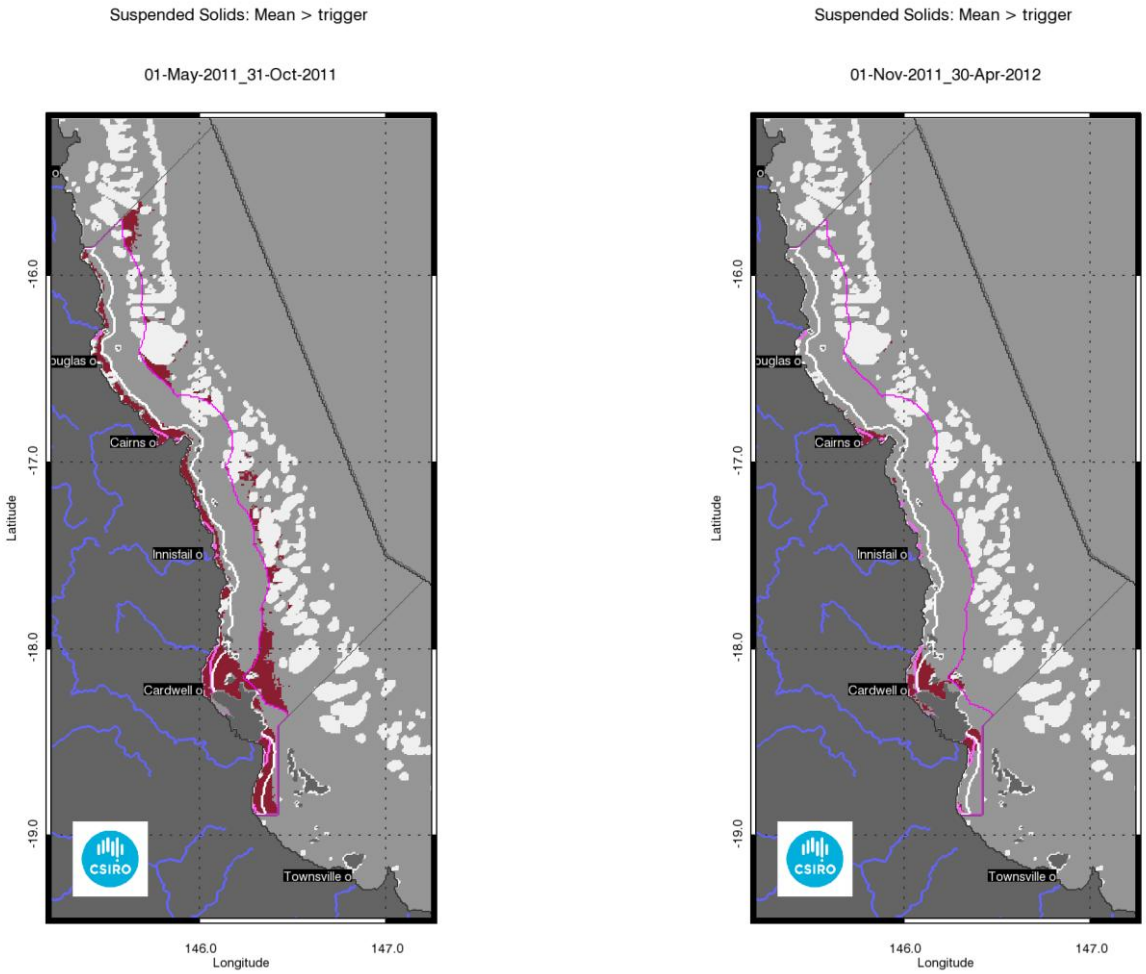


Figure 47. Non-algal particulate matter (NAP as a measure of TSS) exceedance maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

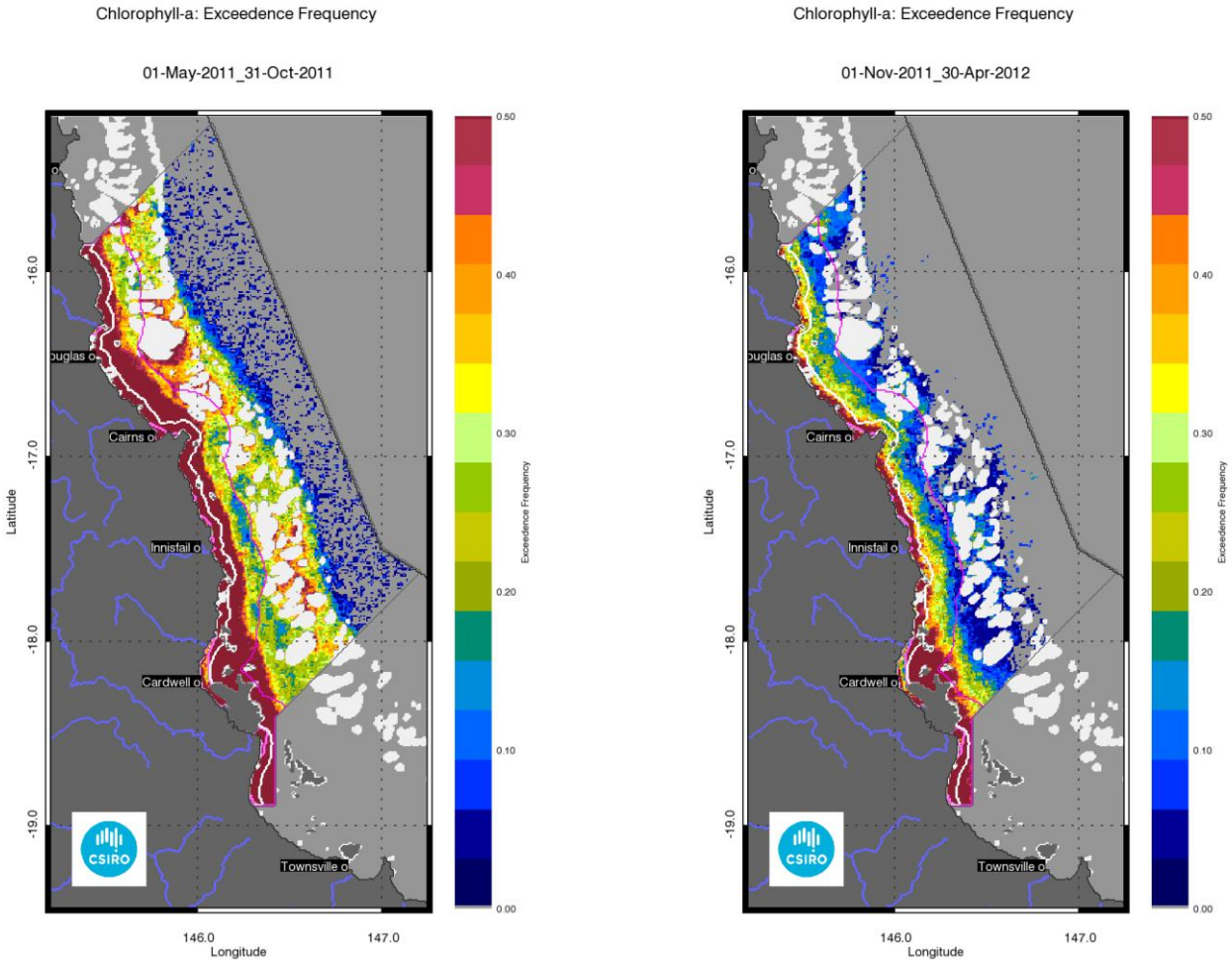


Figure 48. Non-algal particulate matter (NAP as a measure of TSS) exceedance frequency maps for the dry and wet season for the Wet Tropics region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

4.4 Regional reports: Burdekin region

The Burdekin Dry Tropics region includes an aggregation of the Black, Burdekin, Don, Haughton and Ross River catchments and includes several smaller coastal catchments, all of which empty into the GBR lagoon. Because of its geographical location, rainfall in the region is lower than other regions within tropical Queensland, though there is considerable variation year to year with 75% of the annual rainfall received during December to March (Johnson et al. 2011).

4.4.1 Assessment of freshwater extent during the wet season

Figure 51 reports the freshwater extent for wet season 2011/2012 (November 2011- April 2012) for the Burdekin region. The freshwater extent was estimated by applying a threshold of 0.24 m^{-1} for the CDOM seasonal maximum. For the Burdekin region the freshwater extent for the wet season 2011/2012 (November 2011- April 2012) was 5020 km^2 following a river flow almost three times above median flows (Figure 49). The freshwater extent was well correlated with the freshwater discharge (R^2=0.624, Figure 49): in 2009/10 a lower extent (3035 km^2) reflected the freshwater discharge from the Burdekin River that was sightly above the median values (~1.3) while for the wet seasons 2008/2009 and 2010/2011 (7402 and 4912 km^2) the flows were more than five times the annual median flow (Figure 17). In 2010/11 the Burdekin region was also affected by TC Yasi strong winds, large rainfalls and associated flooding.

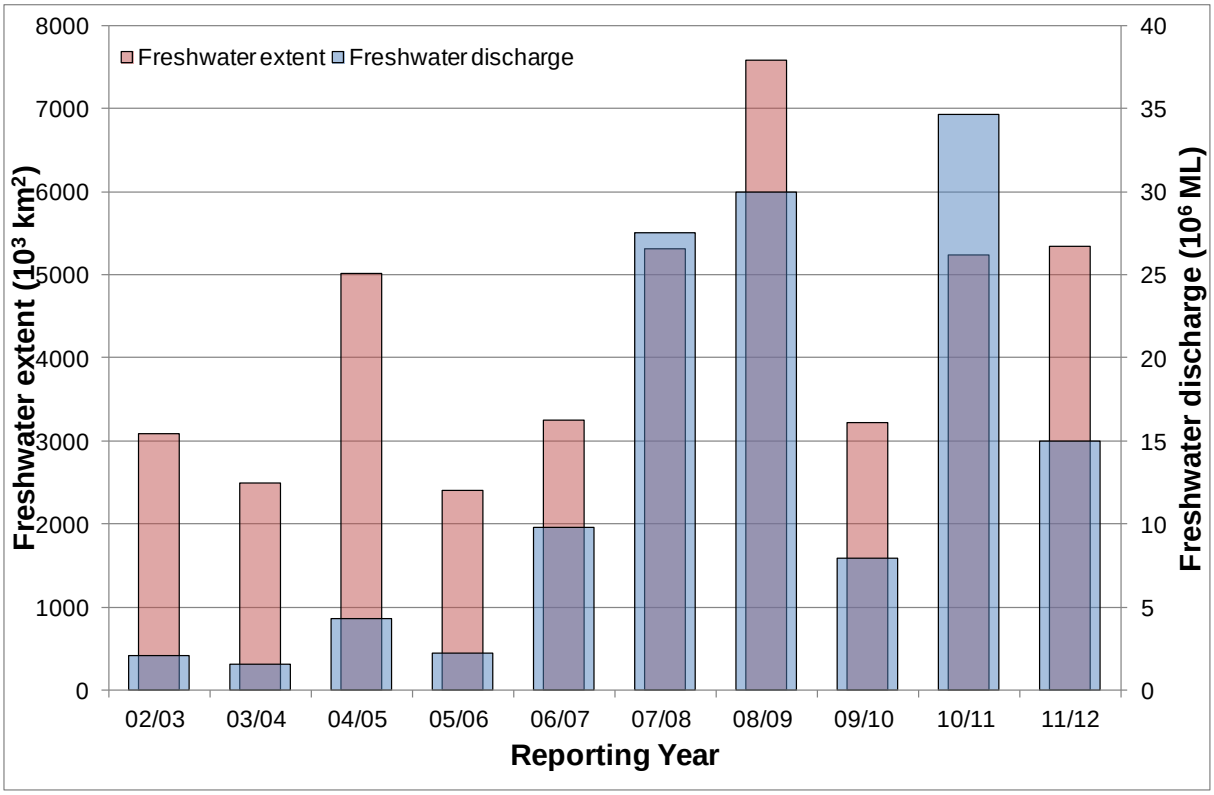


Figure 49. Freshwater discharge and estimated freshwater extent for the Burdekin region based on the CDOM maximum for the wet seasons.

4.4.2 The wet and dry season median maps for chlorophyll-a and Total Suspended Solids.

The wet and dry season CHL median maps of (Figure 52) for the Burdekin region show high CHL concentrations near the coast and in the estuary to lower concentrations towards the East. Median CHL values up to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The wet season values were higher than 1.0 μgL^{-1} for a coastal band ~10 km wide from Cape Upstart to Halifax Bay. The median values in the Offshore region in the reef matrix ranged from ~0.15-0.25 μgL^{-1}.

The wet and dry season median maps of non-algal particulate matter (as a measure of Total Suspended Solids) show a similar pattern, with values higher than 1.5 mgL^{-1} in all the open Coastal area in the wet season (Figure 53). The maps in Figure 54 depict the number of image observations available for calculating the median values for each season. This amount varies from 30 to 40 observations for the wet season and about 90 for the dry season for each pixel location.

4.4.3 Assessment of the marine water quality index and the exceedance of water quality guidelines

The marine water quality for this reporting year for the Burdekin region was scored as "moderate", reflecting a "poor" score for P2R_CHL and "good" for P2R_TSS (Figure 50). The marine water quality index has been consistently "moderate" from 2002/03 to date. The component scores show opposite behaviours, with P2R_CHL showing a decline from "moderate" in 2003/04 – 2006/07 to "poor" in 2007/08 to-date, while P2R_TSS showing a consistent scores of "good" for all reporting years. The P2R_CHL scores seem to respond to the higher freshwater discharges from the Burdekin River in the last five years and the associated estimated freshwater plume extents (Figure 49).

The Enclosed Coastal marine water body accounts for ~15% of the inshore waters used for P2R reporting and for most of the area in Cleveland Bay, Bowling Green Bay and in front of the mouth of the Burdekin River (Table 5, Figure 2).

The annual mean CHL values exceeded the guideline value (2.0 and 0.45 μg/L) in 69% of the Enclosed Coastal waters, in 66% of the Open Coastal area and 12% of the Midshelf areas (Figure 55,Table 22). The mean CHL concentrations exceeded the Guidelines values for 97% of the Enclosed Coastal and 76% of Open Coastal Area in the dry season and 41 and 59 % in the wet season. In the dry season CHL also exceeded the Guidelines for 15 % of the Midshelf and 1% of the Offshore areas (Figure 56, Table 23). Similar exceedance values were retrieved if the median was used for the assessment (i.e. when EF was higher than 0.50 in Figure 57, Table 23).

The annual EG for TSS were recorded in 17% of the Enclosed Coastal and 38 % of the Open Coastal areas (Figure 55, Table 22). The mean values of TSS exceeded the Guidelines values for 43% of the Inshore waters in the dry season and 17% in the wet season (Figure 58 and Table 24). No exceedance was recorded for the Midshelf and Offshore areas for the whole year and both seasons if the mean or the median was used for the assessment. The exceedance of the median values for the Open Coastal Area were significantly lower (35% for the dry season and 7% for the wet season, Figure 59, and Table 24).

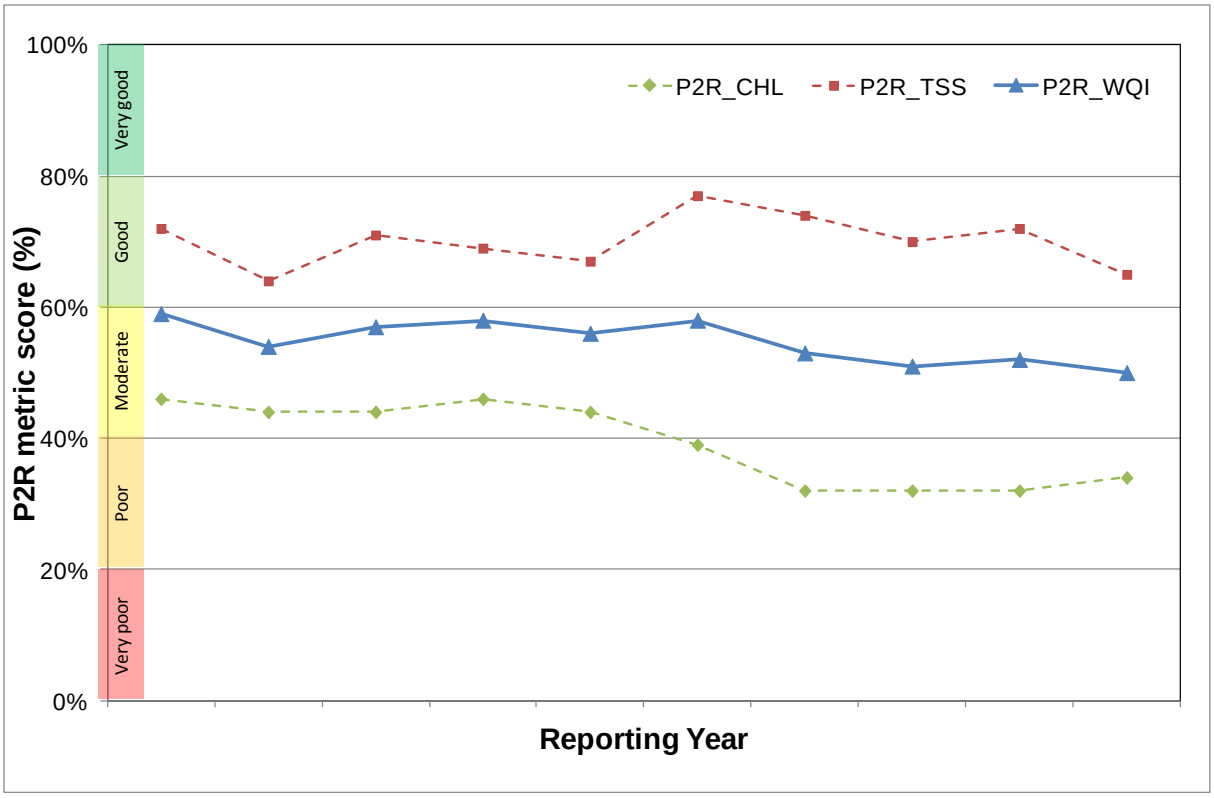


Figure 50. Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) for the Burdekin region based on the assessment of exceedance to the Guidelines.

Table 25 and Table 26 report the Summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EF for that period. These metrics are based on a high number of observations (ranging from 85 thousands valid observations for Open Coastal in the wet season to over 750 thousands for the Offshore are in the dry season). According to these metrics both the mean and the median CHL values of exceeded the Guidelines values for the Open Coastal area in both seasons and for the Midshelf in the dry season only. For TSS only the mean values in the Open Coastal area in the dry season exceeded the trigger value. The mean and median values for the TSS concentration differed substantially (for all water bodies and seasons). The mean values were ~ 2-3 times higher than medians.

Table 22 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Burdekin region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, IS: Inshore, MS: Midshelf, OS: Offshore), , "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2011_30-Apr-2012		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
EC	608	36599	214016	69%	46%	17%	10%
OC	3363	283155	1183776	66%	59%	38%	17%
IS	3971	319754	1397792	66%	57%	35%	16%
MS	11065	775959	3894880	12%	9%	0%	0%
OS	26560	1345345	9349120	0%	0%	0%	0%

Table 23 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Burdekin region (Figure 56, Figure 57). Column and row labels are described in the legend of Table 22.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	608	24698	102752	97%	60%	11901	111264	41%	31%
OC	3363	189107	568347	76%	73%	94048	615429	62%	48%
IS	3971	213805	671099	79%	71%	105949	726693	59%	46%
MS	11065	520485	1869985	15%	14%	255474	2024895	9%	2%
OS	26560	865080	4488640	1%	1%	480265	4860480	0%	0%

Table 24 Summary of the exceedance maps for Non-algal particulate matter (NAP as a measure of TSS) for the dry and wet season for the Burdekin region (Figure 58, Figure 59). Column and row labels are described in the legend of Table 22.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	608	24698	102752	34%	26%	11901	111264	8%	6%
OC	3363	189107	568347	45%	35%	94048	615429	18%	7%
IS	3971	213805	671099	43%	34%	105949	726693	17%	7%
MS	11065	520485	1869985	1%	0%	255474	2024895	0%	0%
OS	26560	865080	4488640	0%	0%	480265	4860480	0%	0%

Table 25. Summary of Chlorophyll-a exceedance for the dry and wet season for the Burdekin region. “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels) for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, MS: Midshelf, OS: Offshore), "Number total obs." provides the total number of observations. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for Chlorophyll–a for the dry/wet season are 1.4/2.8 µg L^{-1} for Enclosed Coastal, 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	24698	102752	**2.64**	**1.77**	57%	11901	111264	2.48	1.78	30%
OC	189107	568347	**0.64**	**0.49**	73%	94048	615429	**0.81**	0.55	45%
MS	520485	1869985	0.25	0.20	28%	255474	2024895	0.38	0.29	12%
OS	865080	4488640	0.18	0.15	12%	480265	4860480	0.19	0.15	1%

Table 26 Summary of Non-algal particulate matter (NAP as a measure of TSS) exceedance for the dry and wet season for the Burdekin region. Column and row labels are described in the legend Table 25. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for TSS for the dry/wet season means are 12/18 mg L^{-1} for Enclosed Coastal, 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	24698	102752	10.37	7.77	36%	11901	111264	8.74	6.02	12%
OC	189107	568347	**2.35**	1.10	34%	94048	615429	1.75	1.07	18%
MS	520485	1869985	0.56	0.46	4%	255474	2024895	0.56	0.27	2%
OS	865080	4488640	0.16	0.12	2%	480265	4860480	0.15	0.13	1%

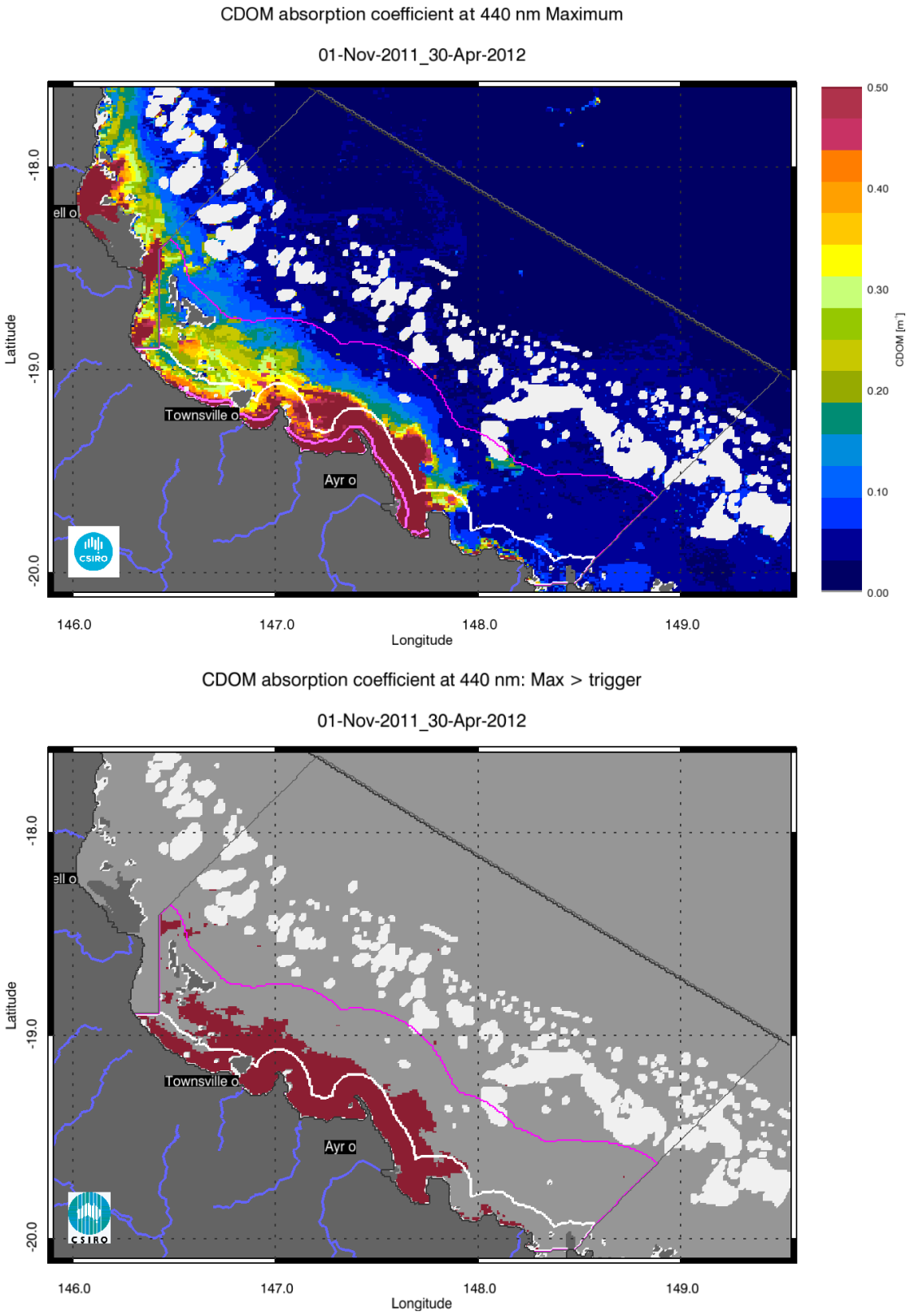


Figure 51. Map of freshwater extent for the wet season for the Burdekin region. The first map presents the maximum value of CDOM for the wet season 2011/2012 (November 2011 - April 2012), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.24 m^{-1}.

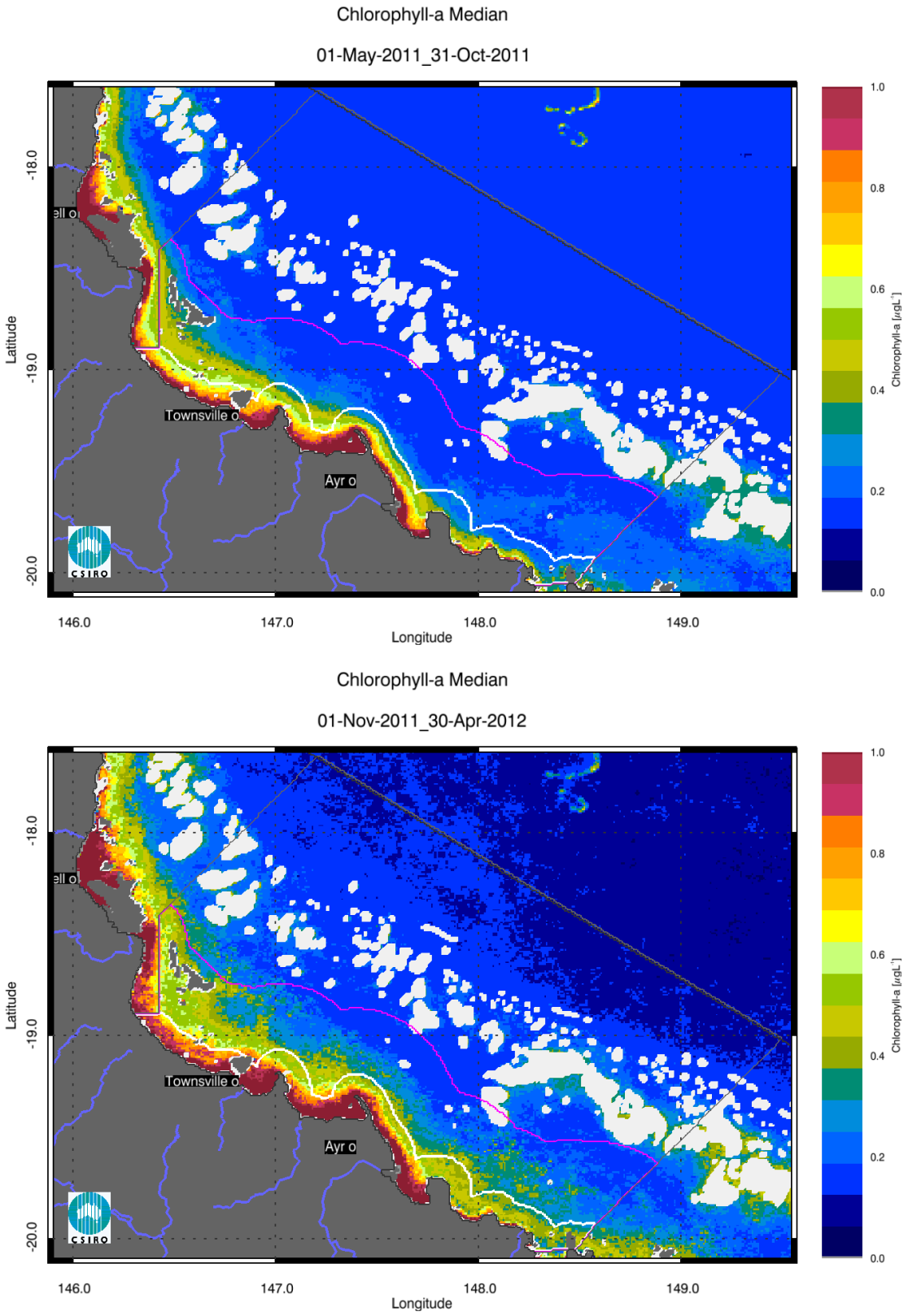


Figure 52. Chlorophyll-a median maps for the dry and wet season for the Burdekin region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll–a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

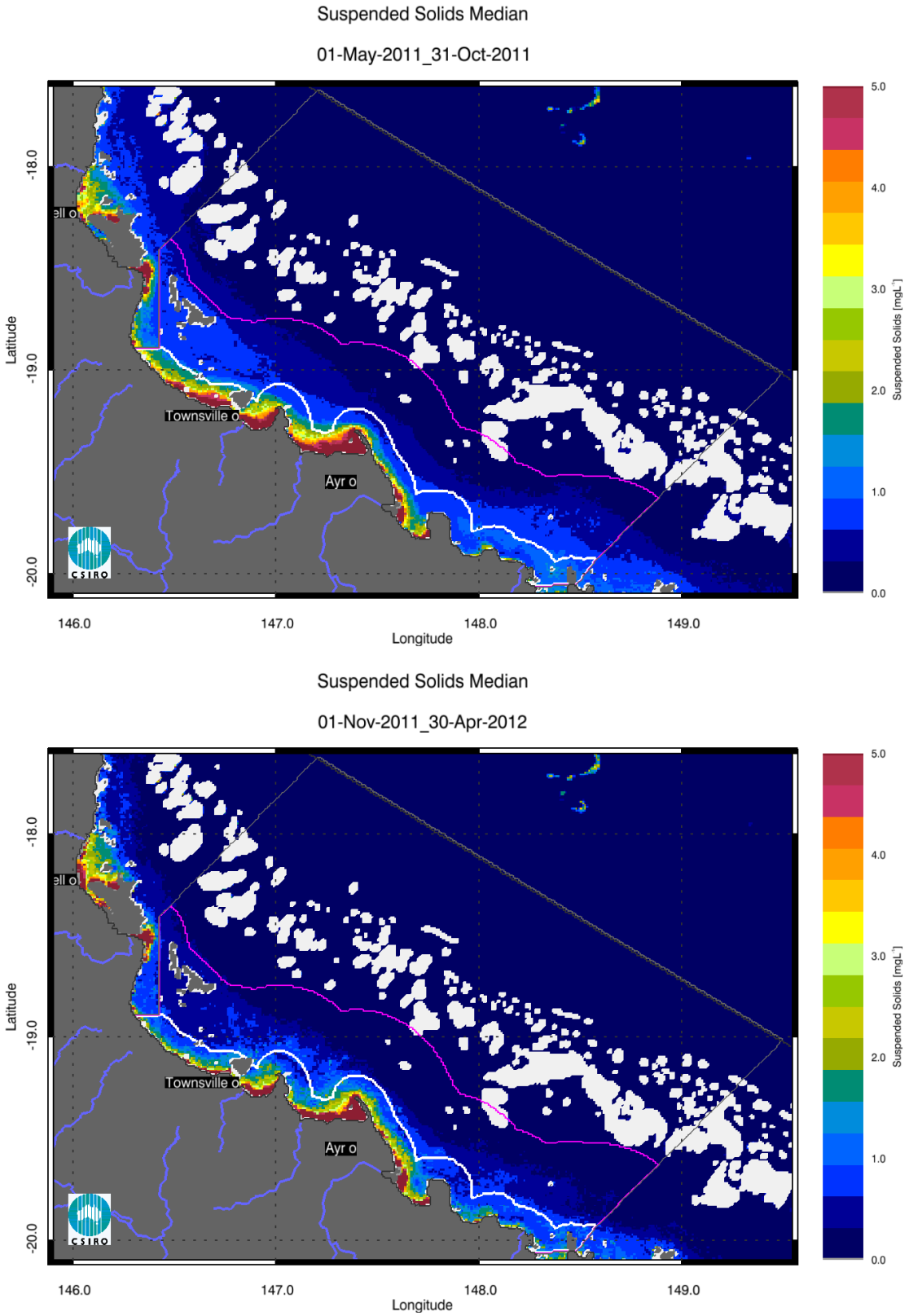


Figure 53. Non-algal particulate matter (NAP as a measure of TSS) median maps for the dry and wet season for the Burdekin region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

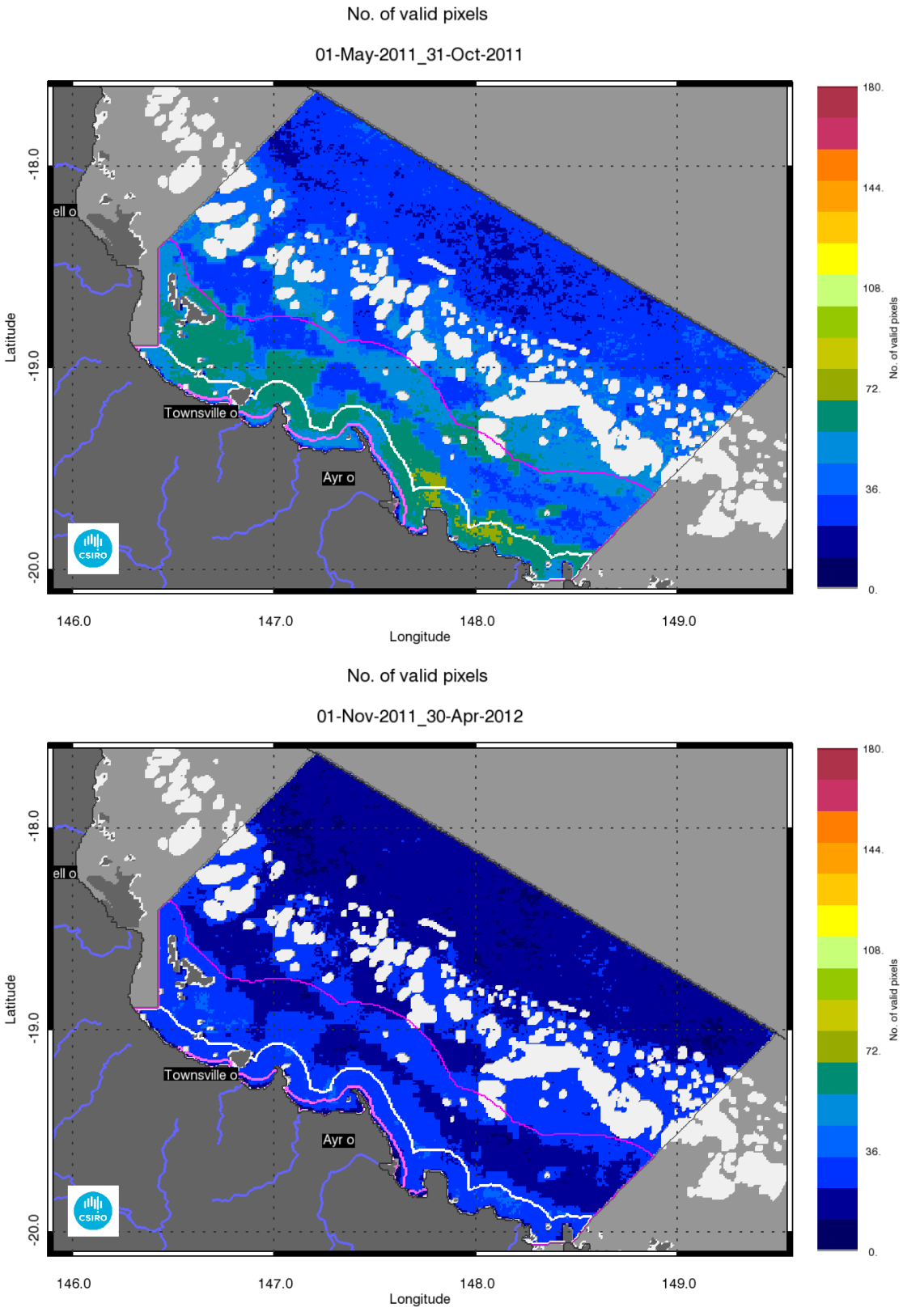
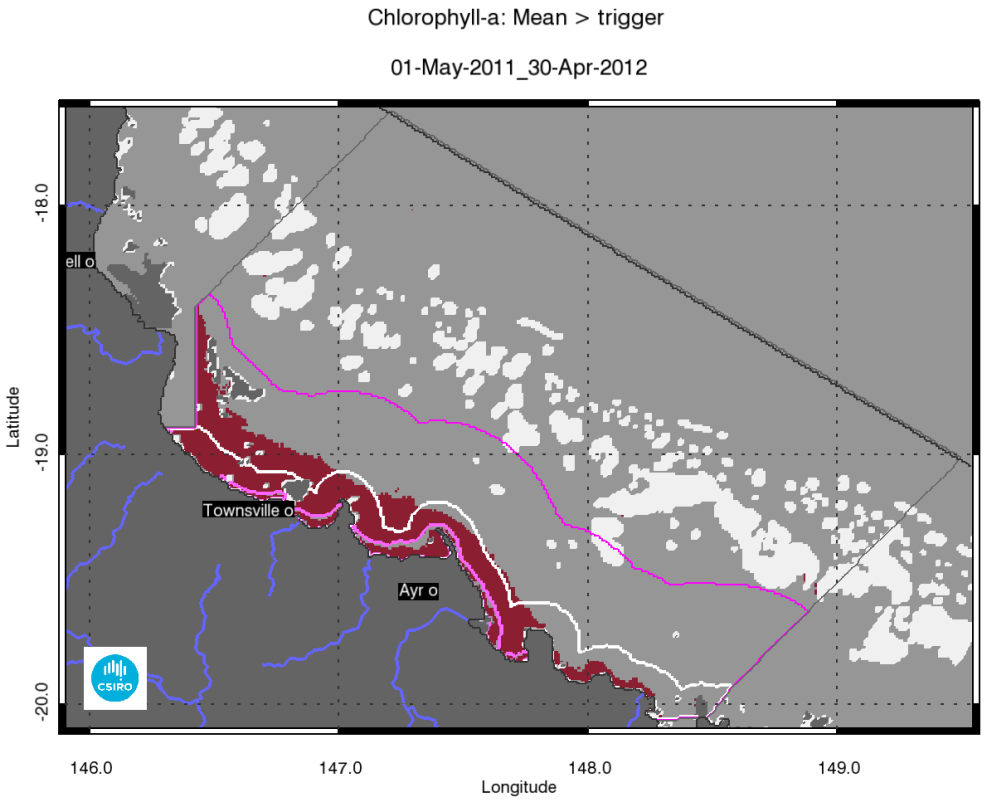


Figure 54. Number of observations used to calculate the median maps (Figure 52 - Figure 53) for the dry and wet season for the Burdekin region. The first map presents the number of observations available for analysis in the dry season 2011 (May - October), while the second map presents the number of observations available for analysis in the wet season 2011/2012 (November 2011 - April 2012).



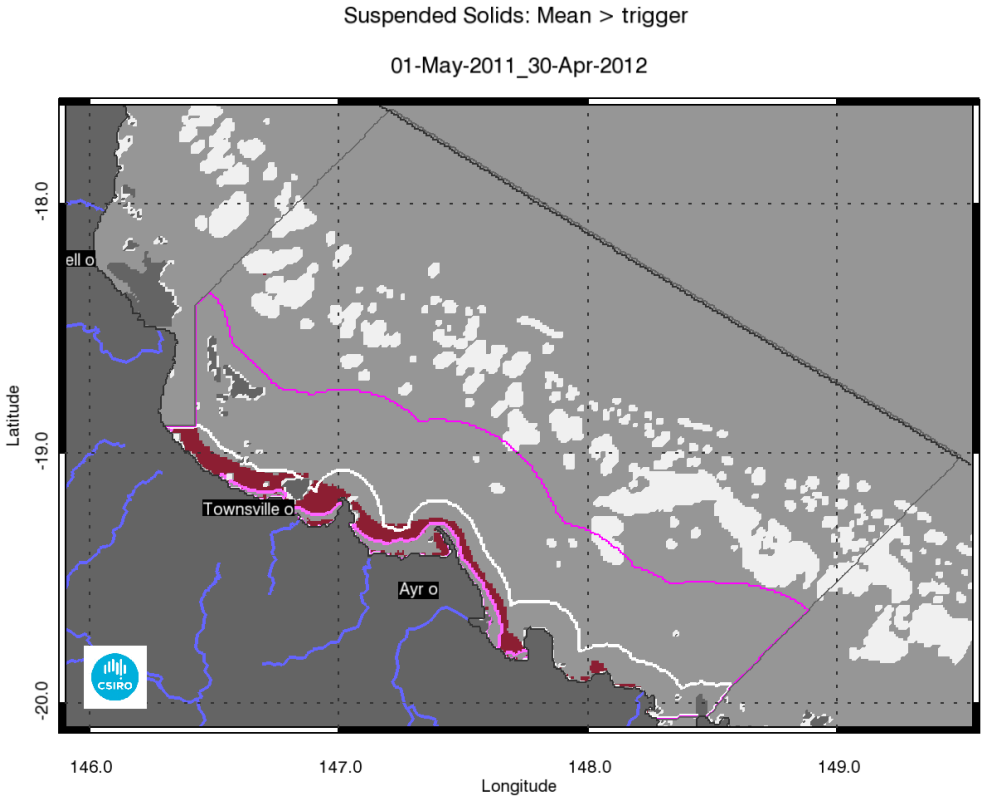


Figure 55. Exceedance maps for the Burdekin region for the reporting year 2011/12 (May 2011 –April 2012). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (NAP as a measure of TSS) exceedance map. The Guideline values for annual means of Chlorophyll–a are 0.45 µg L^{-1} for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore, while for TSS are 2.0 and 0.7 mg L^{-1}.

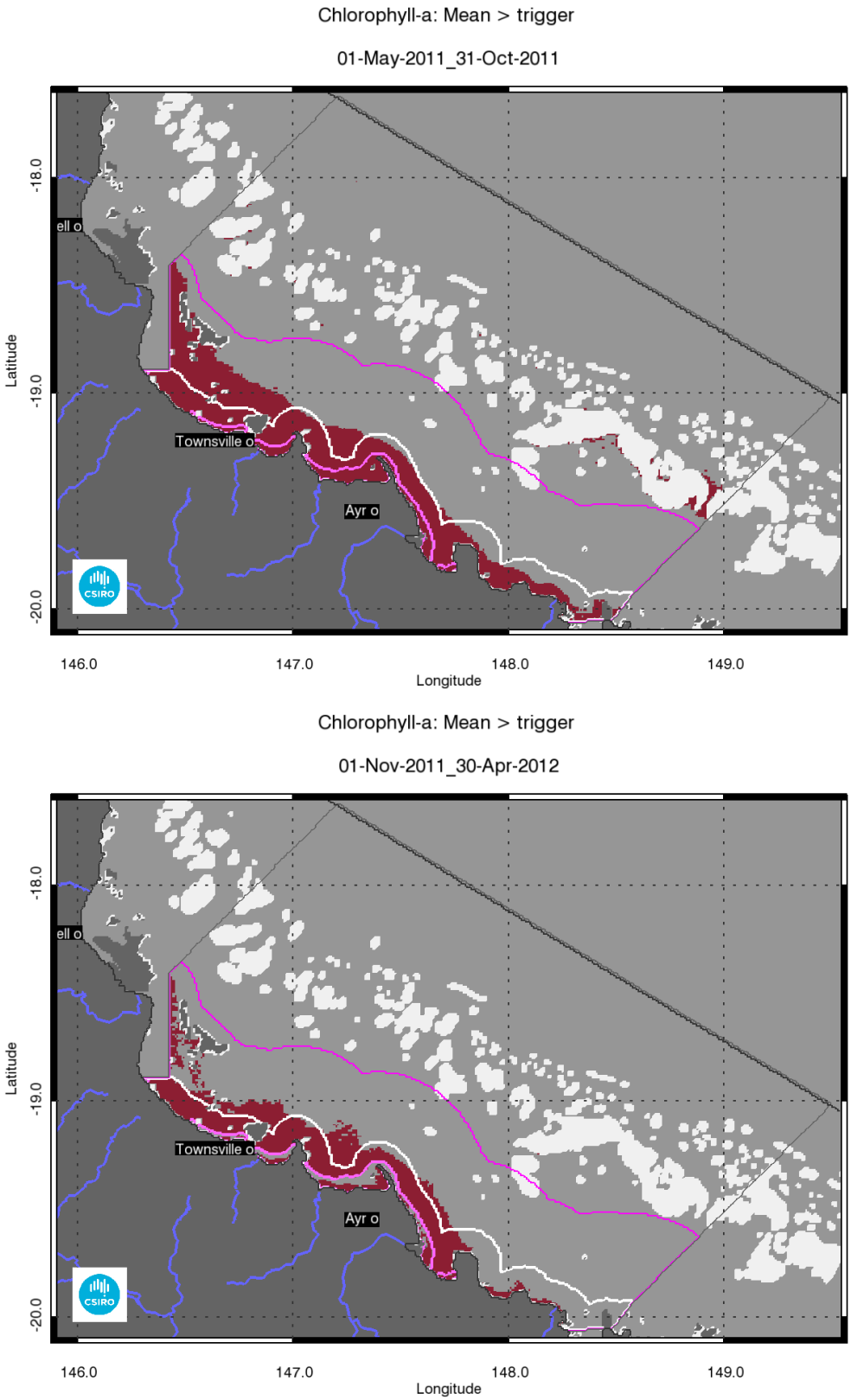


Figure 56. Chlorophyll-a exceedance maps for the dry and wet season for the Burdekin region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll –a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

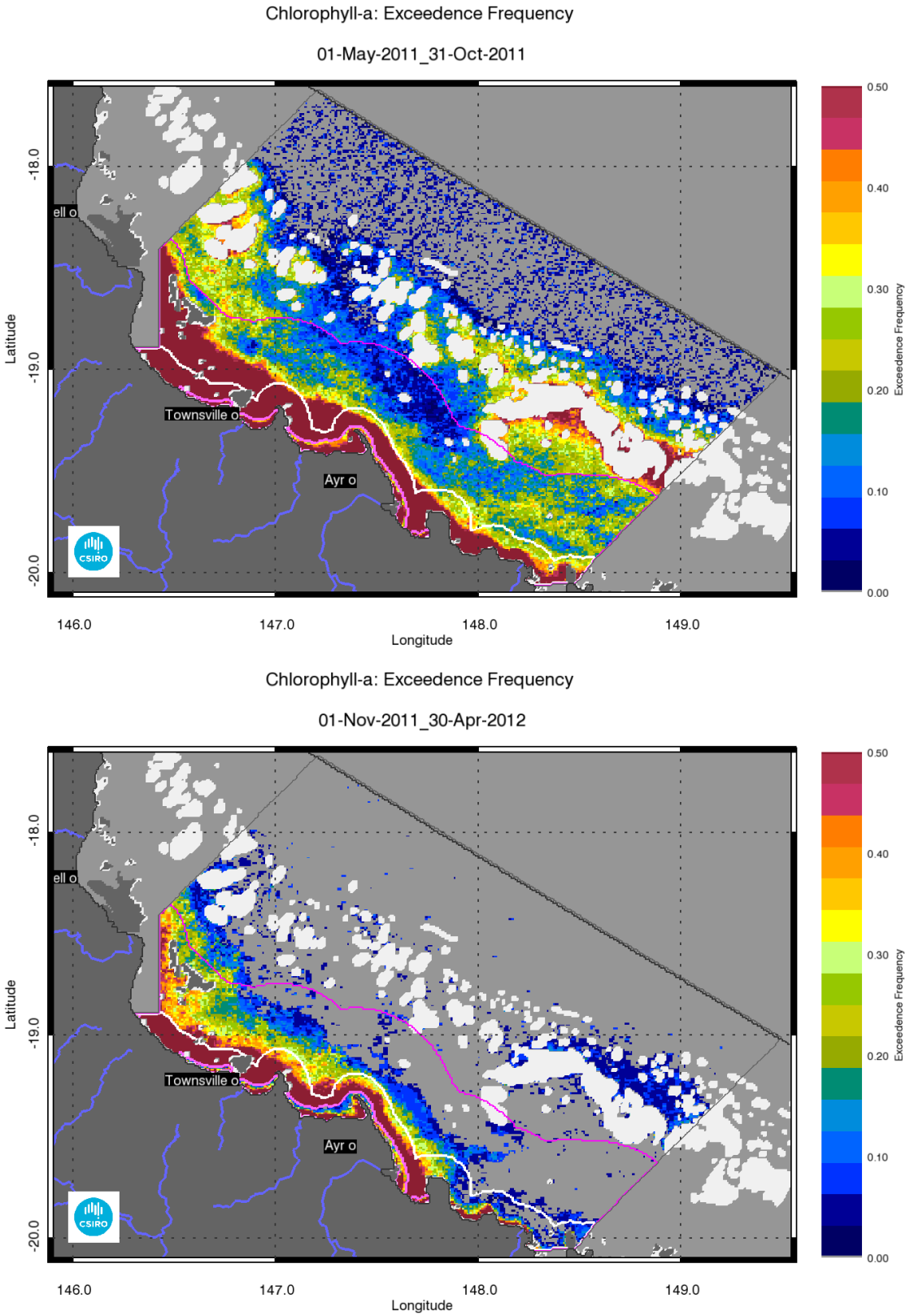


Figure 57. Chlorophyll-a exceedance frequency maps for the dry and wet season for the Burdekin region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll–a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

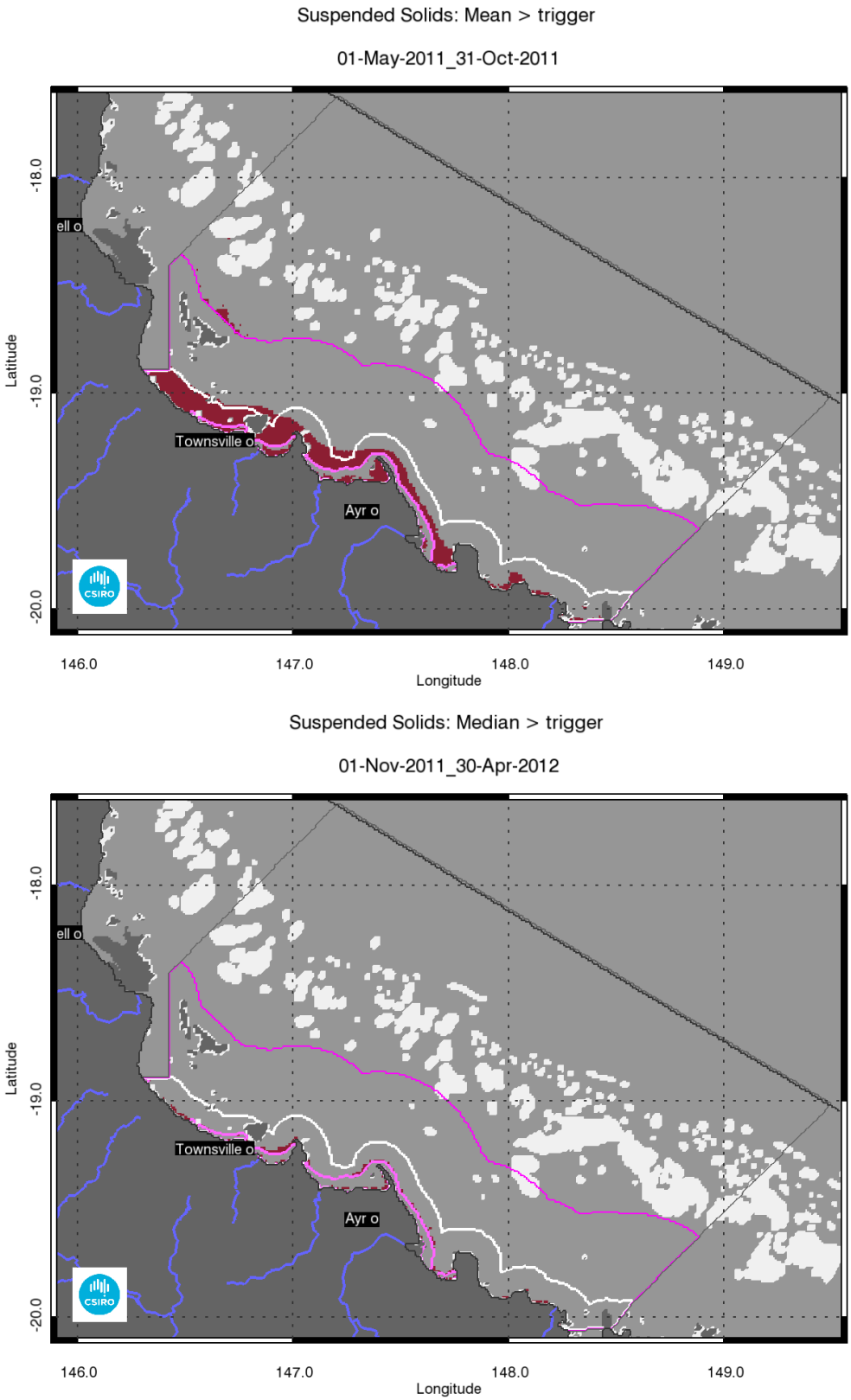


Figure 58. Non-algal particulate matter (NAP as a measure of TSS) exceedance maps for the dry and wet season for the Burdekin region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

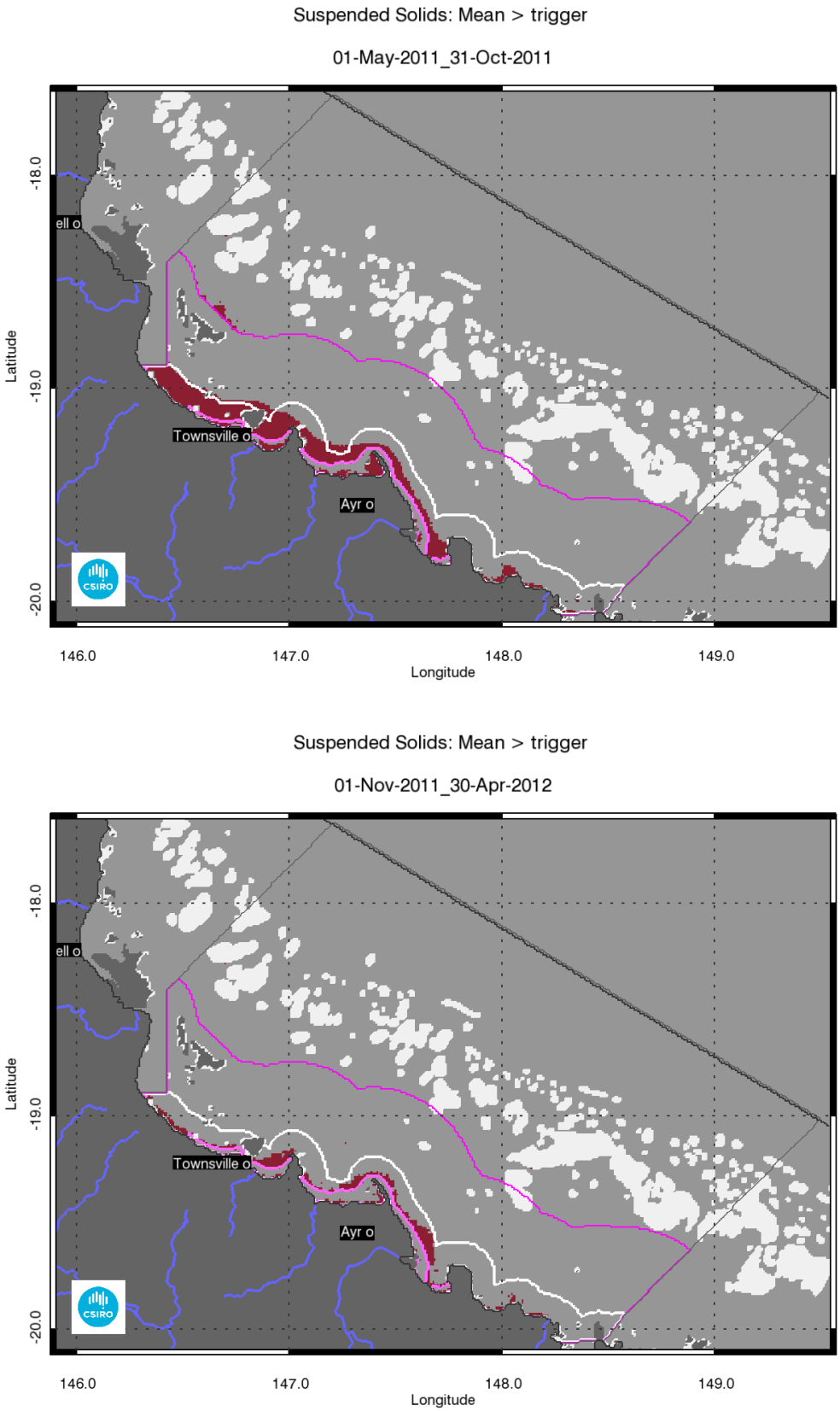


Figure 59. Non-algal particulate matter (NAP as a measure of TSS) exceedance frequency maps for the dry and wet season for the Burdekin region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012).

4.5 Regional reports: Mackay Whitsunday region

The Mackay Whitsunday Region is located in the central section of the GBR and comprises three major river catchments, the Proserpine, O'Connell (both flowing into Repulse Bay) and Pioneer catchments. The climate in this region is wet or mixed wet and dry and the catchment land use is dominated by agriculture such as grazing and cropping (mainly sugarcane on coastal plains), and minor urbanisation (Johnson et al. 2011). The adjacent coastal and inshore marine areas have a large number of high continental islands with well-developed fringing reefs.

4.5.1 Assessment of freshwater extent during the wet season

Figure 62 reports the freshwater extent for wet season 2011/2012 (November 2011- April 2012) for the Mackay Whitsunday region. The freshwater extent was estimated by applying a threshold of 0.24 m^{-1} for the CDOM seasonal maximum. For the Mackay-Whitsunday region the freshwater extent for the wet season 2011/2012 (November 2011- April 2012) was 2793 km^2, 3522km^2 for 2010/11 while in the wet season 2009/2010 was 4281 km^2 (Figure 60). The larger freshwater extents for 2010/2011 and 2009/10 correlates with a freshwater discharge for the Proserpine, O'Connell, Pioneer and Plane Rivers above median flows for both years (R^2=0.591, Figure 60, Figure 17). High CDOM values and associated estimated freshwater extents in the Southern part on this reporting region are most likely due to the flood events occurring in the Fitzroy River.

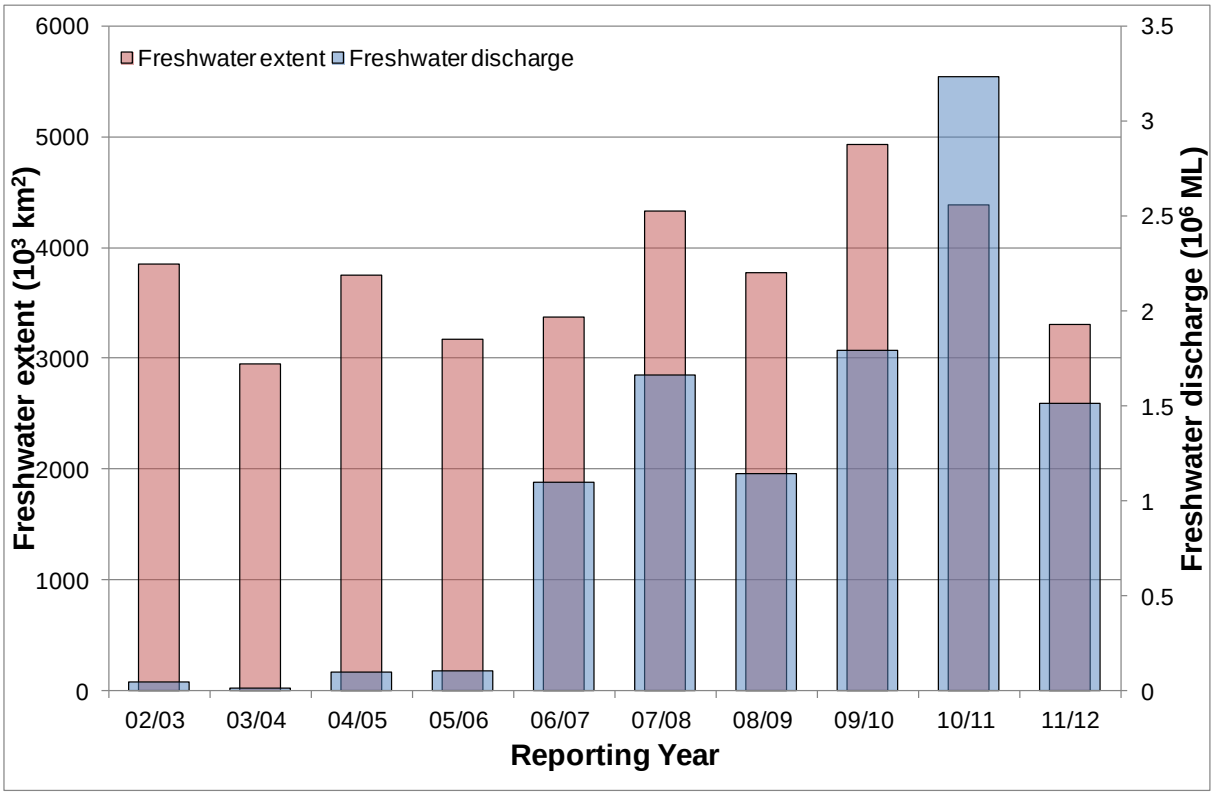


Figure 60. Freshwater discharge and estimated freshwater extent for the Mackay Whitsunday region based on the CDOM maximum for the wet seasons.

4.5.2 The wet and dry season median maps for Chlorophyll-a and Total Suspended Solids.

The wet and dry season CHL median maps (Figure 63) for the Mackay Whitsunday region show high CHL median concentrations near the coast and in the estuary to lower concentrations towards the East. Median CHL values ranging from 0.4 to 0.5 μgL^{-1} extended beyond the coastal to inshore boundary for both seasons. The median values in the Offshore region in the reef matrix ranged from ~0.15-0.25 μgL^{-1}. In the Midshelf and Offshore areas a ~50 km wide band of waters on the western side of the reef matrix showed higher values in the dry season (~0.4 μgL^{-1}) than in the wet season (~0.3 μgL^{-1}).

The wet and dry season median NAP maps (as a measure of Total Suspended Solids) (Figure 64) for the Mackay Whitsunday region show a coastal band ~5-10 km wide with values higher than 1.5-2.0 mgL^{-1} in the dry season and 2.5-3.0 mgL^{-1} in wet season. The high concentrations shown in Broad Sound and Shoalwater Bay are likely to be overestimated. The accuracy of the retrieval from MODIS imagery in these shallow and turbid waters systems cannot be assessed as there is no data available for parameterization and validation. The number of observations per each location available for calculating the median values varies from 30 to 40 observations for the wet season and about 50-70 for the dry season for each pixel location (Figure 65).

4.5.3 Assessment of the marine water quality index and the exceedance of water quality guidelines

The marine water quality for this reporting year for the Mackay Whitsunday region was scored as "moderate", reflecting a "moderate" score for P2R_CHL and P2R_TSS (Figure 61). The marine water quality index has been oscillating in the "good" score band from the 2002/03 to 2009/10 reporting seasons. The P2R_CHL scores were "good" between the 2002/03 and the 2009/10 reporting seasons, while the P2R_TSS scores were "good" from 2002/03 and the 2009/10. For the Mackay Whitsunday region, there was some correlation between the decrease in the marine water quality index as well as the component scores for the last five years with the freshwater discharges from the Proserpine, O'Connell and Pioneer catchments and the associated estimated freshwater plume extents (Figure 60).

The Enclosed Coastal marine water body accounts for ~20% of the inshore waters used for P2R reporting and for most of the area in Port of Bowen, Repulse Bay and Broad Sound (Table 5, Figure 2). In this water body, the annual mean CHL values exceeded the guideline value (2.0 μgL^{-1}) for 26%, while the seasonal means exceeded for 38% and 21 % per the dry and wet season respectively. For TSS in 57% of the Enclosed coastal area exceedance were recorded, while the seasonal means exceeded for 63% and 50 % per the dry and wet season respectively.

For the Mackay Whitsunday region the annual mean CHL values exceeded the guideline value (0.45 μgL^{-1}) for 46 % of the Open Coastal area and 6% of the Midshelf areas (Figure 66, Table 27). The mean CHL values exceeded the Guidelines values for 90% of the Open Coastal area in the dry season and 28 % in the wet season. The mean CHL values exceeded the Guidelines in the wet season only in a ~5-km wide coastal band extending to ~10 km, corresponding to the river mouths of Proserpine, O'Connell, Pioneer and Plane Rivers. In the dry season EG for CHL was observed for 24 % of the Midshelf close to the Open Coastal/Midshelf boundary and for 22% of the Offshore areas within the Reef matrix (Figure 67, Table 28). Similar exceedance values were retrieved if the median was used for the assessment (i.e. for EF > 0.50 in Figure 68, Table 27, Table 28).

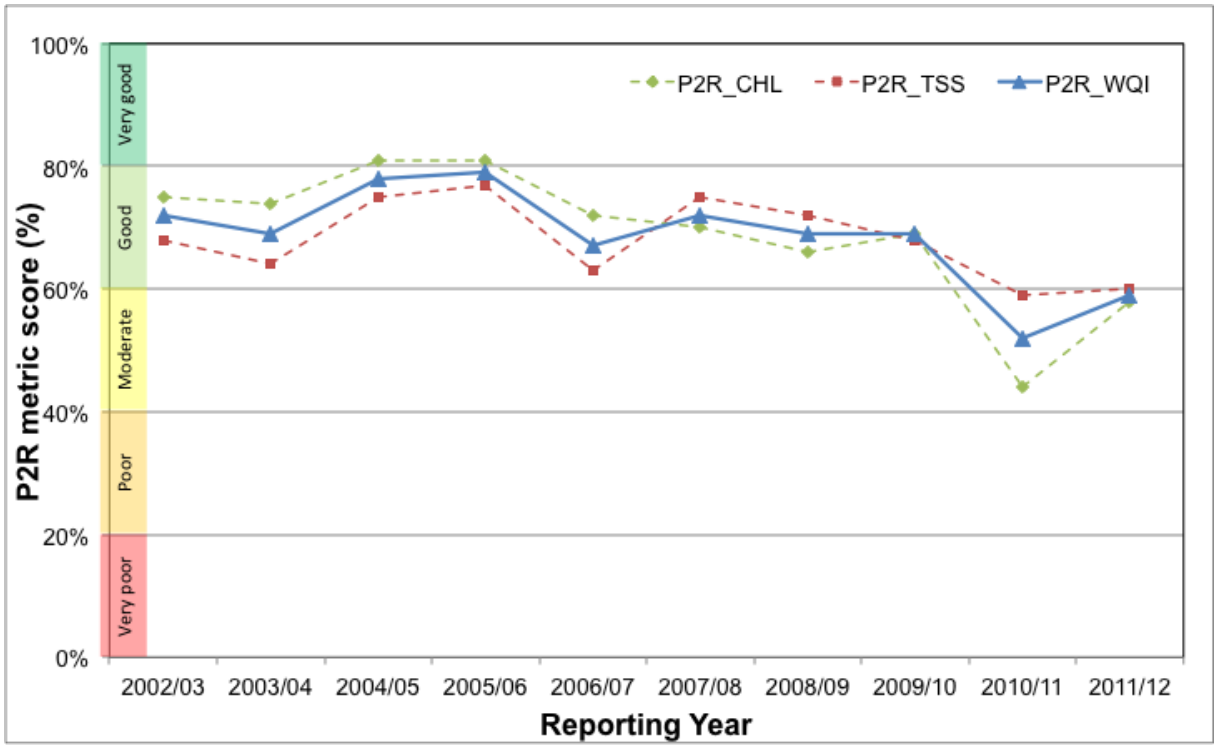


Figure 61. Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) for the Mackay Whitsunday region based on the assessment of exceedance to the Guidelines.

The mean values of TSS exceeded the Guidelines values for 55 % of the Open Coastal area in the dry season and 26 % in the wet season, and for 6-14% of the Midshelf and Offshore areas in the dry and wet seasons. The estimated exceedance for the all areas was significantly lower for the median values that those for the mean values (Figure 70, and Table 29). Over the whole year, EG was recorded for TSS in 35% of the Open Coastal, 40% of the Midshelf and 8% of Offshore areas (Figure 66, Table 27). The spatial patterns in exceedance in Figure 66 and Figure 69 were affected by the coastal to offshore gradients that can be observed in the median maps (Figure 63, Figure 64) and by the steep changes in trigger values between the Midshelf and Offshore areas (Table 3 and Table 4).

Table 30 and Table 31 report the Summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EF for that period. These metrics are based on a high number of observations (ranging from 90 thousand valid observations for Open Coastal area in the wet season to over 1.1 million for the Offshore area in the dry season). According to these metrics both the mean and the median CHL values exceeded the Guidelines values for the Open Coastal area in both seasons, while the mean TSS concentrations exceeded the Guidelines values for the Open Coastal area and Offshore area in both seasons. The mean and median values for the TSS concentration differed substantially (for all water bodies and seasons). The mean values were ~ 2-3 times higher than medians.

Table 27 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Mackay-Whitsunday region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, IS: Inshore, MS: Midshelf, OS: Offshore), , "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

-		01-May-2011_30-Apr-2012		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
EC	925	60113	324675	26%	14%	57%	34%
OC	3651	296878	1281501	46%	39%	35%	15%
IS	4576	356991	1606176	42%	34%	40%	19%
MS	11389	827097	3997539	6%	5%	8%	6%
OS	25580	1582624	8978580	1%	1%	6%	4%

Table 28. Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Mackay Whitsunday region (Figure 67, Figure 68). Column and row labels are described in the legend of Table 27.

MCKY-B09		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	925	41970	152625	38%	18%	18143	172050	21%	15%
OC	3651	203029	602415	90%	85%	93849	679086	28%	22%
IS	4576	244999	755040	80%	71%	111992	851136	26%	21%
MS	11389	568500	1879185	24%	21%	258597	2118354	2%	2%
OS	25580	1028995	4220700	22%	25%	553629	4757880	0%	0%

Table 29. Summary of the exceedance maps for Non-algal particulate matter (NAP as a measure of TSS) for the dry and wet season for the Mackay Whitsunday region (Figure 69, Figure 70). Column and row labels are described in the legend of Table 27.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	925	41970	152625	63%	39%	18143	172050	50%	34%
OC	3651	203029	602415	55%	24%	93849	679086	26%	10%
IS	4576	244999	755040	56%	27%	111992	851136	31%	15%
MS	11389	568500	1879185	14%	9%	258597	2118354	6%	4%
OS	25580	1028995	4220700	8%	6%	553629	4757880	6%	4%

Table 30. Summary of Chlorophyll-a exceedance for the dry and wet season for the Mackay Whitsunday region. “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels) for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, MS: Midshelf, OS: Offshore), , "Number total obs." provides the total number of observations. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 1.4/2.8 µg L^{-1} for Enclosed Coastal, 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	41970	152625	1.33	0.72	21%	18143	172050	1.61	0.94	16%
OC	203029	602415	**0.44**	**0.39**	64%	93849	679086	0.58	0.50	32%
MS	568500	1879185	0.28	0.24	34%	258597	2118354	0.37	0.35	7%
OS	1028995	4220700	0.23	0.19	33%	553629	4757880	0.26	0.21	3%

Table 31. Summary of Non-algal particulate matter (NAP as a measure of TSS) exceedance for the dry and wet season for the Mackay Whitsunday region. Column and row labels are described in the legend Table 23. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for TSS for the dry/wet season means are 4/6 mg L^{-1} for Enclosed Coastal, 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	41970	152625	**6.55**	2.66	40%	18143	172050	**6.14**	2.62	27%
OC	203029	602415	**2.23**	1.21	36%	93849	679086	2.19	1.35	22%
MS	568500	1879185	1.47	0.95	22%	258597	2118354	1.30	0.76	14%
OS	1028995	4220700	0.30	0.21	12%	553629	4757880	0.29	0.17	6%

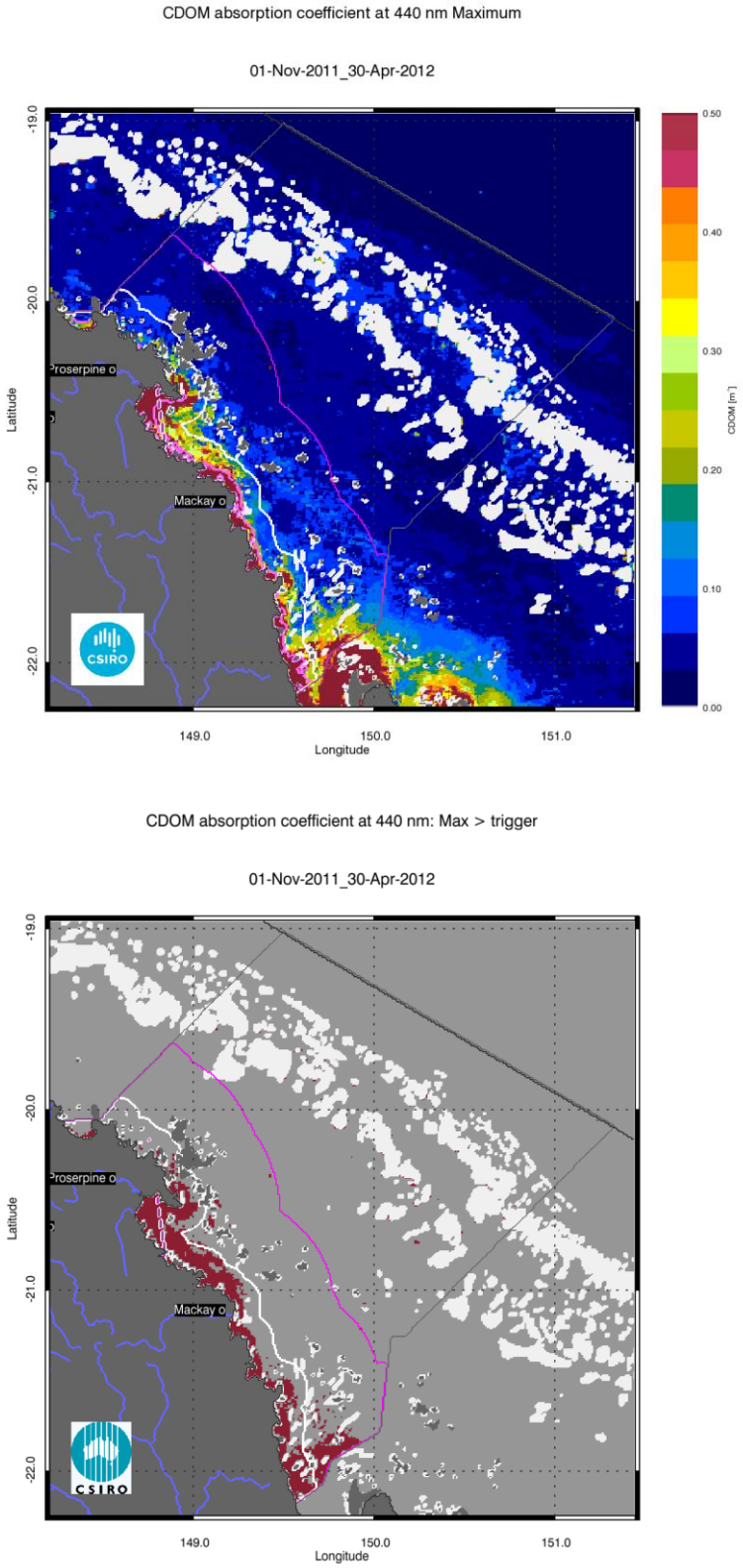


Figure 62. Map of freshwater extent for the wet season for the Mackay Whitsunday region. The first map presents the maximum value of CDOM for the wet season 2011/2012 (November 2011 - April 2012), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.24 m^{-1}.

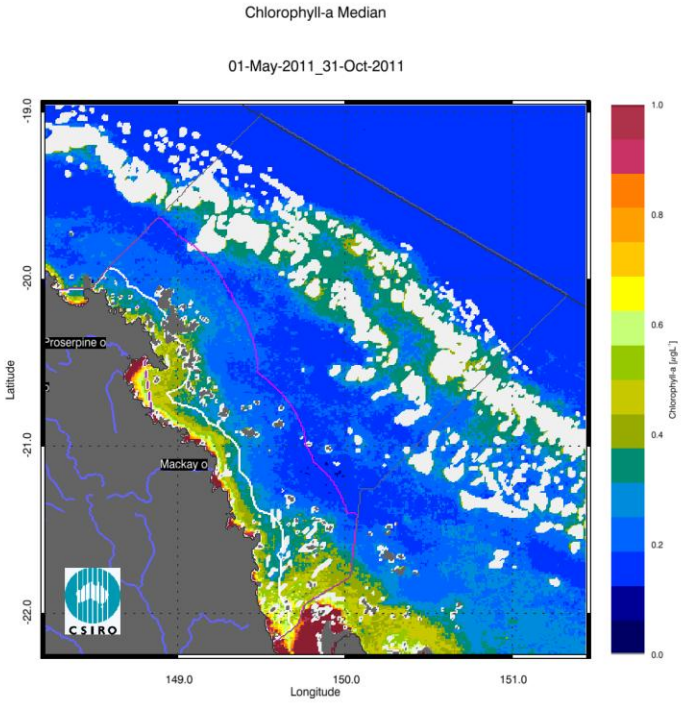
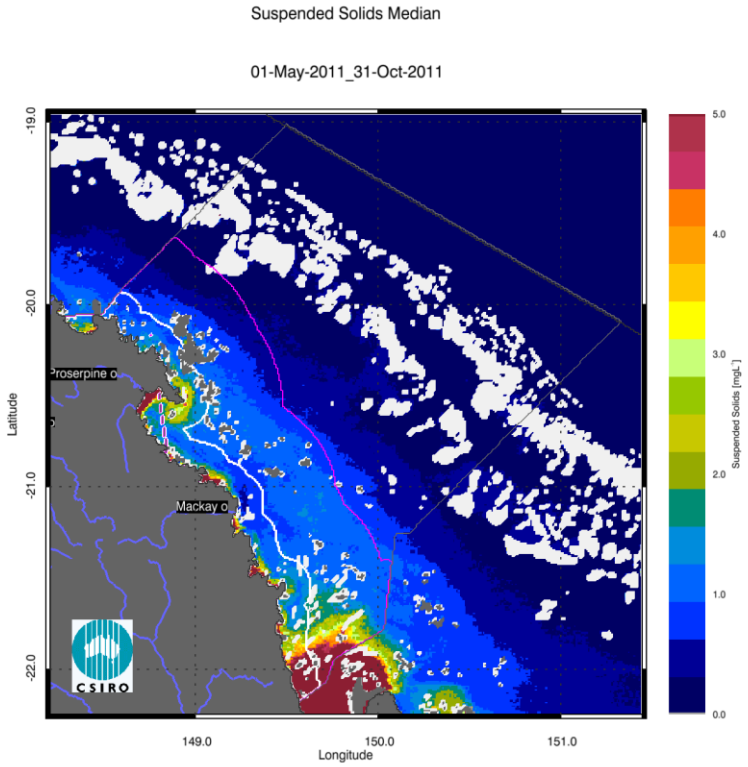


Figure 63. Chlorophyll-a median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.



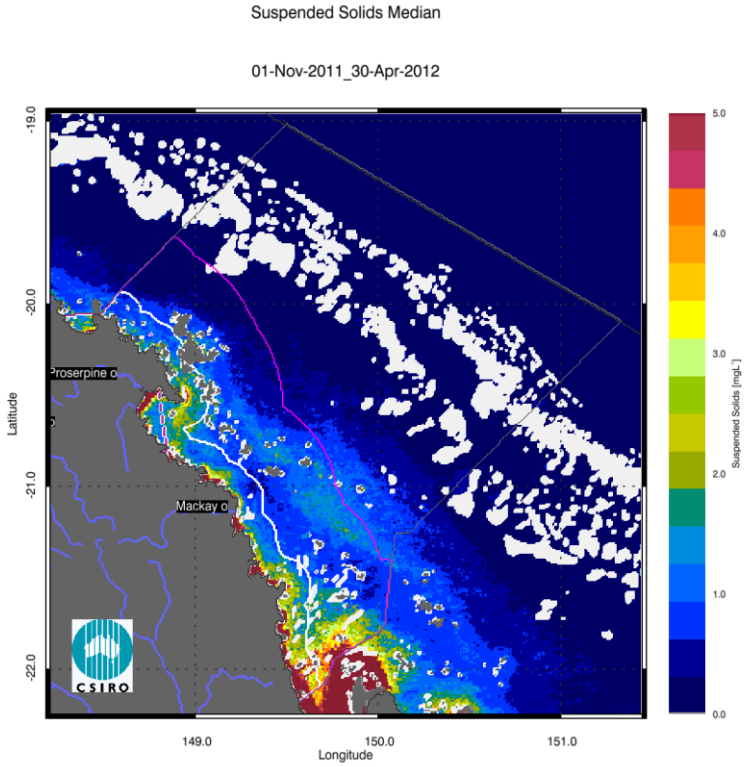
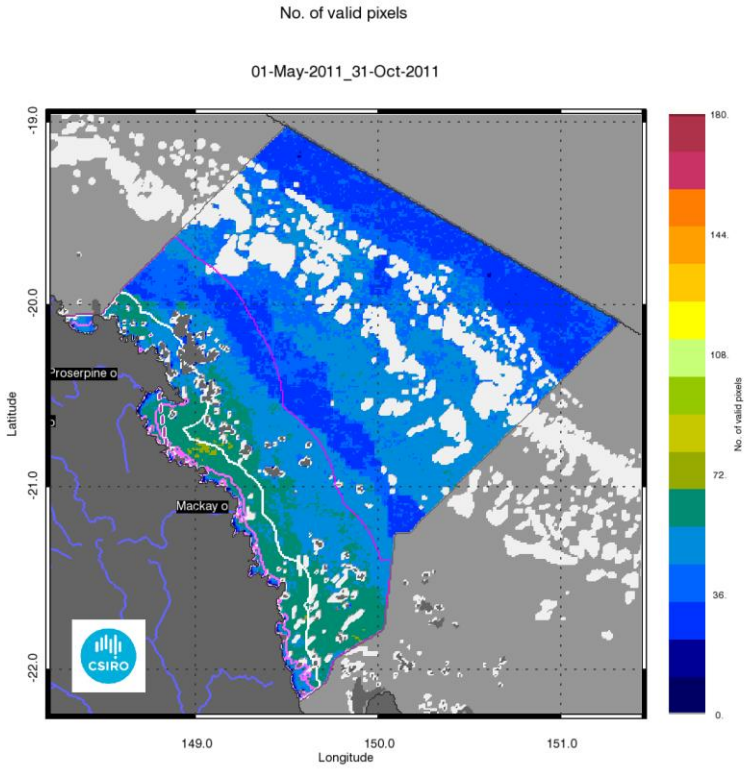


Figure 64. Non-algal particulate matter (NAP as a measure of TSS) median maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).



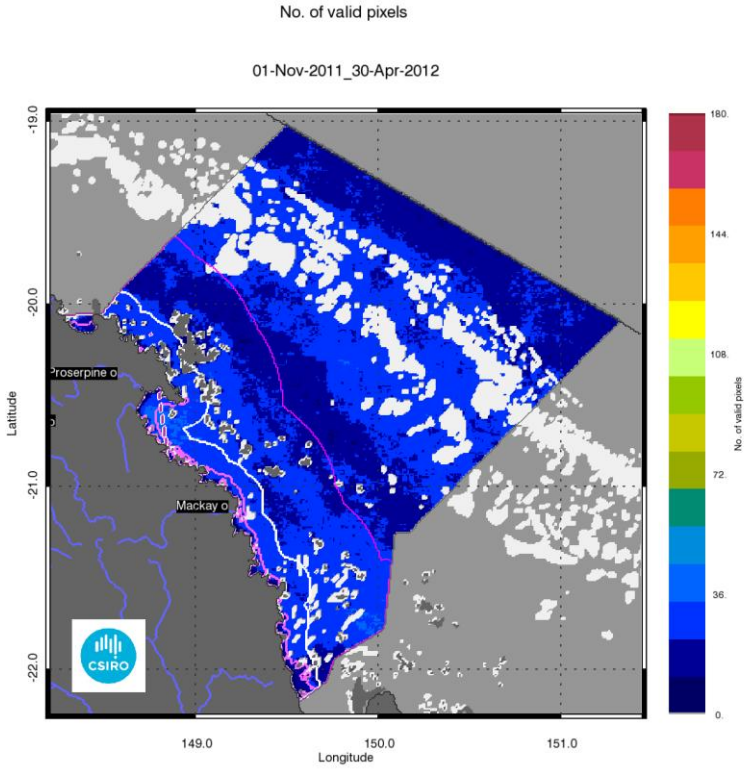
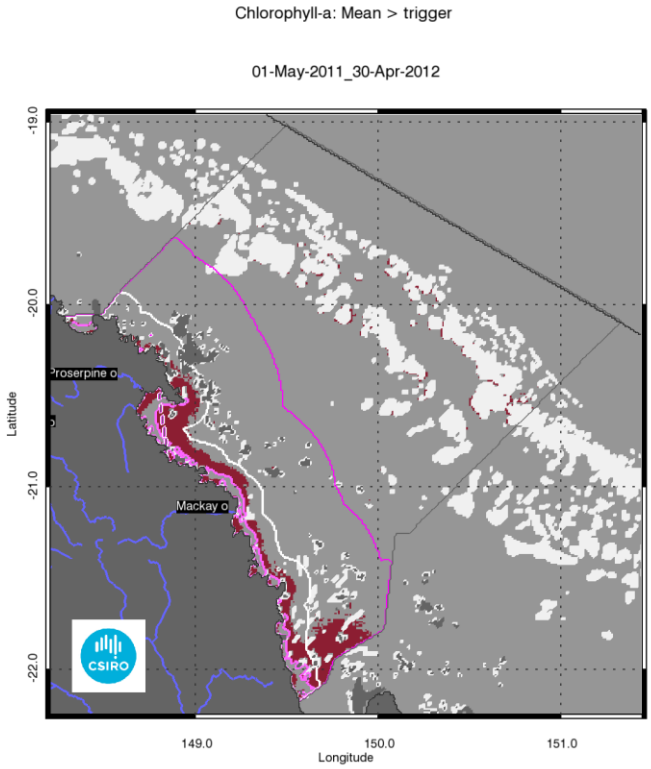


Figure 65. Number of observations used to calculate the median maps (Figure 63 - Figure 64) for the dry and wet season for the Mackay Whitsunday region. The first map presents the number of observations available for analysis in the dry season 2011 (May - October), while the second map presents the number of observations available for analysis in the wet season 2011/2012 (November 2011 - April 2012).



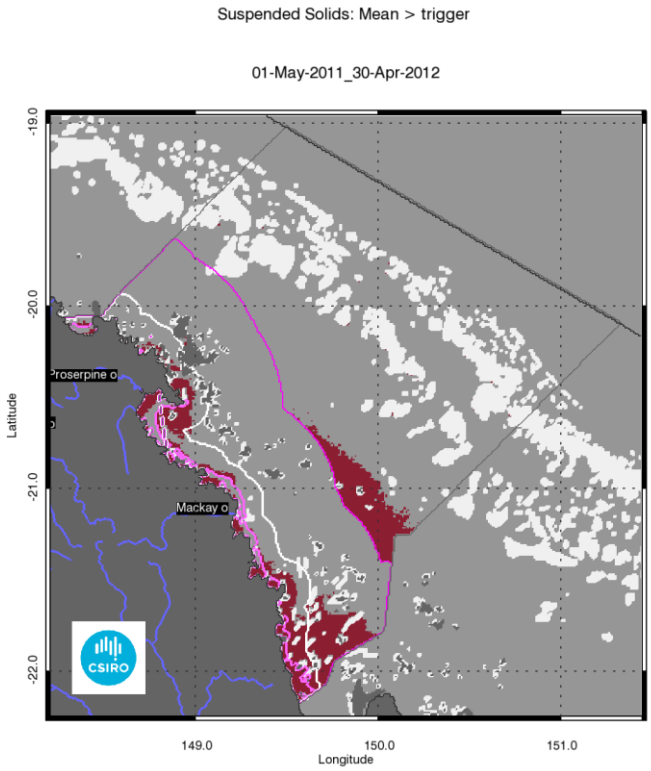
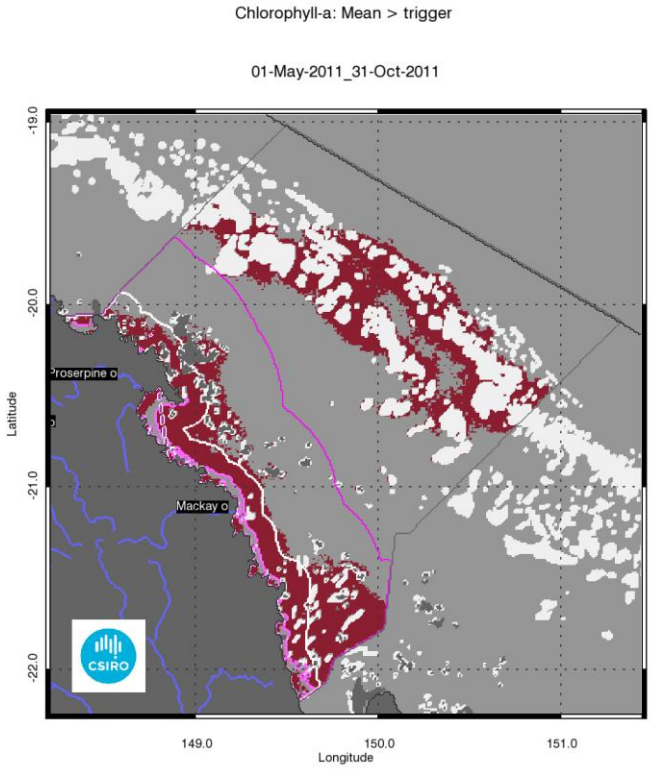


Figure 66. Exceedance maps for the Mackay Whitsunday region for the reporting year 2011/12 (May 2011 –April 2012). The first map presents the exceedance map, while the second map presents the Non-algal particulate matter (NAP as a measure of TSS) exceedance map. The Guideline values for annual means of Chlorophyll-a are 0.45 µg L^{-1} for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore, while for TSS are 2.0 and 0.7 mg L^{-1}.



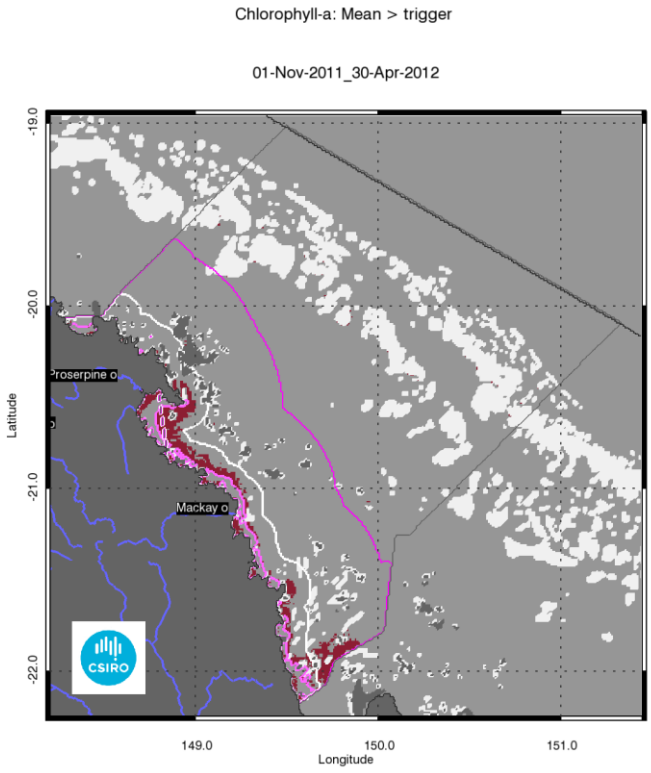
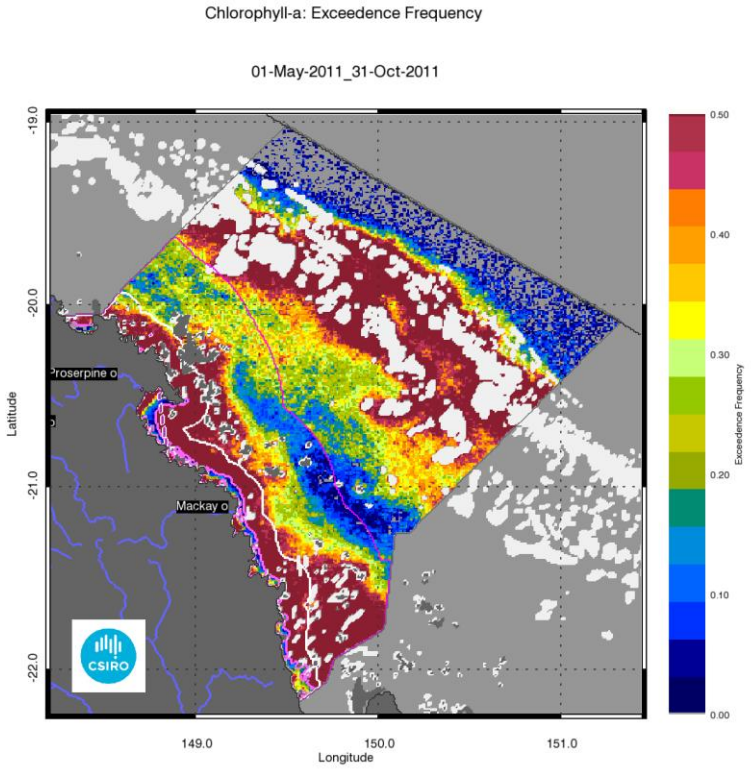


Figure 67. Chlorophyll-a exceedance maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.



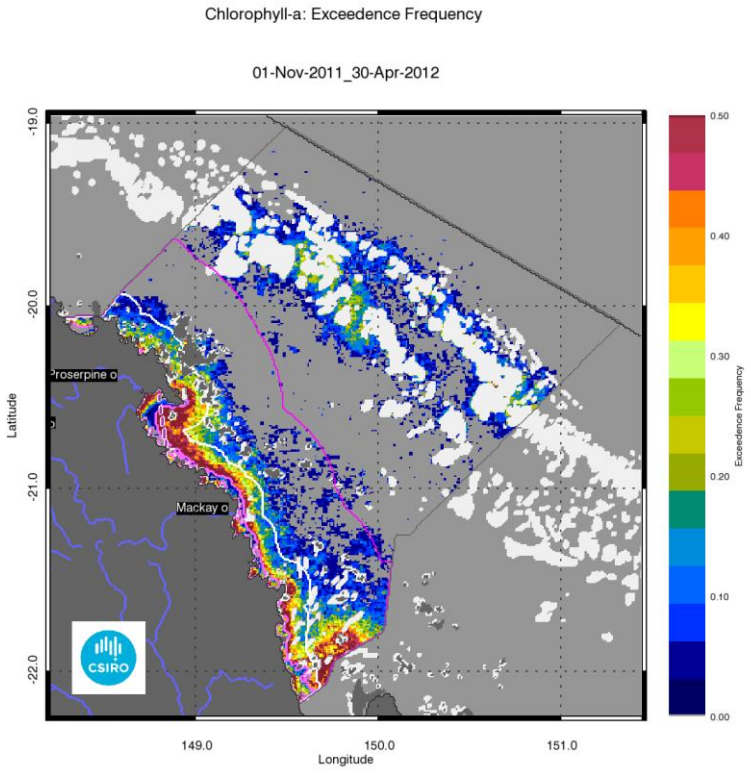
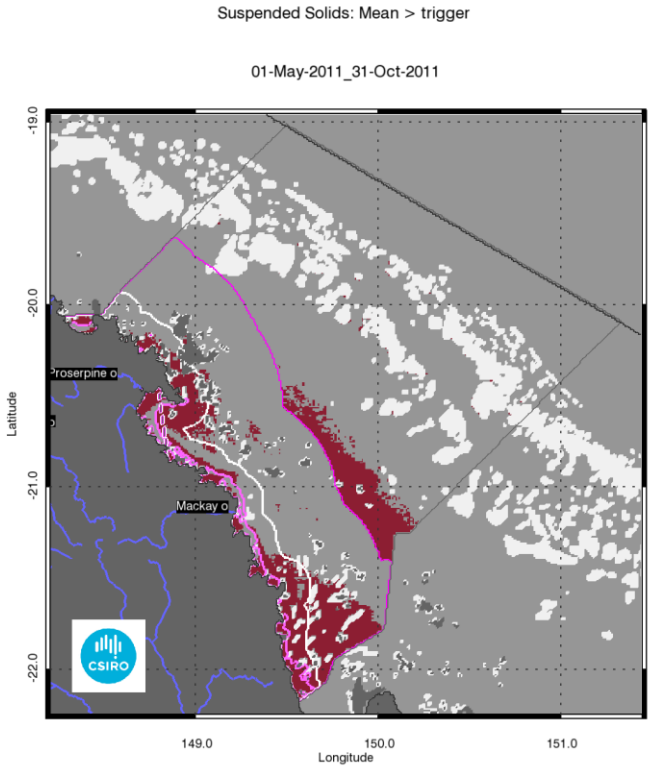


Figure 68. Chlorophyll-a exceedance frequency maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.



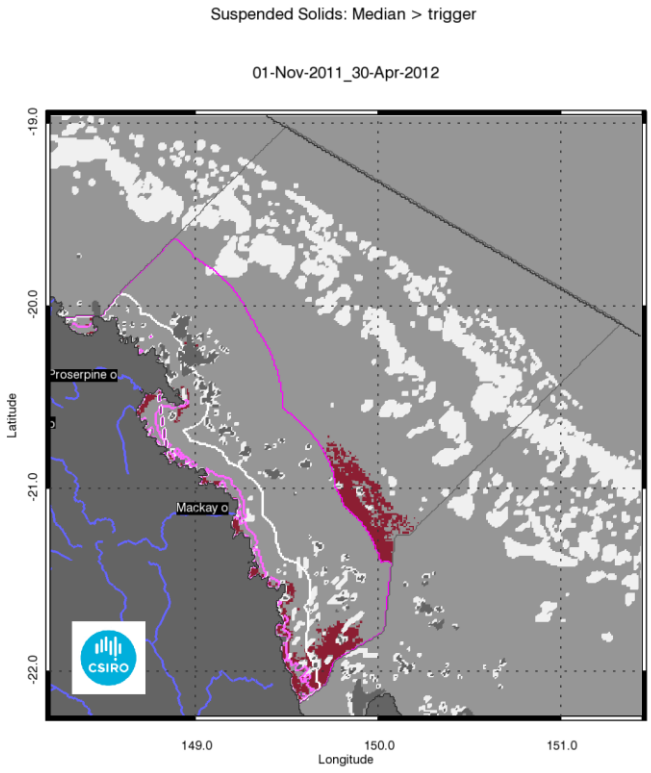
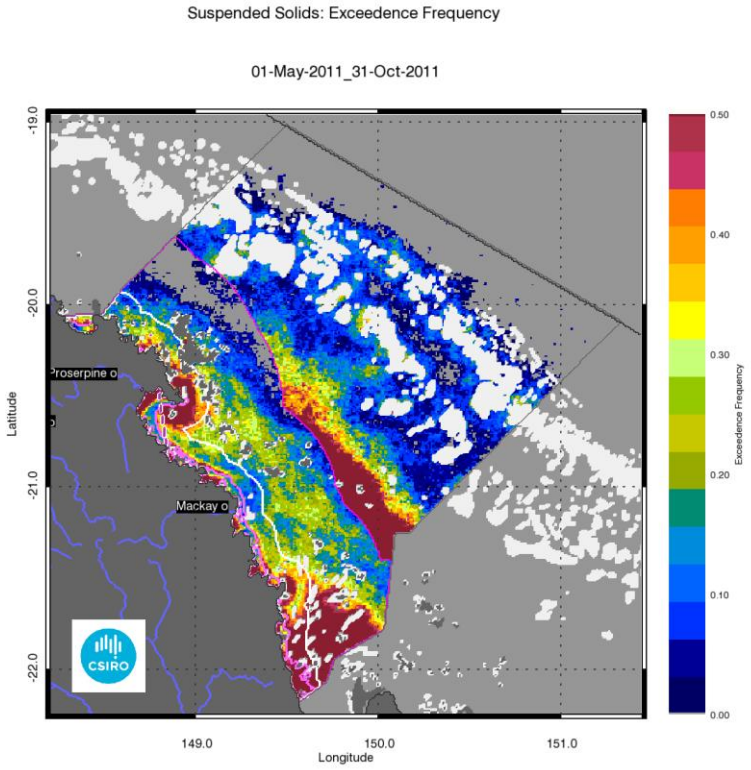


Figure 69. Non-algal particulate matter (NAP as a measure of TSS) exceedance maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012).



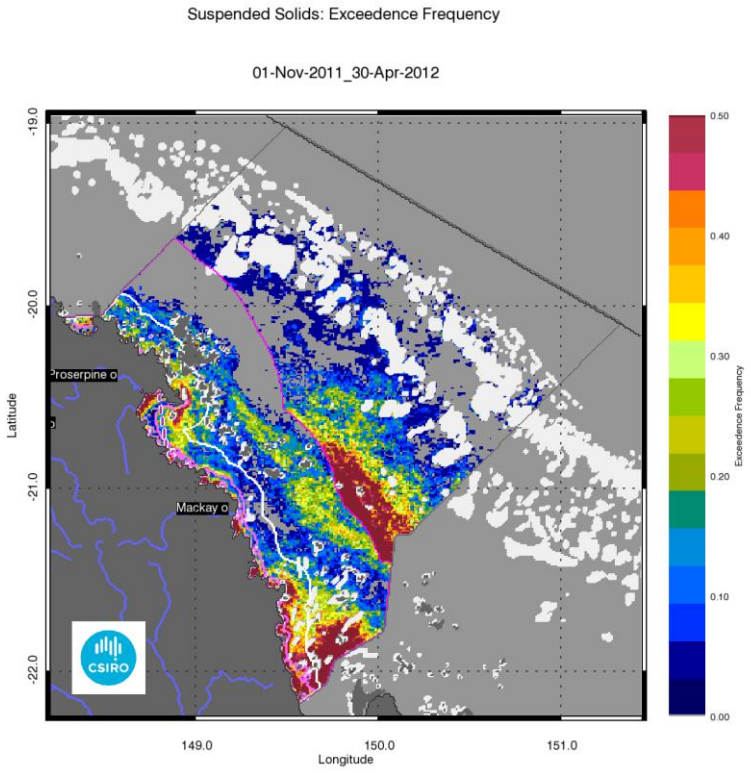


Figure 70. Non-algal particulate matter (NAP as a measure of TSS) exceedance frequency maps for the dry and wet season for the Mackay Whitsunday region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012).

4.6 Regional reports: Fitzroy Region

The Fitzroy Region is one of the two large dry tropical catchment regions in the GBR Region with cattle grazing as the primary land use (Brodie et al. 2003). Fluctuations in climate and cattle numbers greatly affect the state and nature of vegetation cover, and therefore, the susceptibility of soils to erosion, which leads to runoff of suspended sediments and associated nutrients (Johnson et al. 2011). The main river system influencing the region is the Fitzroy River. A strong gradient in water quality exists between the reefs in this region with increasing distance from both the coast and Fitzroy river mouth.

4.6.1 Assessment of freshwater extent during the wet season

This year's freshwater discharge for the Fitzroy River was almost 3 times above the long term median flow slightly larger than the 1991 floods and three times flows of the 2007/08 and 2009/10 wet seasons (Figure 17). The estimated freshwater extent for the whole was highly correlated to the total freshwater discharges (R^2=0.725, Figure 71): the estimated freshwater extent was 6399 km^2, 7978 km^2 for the wet season 2010/11, while in the wet season 2009/10 was 6555 km^2 (Figure 71). High CDOM values and associated estimated freshwater extent in the southern part on this reporting region are most likely due to also to a contribution by flood events occurring in Baffle Creek and other coastal streams in the Burnett Mary region.

4.6.2 The wet and dry season median maps for Chlorophyll-a and Total Suspended Solids.

The wet and dry season median CHL maps (Figure 74) for the Fitzroy Estuary –Keppel Bay region show high CHL near the coast and in the estuary to lower concentrations towards the east. Median CHL values of chlorophyll-a to 0.5 μgL^{-1} extended as far as the Bunker group for both seasons. Median values of ~ 0.3 μgL^{-1} were observed in the offshore area particularly in the Swain group.

The wet and dry season median NAP maps (as a measure of TSS) (Figure 75) show values higher than 3 mgL^{-1} for a coastal band ~10 km wide, up to 50 km north of the river mouth for the wet season, while during the dry season values were higher than 3.0 mgL^{-1} only for the area close to the river mouth. Towards the northeast of Shoalwater Bay and Broad Sound increased levels of non-algal particulate matter reach out further into the lagoon. High concentrations of NAP may be related to the strong tidal regime and re-suspension in the area. It is also likely that bottom visibility affects the accuracy of the retrieval for the shallow portion of these embayments. Care must be taken in interpreting the results for Shoalwater Bay and Broad Sound as the retrieval algorithm from the MODIS imagery was not parameterised nor validated for these waters

The maps in Figure 76 present the number of observations available for calculating the median values for each season. This amount varies from 30 to about 50 for each season for each pixel location.

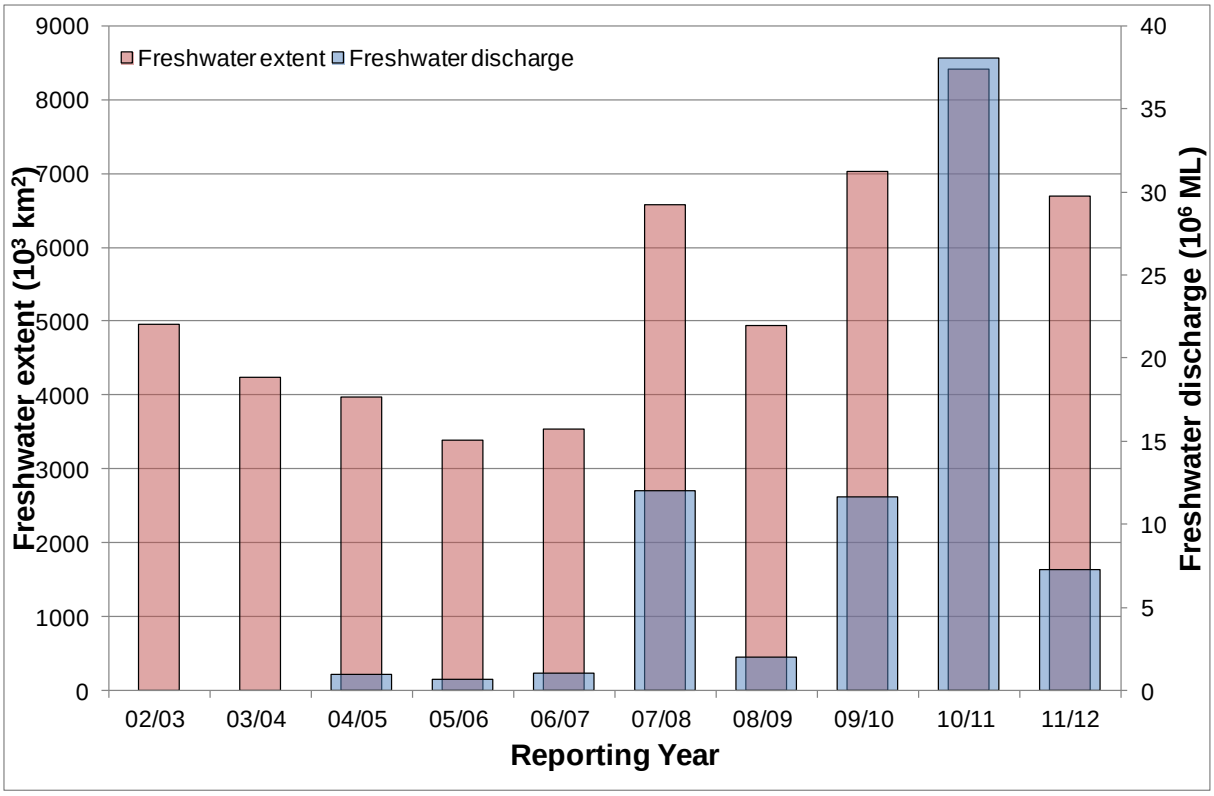


Figure 71. Freshwater discharge and estimated freshwater extent for the Fitzroy region based on the CDOM maximum for the wet seasons. Freshwater discharge was nil in 2002/2003 and 2003/2004 wet seasons.

4.6.3 Assessment of the marine water quality index and the exceedance of water quality guidelines

The marine water quality for this reporting year for the Fitzroy region was scored as "poor", reflecting a "very poor" score for P2R_CHL and "moderate" for P2R_TSS (Figure 72). The marine water quality index and the component scores have been steady as "moderate" since the 2002/03 to the 2010/11 reporting seasons. Over the last decade the P2R_CHL score declined from "moderate" (2002/03 - 2007/08) to "poor" (2007/08 - 2010/11) and "very poor" in response to the large flood conditions of the Fitzroy river and the associated estimated freshwater plumes extending beyond Keppel Bay (Figure 71, Figure 73).

The Enclosed Coastal marine water body accounts for ~23% of the inshore waters used for P2R reporting and for most of the area in Keppel Bay, Port Curtis and in Broad Sound (Table 5, Figure 2). The annual mean CHL values exceeded the guideline value (2.0 μgL^{-1}) for 89% of these waters; the seasonal mean CHL values exceeded the Guidelines values for 93% and 67% in the dry and wet season respectively. The annual mean TSS values exceeded the guideline value (15.0 mgL^{-1}) for 66% of these waters, while the seasonal mean TSS values exceeded the seasonally adjusted Guidelines values for 71% and 47% in the dry and wet season respectively.

For the Fitzroy region the annual mean CHL values exceeded the guideline value (0.45 μgL^{-1}) for 81% of the Open Coastal area and 8% of the Midshelf area (Figure 77, Table 32). The seasonal mean CHL values exceeded the Guidelines values for 94% of the Open Coastal Area in the dry season and 65% in

the wet season. In the dry season CHL also exceeded the Guidelines for 22 % of the Midshelf and 8% of the Offshore areas (Figure 78, Table 33). Similar exceedance values were retrieved if the median was used for the assessment (i.e. when EF >0.50 in Figure 79, Table 32, Table 33). The seasonal mean values of TSS exceeded the Guidelines values for 39% of the Open Coastal Area in the dry season and 35 % in the wet season (Figure 80 and Table 34). Over the whole year, exceedance of TSS Guideline values was recorded in 35% of the Open Coastal (Figure 77, Table 32). In the seasonal EF maps (Figure 81), low exceedance was recorded for the Midshelf and Offshore areas in both seasons if either the mean or the median was used for the assessment (Figure 80, Figure 81 and Table 34).

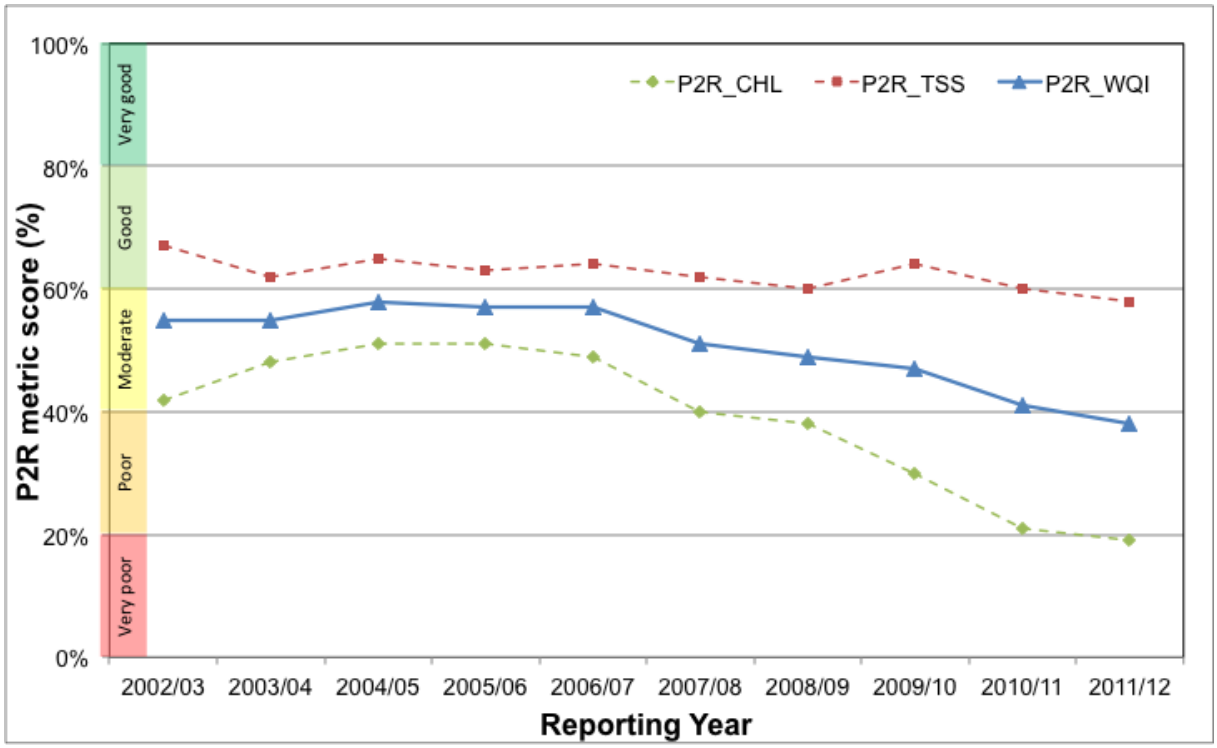


Figure 72. Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) for the Fitzroy region based on the assessment of exceedance to the Guidelines.

As observed for other reporting regions, the spatial patterns in exceedance for both variables for the mean values (Figure 78, Figure 80) and the median values (Figure 79 and Figure 81) are affected by the coastal to offshore gradients that can be observed in the median maps (Figure 74, Figure 75) and by the steep changes in trigger values between the Midshelf and Offshore areas.

Table 35 and Table 36 report the summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EF for that period. These metrics are based on a high number of observations (ranging from 130 thousands valid observations for Open Coastal in the wet season to almost 2 million for the Offshore area in the dry season). According to these metrics both the mean and the median CHL values exceeded the Guidelines values for the all three water bodies in the dry season and in the Open Coastal area in the wet season. The mean and median values for the TSS concentration differed substantially (Table 36) for all regions and seasons. The mean values were ~ 2-3 times higher than medians. Only the mean values of TSS exceeded the Guidelines values for the Open Coastal areas for both seasons.

Table 32 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Fitzroy region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, IS: Inshore, MS: Midshelf, OS: Offshore), , "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

FITZ-B09		01-May-2011_30-Apr-2012		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
EC	1336	64806	510352	89%	70%	66%	62%
OC	4583	386548	1750706	79%	63%	35%	24%
IS	5919	451354	2261058	81%	64%	42%	32%
MS	18421	1440360	7036822	8%	6%	3%	2%
OS	48664	3074209	18589648	0%	0%	1%	0%

Table 33 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Fitzroy region (Figure 78, Figure 79). Column and row labels are described in the legend of Table 32.

FITZ-B09		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	1336	48576	244488	93%	78%	16230	265864	68%	59%
OC	4583	253522	838689	94%	86%	133026	912017	64%	57%
IS	5919	302098	1083177	94%	84%	149256	1177881	65%	57%
MS	18421	938111	3371043	22%	15%	502249	3665779	8%	8%
OS	48664	2114890	8905512	8%	11%	959319	9684136	0%	0%

Table 34 Summary of the exceedance maps for Non-algal particulate matter (NAP as a measure of TSS) for the dry and wet season for the Fitzroy region (, Figure 80, Figure 81).). Column and row labels are described in the legend of Table 32.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	1336	48576	244488	71%	66%	16230	265864	37%	33%
OC	4583	253522	838689	39%	29%	133026	912017	35%	24%
IS	5919	302098	1083177	47%	37%	149256	1177881	35%	26%
MS	18421	938111	3371043	4%	4%	502249	3665779	3%	2%
OS	48664	2114890	8905512	2%	1%	959319	9684136	1%	0%

Table 35. Summary of Chlorophyll-a exceedance for the dry and wet season for the Fitzroy region. “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels) for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, MS: Midshelf, OS: Offshore), , "Number total obs." provides the total number of observations. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 1.4/2.8 µg L^{-1} for Enclosed Coastal, 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	48576	244488	**3.08**	**2.56**	64%	16230	265864	**3.66**	**2.92**	52%
OC	253522	838689	**0.63**	**0.46**	74%	133026	912017	**0.91**	**0.70**	55%
MS	938111	3371043	0.29	0.24	34%	502249	3665779	0.43	0.37	18%
OS	2114890	8905512	0.23	0.18	29%	959319	9684136	0.23	0.19	2%

Table 36 Summary of Non-algal particulate matter (NAP as a measure of TSS) exceedance for the dry and wet season for the Fitzroy region. Column and row labels are described in the legend of Table 35. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for TSS for the dry/wet season means are 12/18 mg L^{-1} for Enclosed Coastal, 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	48576	244488	**19.81**	**14.96**	56%	16230	265864	14.10	10.60	29%
OC	253522	838689	**2.67**	0.85	32%	133026	912017	**2.54**	1.19	25%
MS	938111	3371043	0.79	0.39	6%	502249	3665779	0.71	0.32	4%
OS	2114890	8905512	0.23	0.17	6%	959319	9684136	0.19	0.14	2%

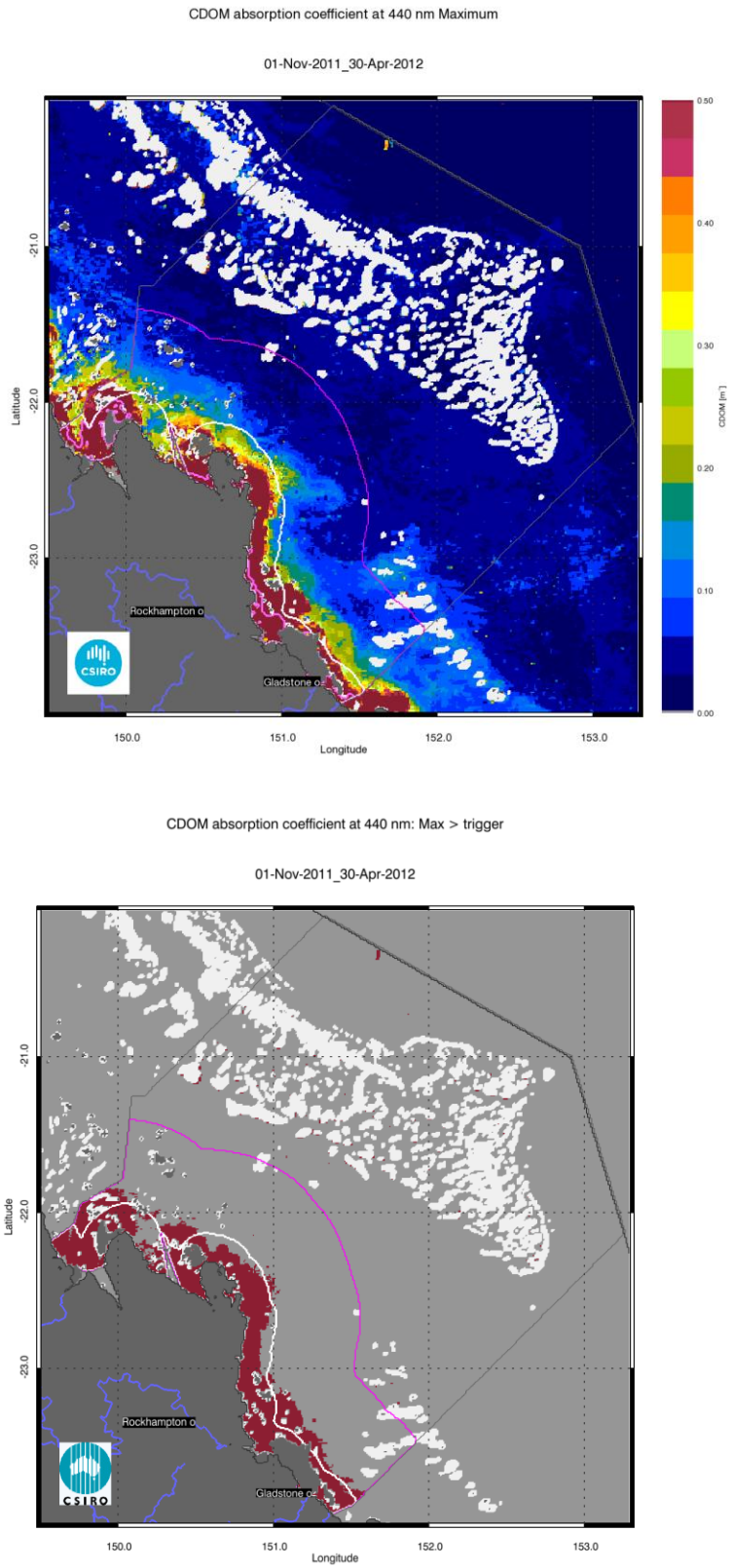
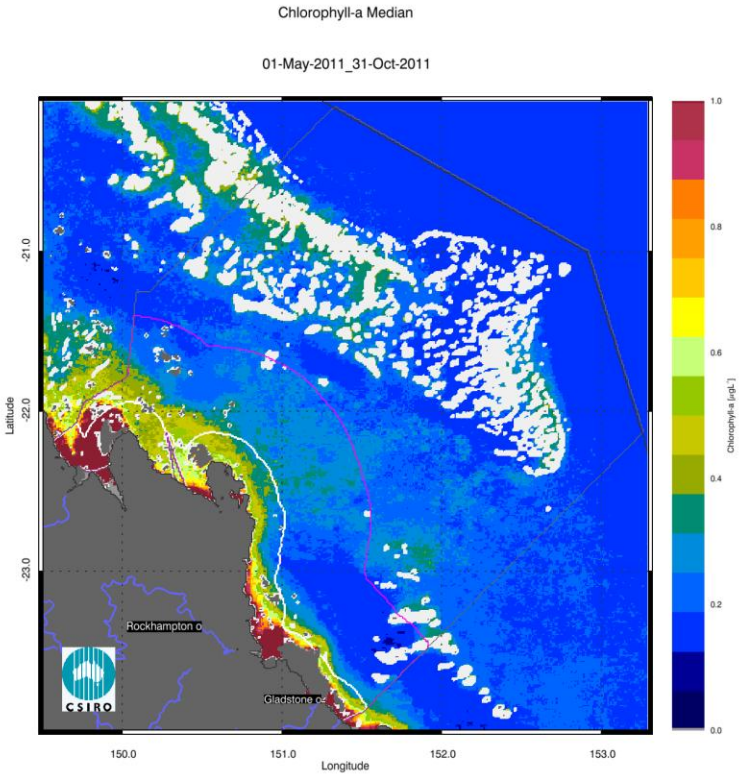


Figure 73. Map of freshwater extent for the wet season for the Fitzroy region. The first map presents the maximum value of CDOM for the wet season 2011/2012 (November 2011 - April 2012), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.24 m^{-1}.



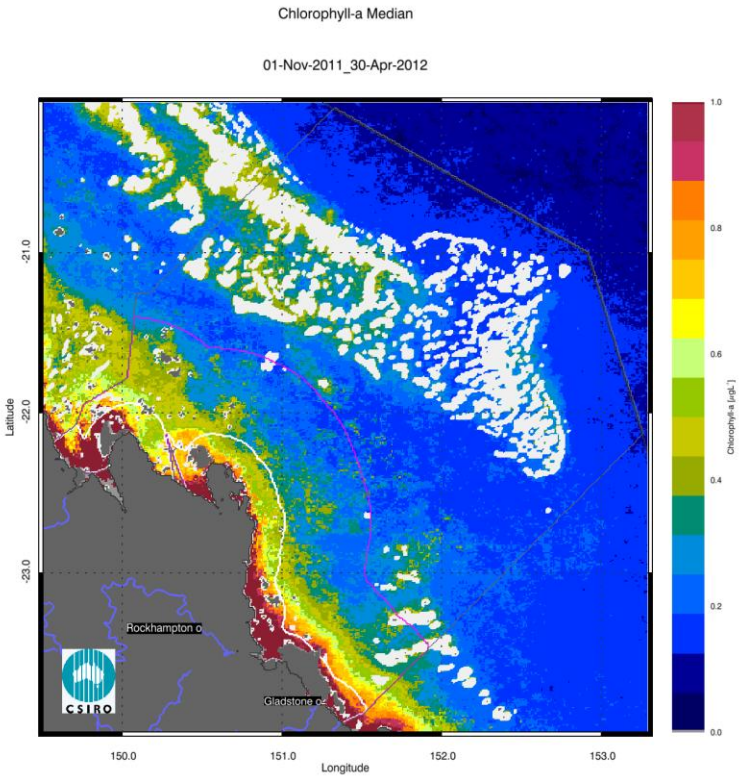


Figure 74. Chlorophyll-a median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

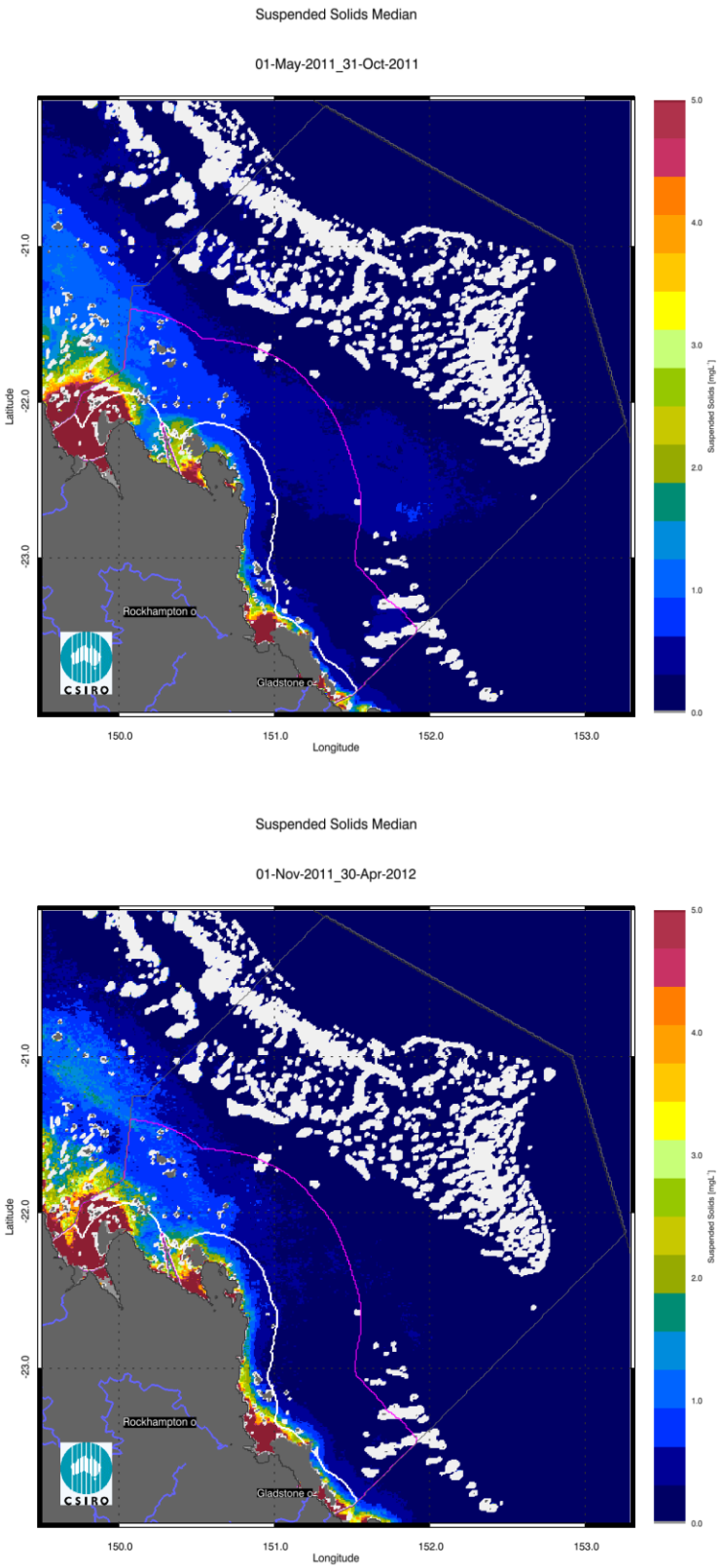


Figure 75. Non-algal particulate matter (NAP as a measure of TSS) median maps for the dry and wet season for the Fitzroy region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

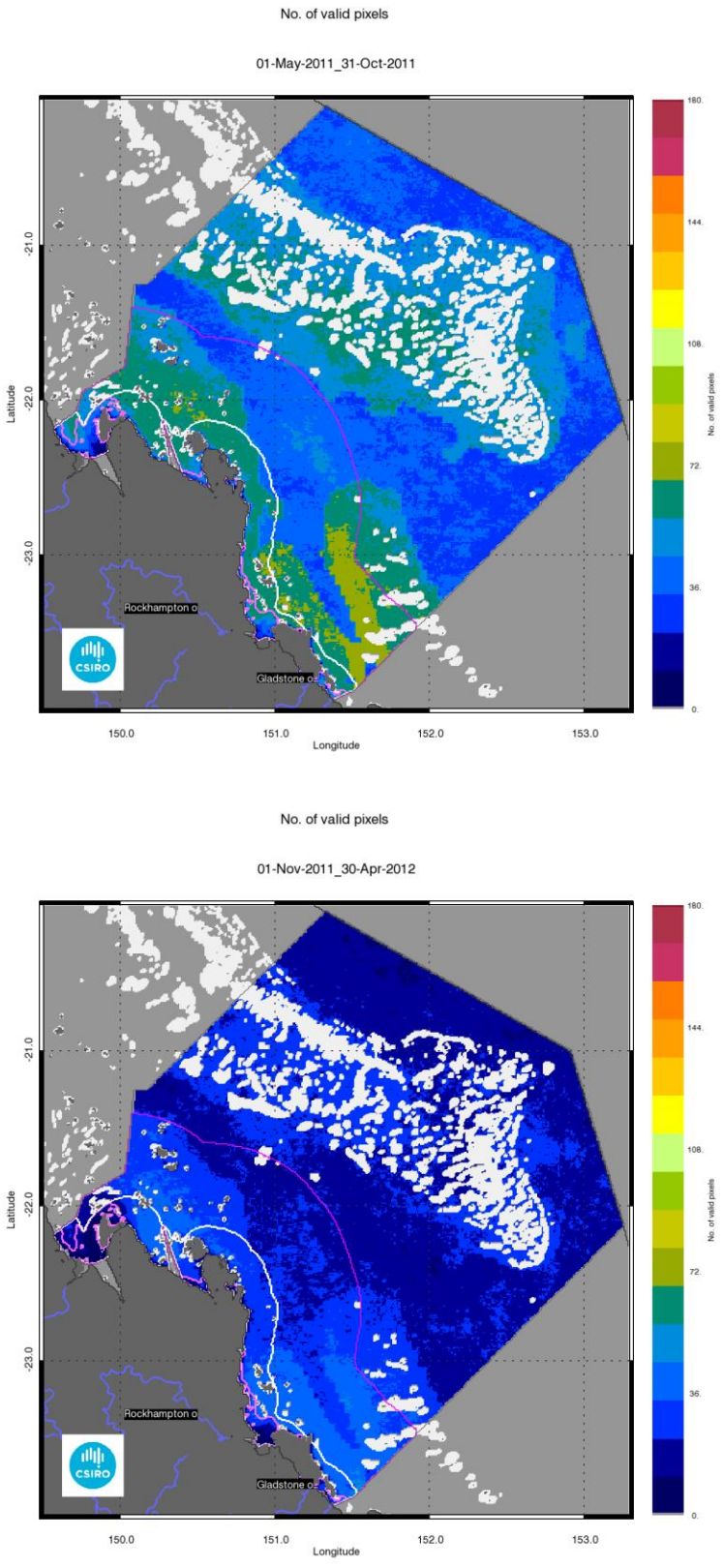
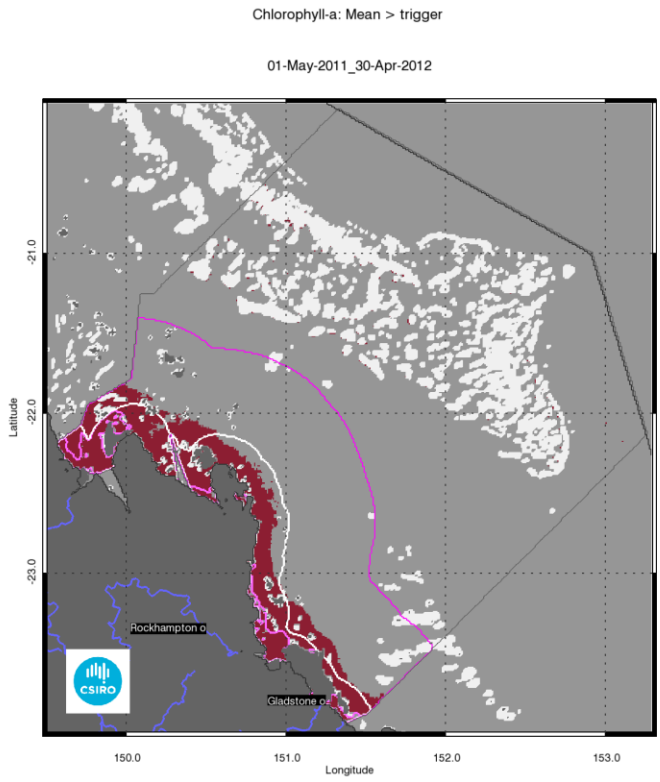


Figure 76. Number of observations used to calculate the median maps (Figure 74 - Figure 75) for the dry and wet season for the Fitzroy region. The first map presents the number of observations available for analysis in the dry season 2011 (May - October), while the second map presents the number of observations available for analysis in the wet season 2011/2012 (November 2011 - April 2012).



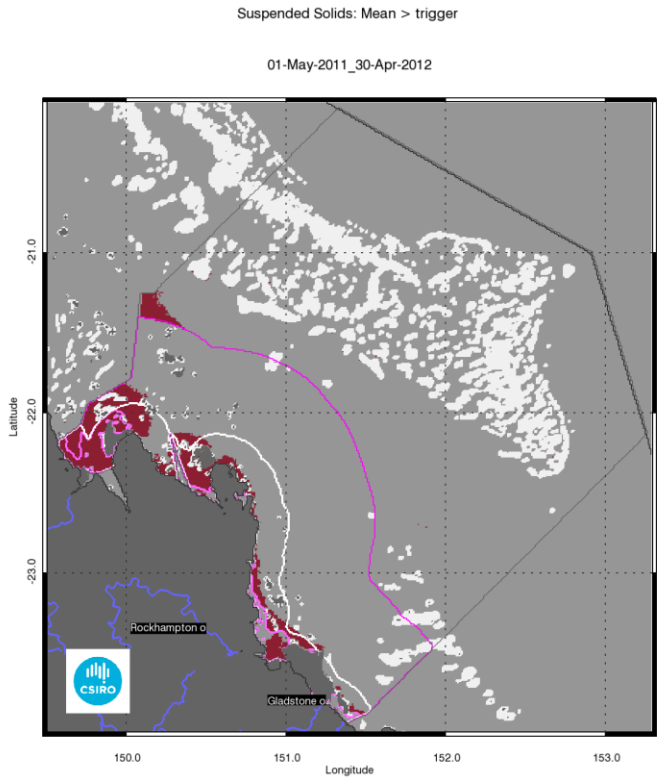


Figure 77. Exceedance maps for the Fitzroy region for the reporting year 2011/12 (May 2011 –April 2012). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (NAP as a measure of TSS) exceedance map. The Guideline values for annual means of Chlorophyll-a are 0.45 µg L^{-1} for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore, while for TSS are 2.0 and 0.7 mg L^{-1}.

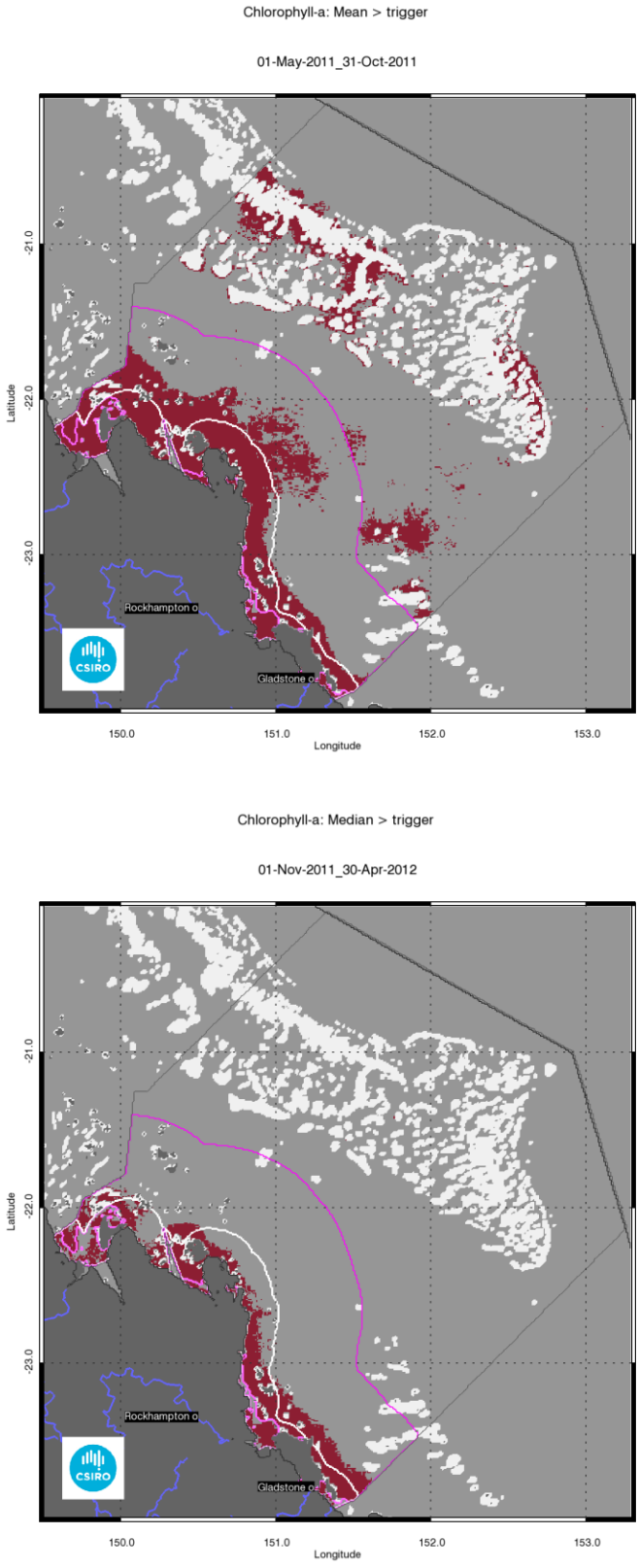


Figure 78. Chlorophyll-a exceedance maps for the dry and wet season for the Fitzroy region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

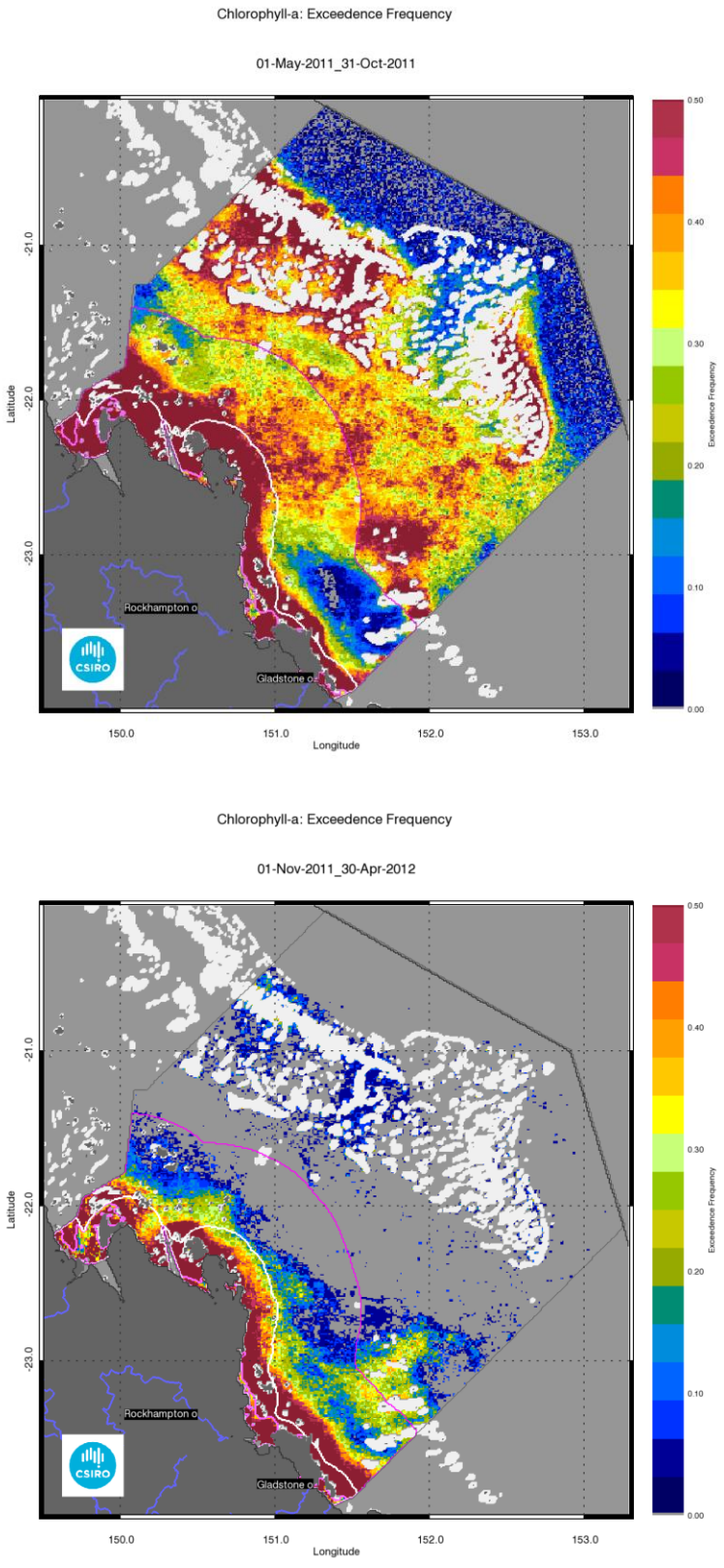


Figure 79. Chlorophyll-a exceedance frequency maps for the dry and wet season for the Fitzroy region. Top: exceedance frequency for the dry season 2011 (May - October); bottom: exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

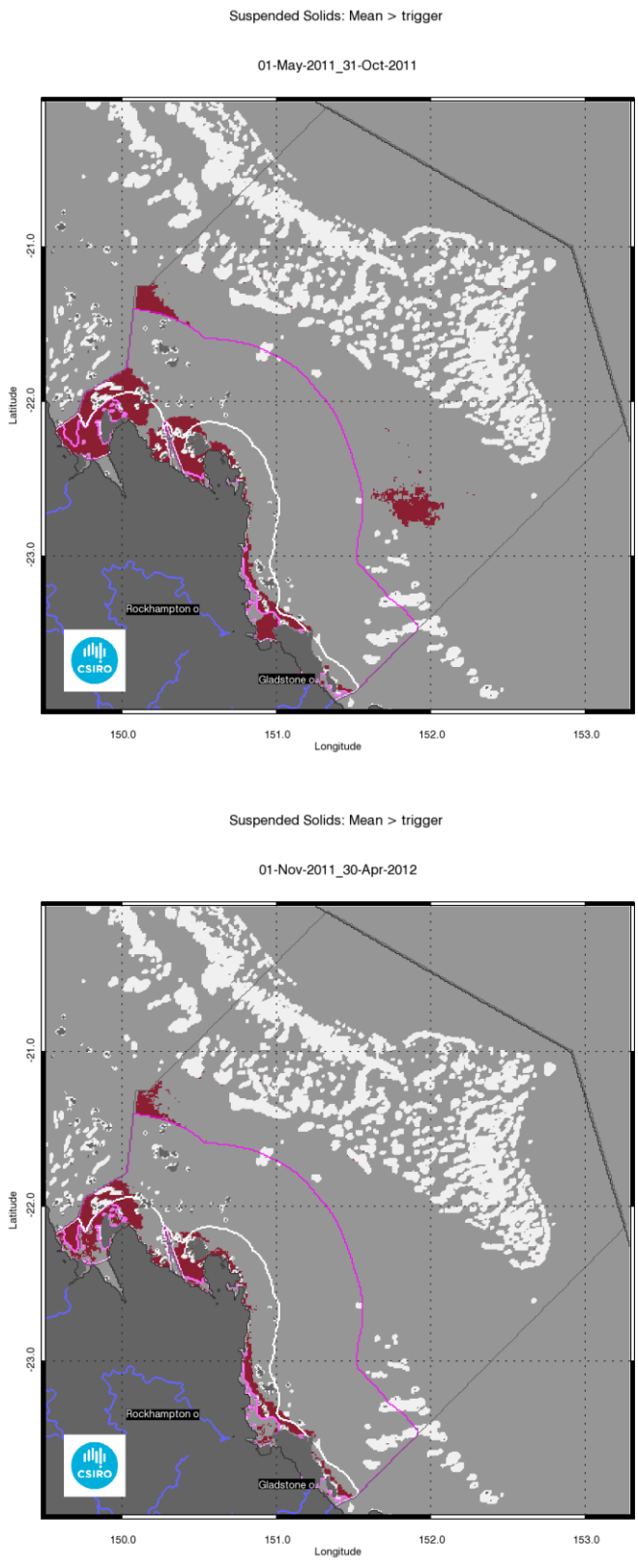


Figure 80. Non-algal particulate matter (NAP as a measure of TSS) exceedance maps for the dry and wet season for the Fitzroy region. Top: exceedance for the dry season 2011 (May - October); bottom: exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

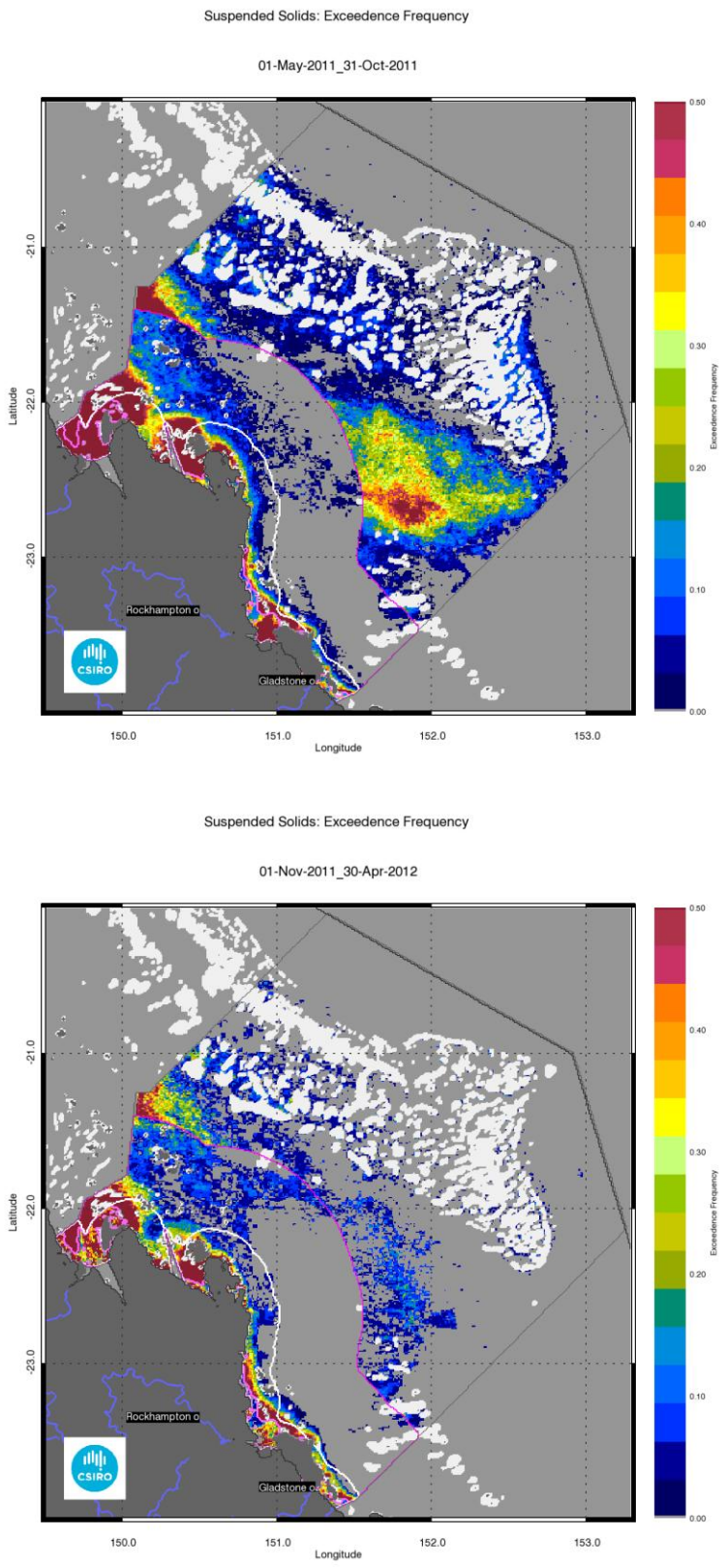


Figure 81. Non-algal particulate matter (NAP as a measure of TSS) exceedance frequency maps for the dry and wet season for the Fitzroy region. Top: exceedance frequency for the dry season 2011 (May - October); bottom: exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

4.7 Regional reports: Burnett Mary region

The Burnett Mary region is the southernmost in the GBR and is comprised of a number of catchments, though only the northernmost catchment, the Baffle Basin, is within the GBR. In this report, the estimate of freshwater extent and the assessment of compliance to the Guidelines using earth observation data is performed only for the GBRMPA section of the Burnett Mary NRM region. The Enclosed Coastal marine water body accounts for ~21% of the inshore waters used for P2R reporting (Table 5, Figure 2). Caution should be used when interpreting the results for this region as limited field information was used for the parameterization and validation on the remote sensing retrievals.

4.7.1 Assessment of freshwater extent during the wet season

Figure 84 reports the freshwater extent for wet season 2011/2012 (November 2011- April 2012) for the Burnett Mary region. The freshwater extent was estimated by applying a threshold of 0.24 m^{-1} for the CDOM seasonal maximum. For the Burnett Mary region the freshwater extent for the wet season 2011/2012 (November 2011 - April 2012) was 1797 km^2 , 1595 km^2 for the wet season 2010/11, while in the wet season 2009/10 was 1137 km^2 (Figure 82). The high estimated freshwater extent for the last three years correlates with the record peak and flow levels recorded for Burnett and Mary Rivers floods over December 2010 and January 2011 and the large freshwater discharges of 2009/10 (Figure 17, Figure 82). This year's large estimated freshwater extent may also be due to flows from Baffle Creek and the Calliope River that flow directly in the GBRMPA section of the Burnett Mary NRM region.

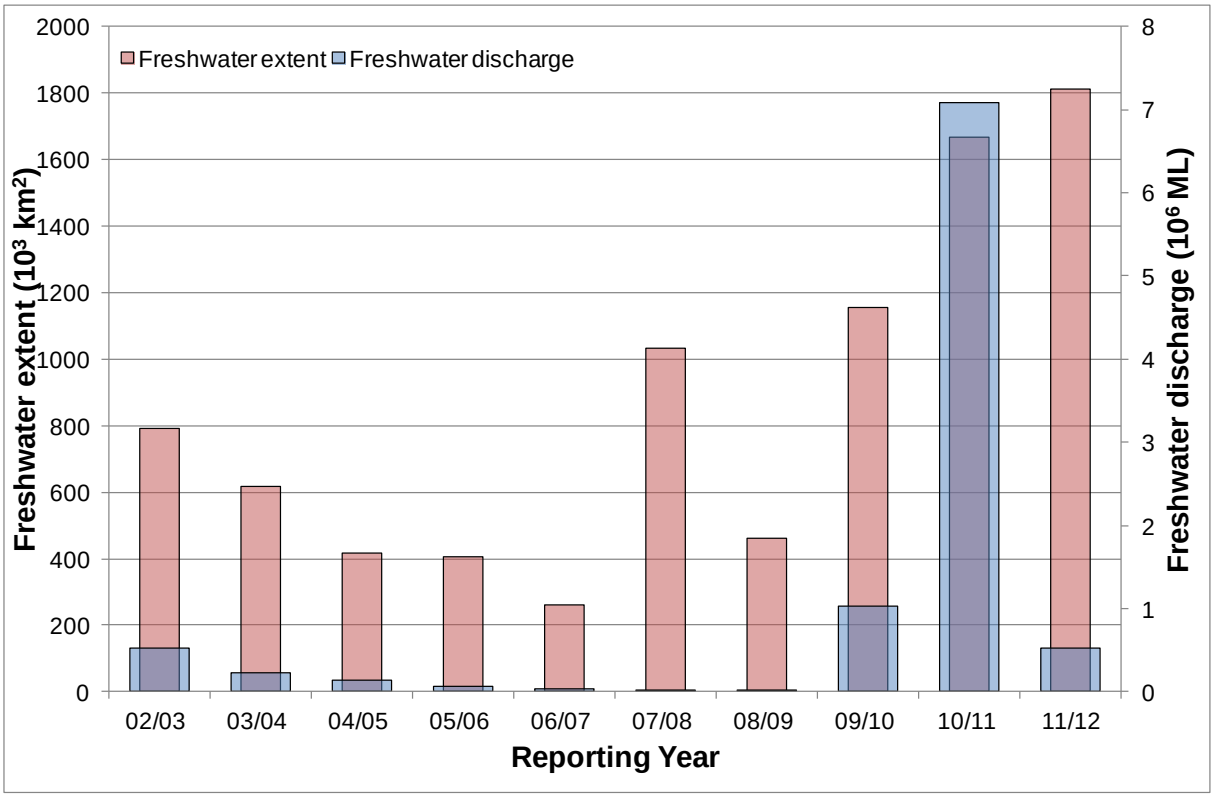


Figure 82. Freshwater discharge and estimated freshwater extent for the Burnett Mary region based on the CDOM maximum for the wet seasons.

4.7.2 The wet and dry season median maps for Chlorophyll-a and Total Suspended Solids.

Both seasonal median CHL maps (Figure 85) for the Burnett Mary region show high CHL near the coast and in the estuary to lower concentrations towards the East. Median CHL values to 0.5 μgL^{-1} extended to the Offshore region reaching the Capricorn Bunker group. The wet and dry season median maps of NAP (Figure 86) for the Burnett Mary region show values higher than 2 mgL^{-1} in the dry season and higher than 4 mgL^{-1} in correspondence with river mouths. The high concentrations shown near Breaksea Spit are likely to be overestimated. The accuracy of the retrieval from MODIS imagery in these shallow waters systems cannot be assessed as there is no data available for parameterization and validation.

The maps in Figure 87 depict the number of observations per pixel location available for calculating the median values for each season. The maps show that this amount varies from 30 to 60 observations for both seasons for each pixel location.

4.7.3 Assessment of the marine water quality index and the exceedance of water quality guidelines

The marine water quality for this reporting year for the Mary Burnett region was scored as "moderate", reflecting a "very poor" score for P2R_CHL and "very good" for P2R_TSS (Figure 83). The marine water quality index and the component score have been steadily declining from 2006/07, as the P2R_CHL scores declined from "good" to "very poor" in the last five years while the P2R_TSS scores were "very good" since the 2002/03 reporting season. The "poor" and "very poor" score for the P2R_CHL in the last three reporting seasons is likely to be a response to the high freshwater discharges from the Baffle Creek as well as the Burnett and Mary Rivers and the associated estimated freshwater plume extents of the last three years (Figure 82).

The Enclosed Coastal marine water body accounts for ~21% of the inshore waters used for P2R reporting, mostly in Rodds Bay in front of Port Curtis (Table 5, Figure 2). For the Enclosed Coastal waters, no exceedance to the guidelines (15 mg/L) for TSS was recorded in the annual or seasonal means, while CHL values exceeded the guidelines for (2.0 µg/L) for 26-49% of the area in the annual and seasonally adjusted means. For the Burnett Mary region the annual mean CHL values exceeded the guideline values (0.45 µg/L) for 99% of the Open Coastal area and 19% of the Midshelf area, while exceedance of TSS guideline values were recorded in 10% of the Open Coastal, and 8% of the Midshelf (Figure 88, Table 37). The mean CHL values the Guidelines values for 97% of the Open Coastal area in the dry season and 96 % in the wet season. The dry season EG for CHL occurred in 99 % of the Midshelf and 29% of the Offshore areas (Figure 89, Table 38). Similar exceedance extents were retrieved for EF >0.50, i.e. if the median was used for the assessment (Figure 90, Table 37, Table 38). The mean values of TSS exceeded the Guidelines values for 15 % of the Open Coastal area in the dry season and for 26% in the wet season. No exceedance was estimated for TSS in the Midshelf area, while for the Offshore area a REEG of 24% was recorded in the dry season (Figure 92 , and Table 39).

Similarly to the other reporting regions, the spatial patterns in exceedance for both variables (Figure 88 Figure 90) were affected by the coastal to offshore gradients observed in the median maps (Figure 85, Figure 86) and by the steep changes in trigger values between the Midshelf and Offshore areas.

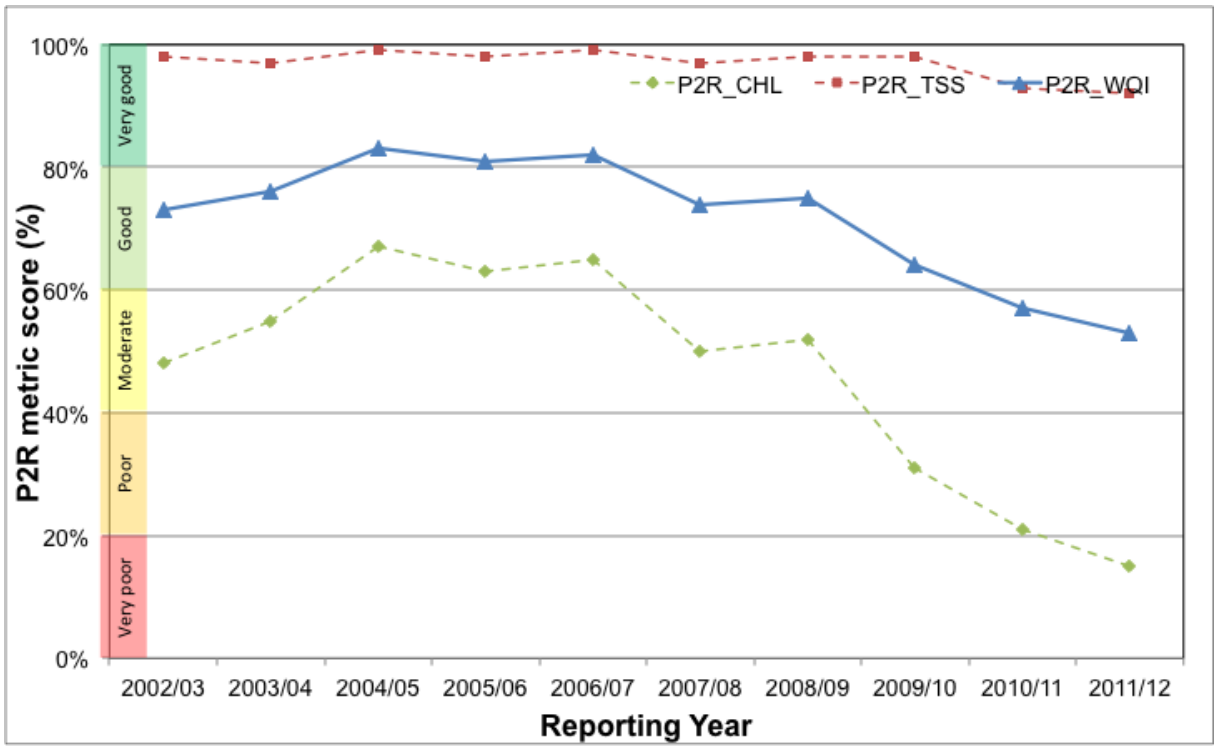


Figure 83. Paddock to Reef marine water quality index (P2R_WQI) and component scores (P2R_CHL and P2R_TSS) for the Mary Burnett region based on the assessment of exceedance to the Guidelines.

Table 40 and Table 41 report the summary of exceedance for both variables, providing mean and median concentrations computed on all the valid observations for each water body for each season, along with the EFEF for that period. These metrics are based on a high number of observations (ranging from 17 thousands valid observations for Open Coastal area in the wet season to over 1.4 million for the Offshore area in the dry season). According to these metrics both the mean and the median CHL values exceeded the Guidelines values for the Open Coastal area in both seasons, and for the Midshelf in the dry season, while no exceedance were estimated for the mean TSS values. As observed for all the reporting regions the mean and median values for the TSS concentration differed substantially (for all areas and seasons). The mean values were ~ 2-3 times higher than medians.

Table 37 Summary of the annual exceedance maps for Chlorophyll-a and Total Suspended Solids for the Mary-Burnett region. "Surface Area" is the surface area in square kilometres for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, IS: Inshore, MS: Midshelf, OS: Offshore), , "Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels), "Number total obs." provides the total number of observations, "Mean > trigger" and "Median > trigger" report the relative area for each water body where the mean or the median exceeded the trigger value.

		01-May-2011_30-Apr-2012		Chlorophyll-a		Total Suspended Solids	
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Mean > trigger	Median > trigger
EC	154	11173	56210	30%	16%	0%	0%
OC	599	55211	218635	99%	75%	10%	3%
IS	753	66384	274845	85%	63%	8%	3%
MS	3401	305469	1241365	20%	5%	1%	1%
OS	33928	1850546	12383720	0%	0%	0%	0%

Table 38 Summary of the exceedance maps for Chlorophyll-a for the dry and wet season for the Burnett Mary region (Figure 89, Figure 90). Column and row labels are described in the legend of Table 37.

		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	154	7263	26950	49%	23%	3910	29260	26%	18%
OC	599	34726	104825	99%	88%	20485	113810	98%	97%
IS	753	41989	131775	89%	75%	24395	143070	83%	81%
MS	3401	188873	595175	19%	12%	116596	646190	24%	20%
OS	33928	1164131	5937400	1%	1%	686415	6446320	0%	0%

Table 39 Summary of the exceedance maps for Non-algal particulate matter (NAP as a measure of TSS) for the dry and wet season for the Burnett Mary region (Figure 91, Figure 92). Column and row labels are described in the legend of Table 37.

MABU-B09		01-May-2011_31-Oct-2011				01-Nov-2011_30-Apr-2012			
	Surface Area	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger	Number valid obs.	Number total obs.	Mean > trigger	Median > trigger
EC	154	7263	26950	0%	0%	3910	29260	0%	0%
OC	599	34726	104825	9%	4%	20485	113810	17%	6%
IS	753	41989	131775	7%	3%	24395	143070	14%	5%
MS	3401	188873	595175	1%	1%	116596	646190	1%	1%
OS	33928	1164131	5937400	0%	0%	686415	6446320	0%	0%

Table 40. Summary of Chlorophyll-a exceedance for the dry and wet season for the Burnett Mary region. “Number valid obs." is the number of pixels with valid observations (i.e. cloud-free and error-free pixels) for each of the three reporting water bodies for this region: (EC: Enclosed Coastal, OC: Open Coastal, MS: Midshelf, OS: Offshore), "Number total obs." provides the total number of observations. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 1.4/2.8 µg L^{-1} for Enclosed Coastal, 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	7263	26950	**1.40**	1.04	31%	3910	29260	2.06	1.57	22%
OC	34726	104825	**0.53**	**0.45**	75%	20485	113810	**1.31**	**0.94**	71%
MS	188873	595175	0.25	0.20	23%	116596	646190	0.55	0.48	33%
OS	1164131	5937400	0.19	0.17	9%	686415	6446320	0.20	0.16	4%

Table 41 Summary of Non-algal particulate matter (NAP as a measure of TSS) exceedance for the dry and wet season for the Burnett Mary region. Column and row labels are described in the legend of Table 40. Mean and median are presented in red and bold if they exceed the trigger value in the Guidelines. The seasonally adjusted Guideline values for TSS for the dry/wet season means are 12/18 mg L^{-1} for Enclosed Coastal, 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

	01-May-2011_31-Oct-2011					01-Nov-2011_30-Apr-2012				
	Number valid obs.	Number total obs.	Mean	Median	EP	Number valid obs.	Number total obs.	Mean	Median	EP
EC	7263	26950	4.26	2.71	6%	3910	29260	7.06	4.38	8%
OC	34726	104825	0.73	0.41	8%	20485	113810	**1.59**	0.99	17%
MS	188873	595175	0.28	0.19	1%	116596	646190	0.41	0.21	2%
OS	1164131	5937400	0.13	0.10	1%	686415	6446320	0.13	0.12	1%

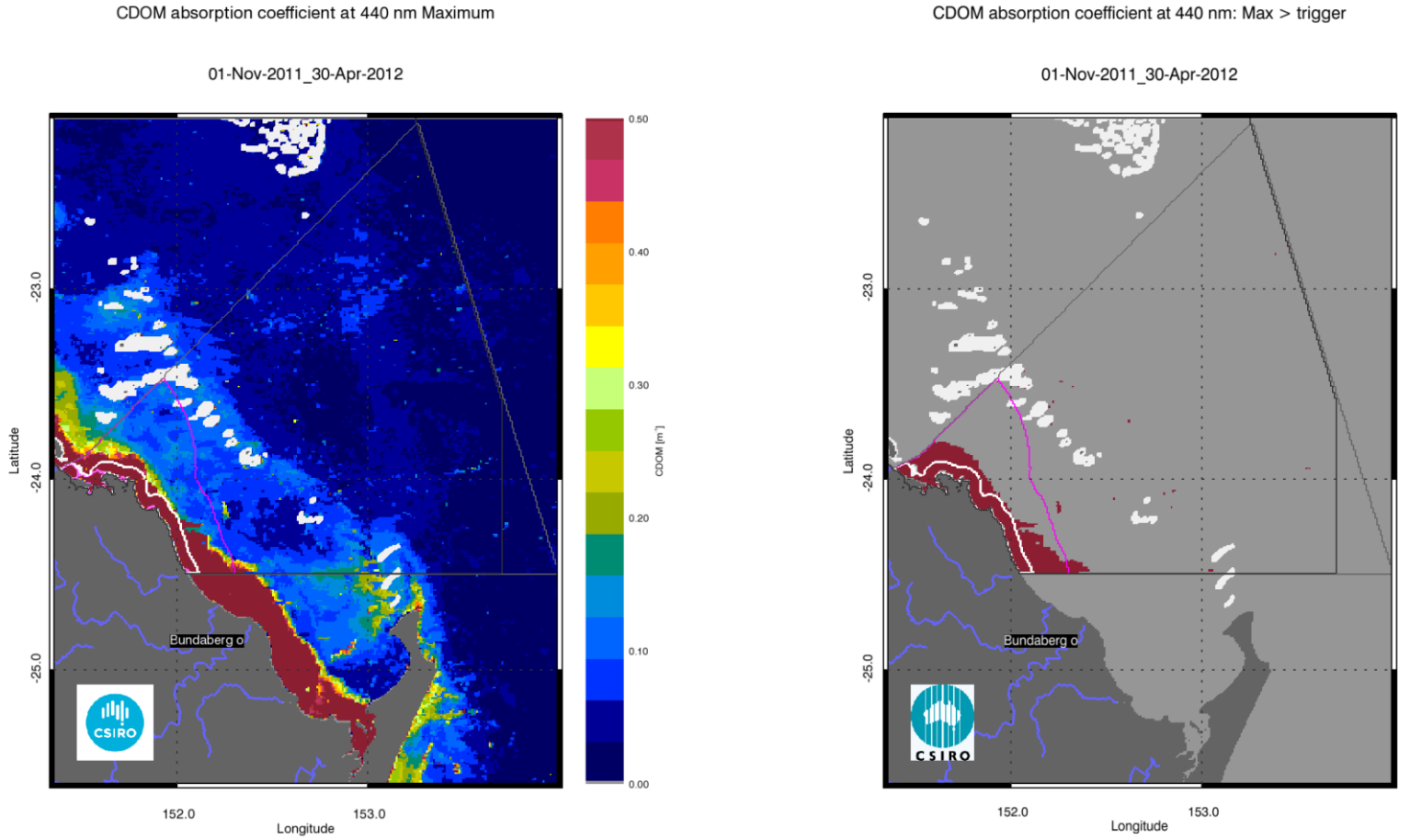


Figure 84. Map of freshwater extent for the wet season for Burnett Mary region. The first map presents the maximum value of CDOM for the wet season 2011/2012 (November 2011 - April 2012), while the second map presents freshwater extent estimated with a threshold for the CDOM seasonal maximum of 0.24 m^{-1}.

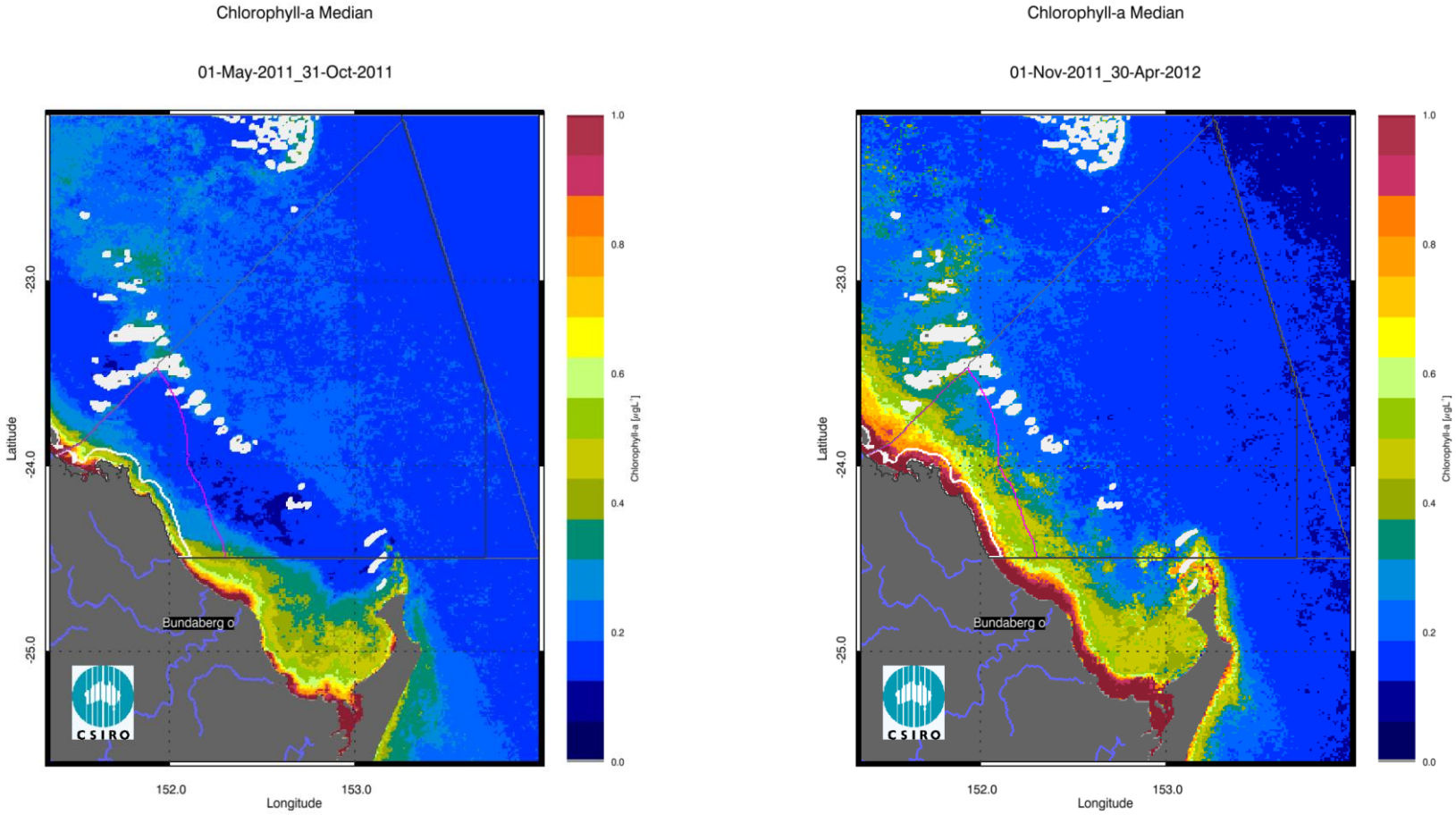


Figure 85. Chlorophyll-a median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

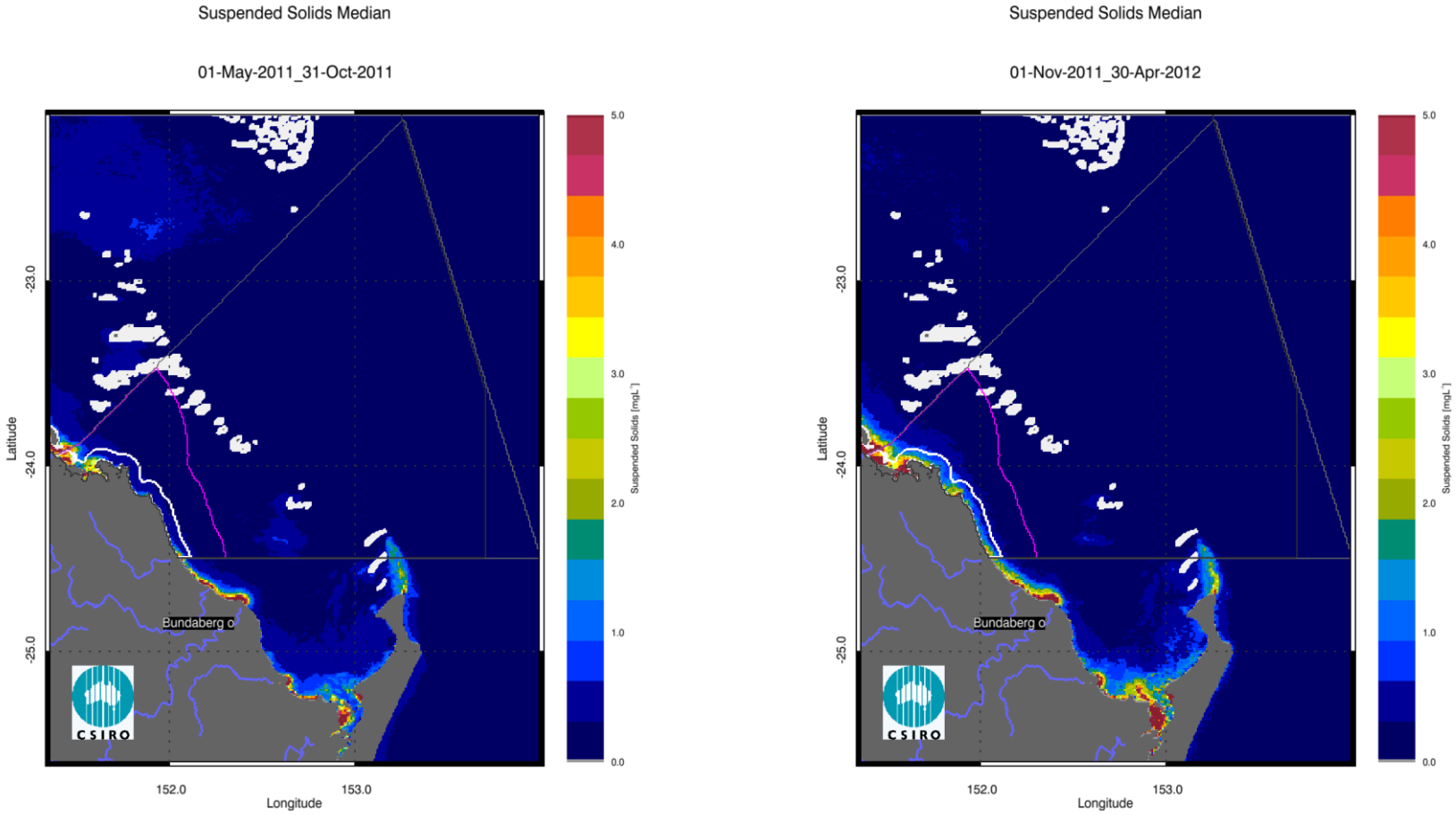


Figure 86. Non-algal particulate matter (NAP as a measure of TSS) median maps for the dry and wet season for the Burnett Mary region. The first map presents the median for the dry season 2011 (May - October), while the second map presents the median for the wet season 2011/2012 (November 2011 - April 2012).

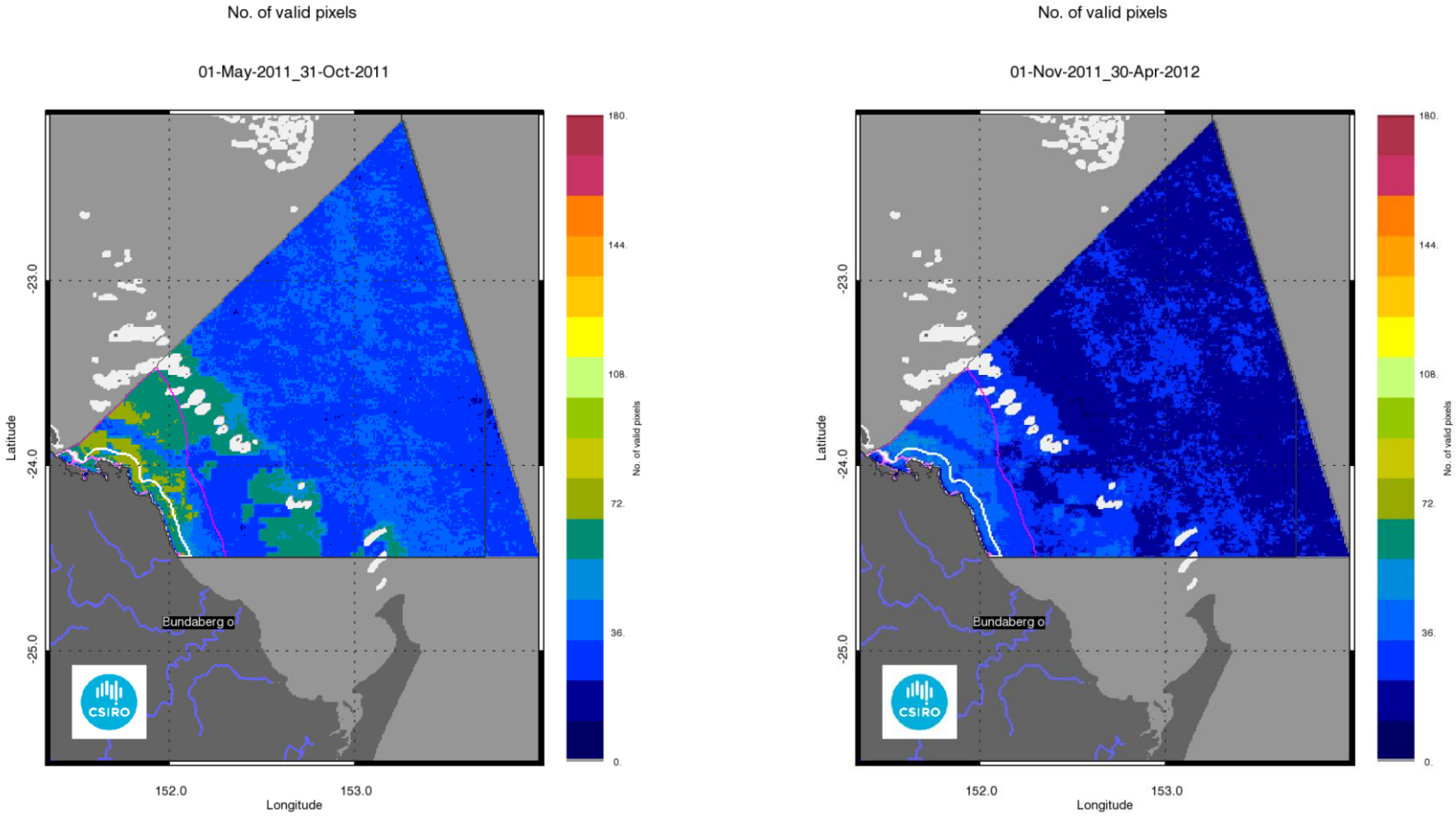


Figure 87. Number of observations used to calculate the median maps (Figure 85 - Figure 86) for the dry and wet season for the Burnett Mary region. The first map presents the number of observations available for analysis in the dry season 2011 (May - October), while the second map presents the number of observations available for analysis in the wet season 2011/2012 (November 2011 - April 2012).

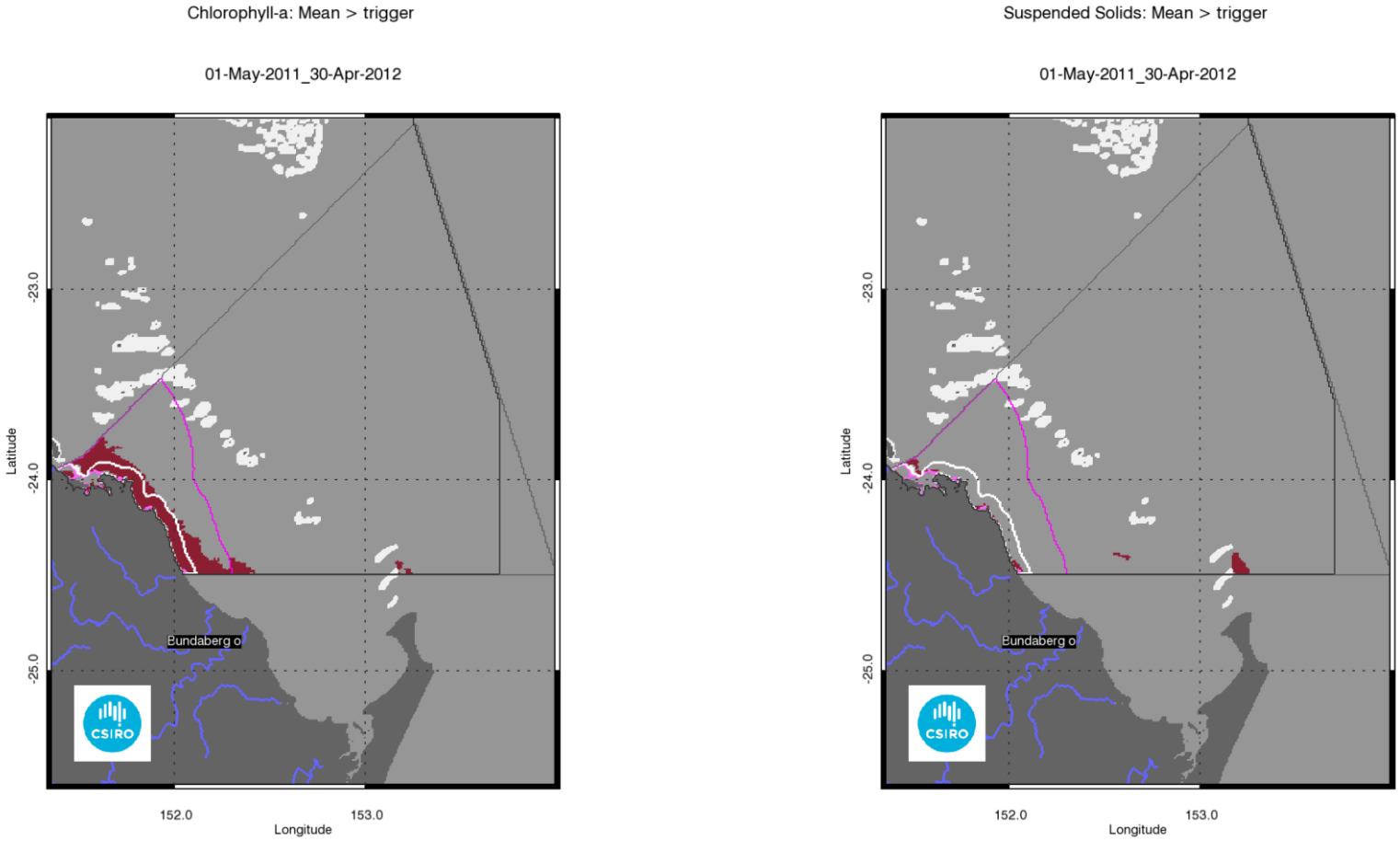


Figure 88. Exceedance maps for the Burnett Mary region for the whole year (May 2011 –April 2012). The first map presents the Chlorophyll-a exceedance map, while the second map presents the Non-algal particulate matter (NAP as a measure of TSS) exceedance map. The Guideline values for annual means of Chlorophyll-a are 0.45 µg L^{-1} for Open Coastal and Midshelf and 0.40 µg L^{-1} for Offshore, while for TSS are 2.0 and 0.7 mg L^{-1}.

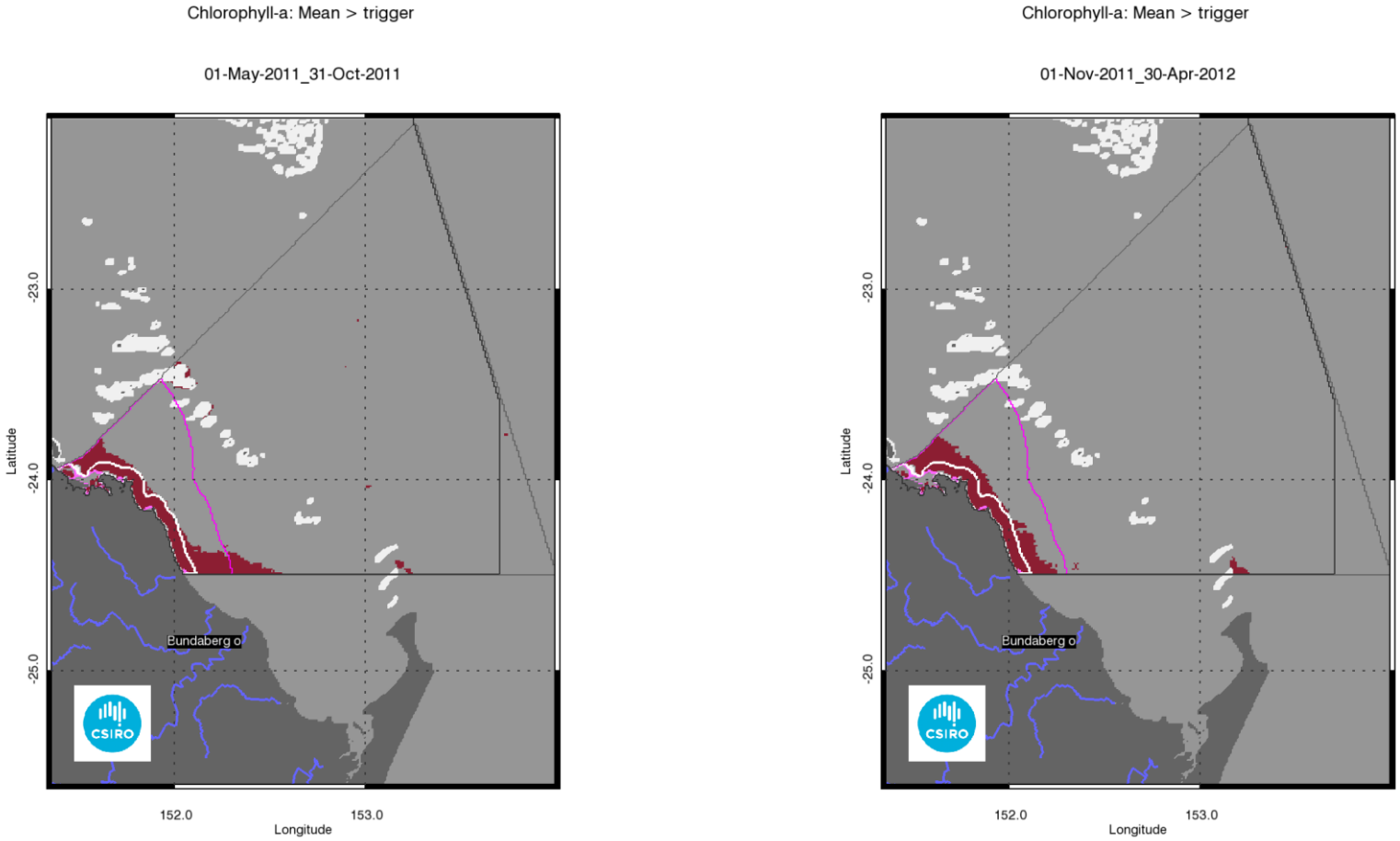


Figure 89. Chlorophyll-a exceedance maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll –a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

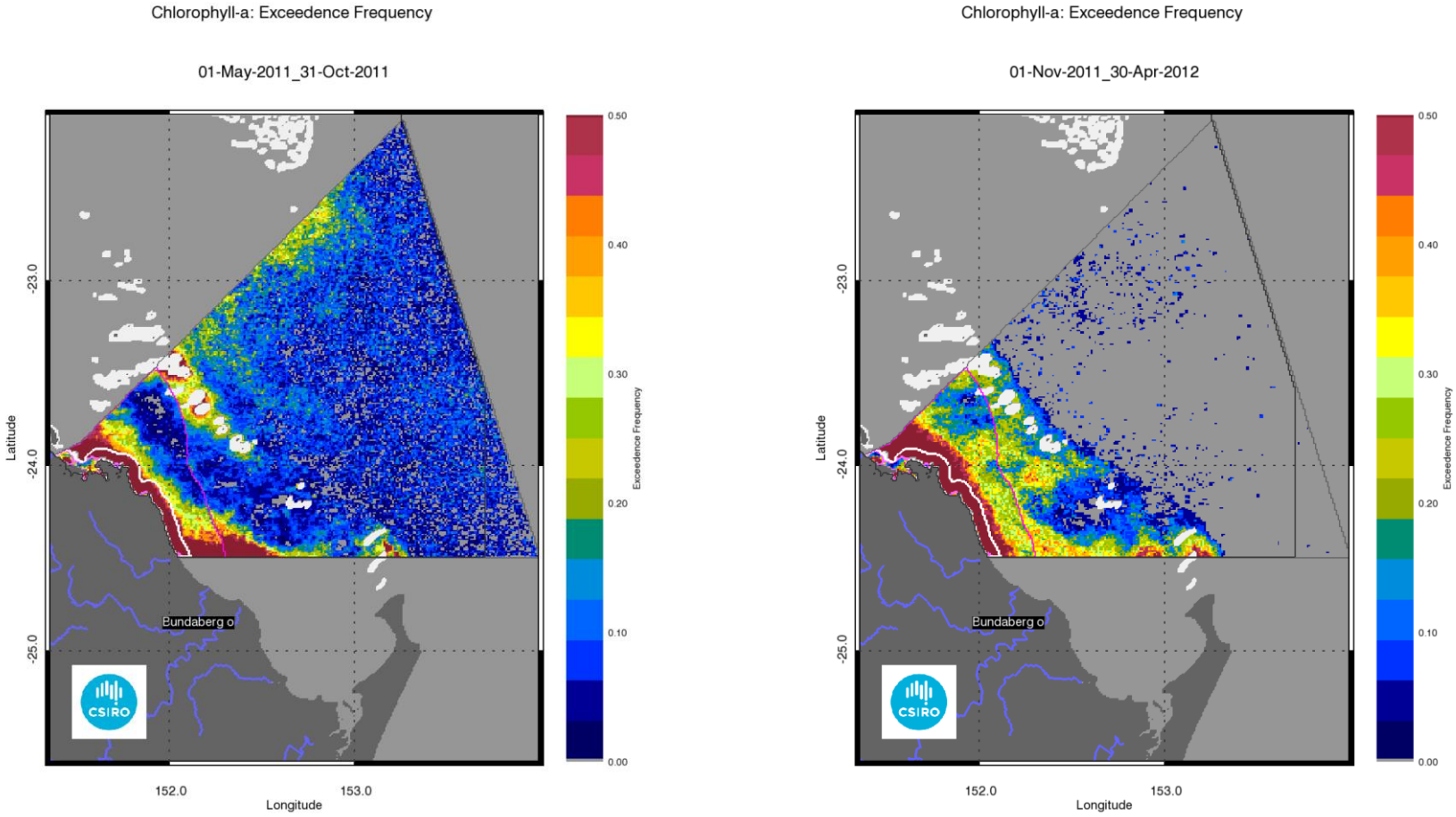


Figure 90. Chlorophyll-a exceedance frequency maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for Chlorophyll-a for the dry/wet season are 0.32/0.63 µg L^{-1} for Open Coastal and Midshelf and 0.28/0.56 µg L^{-1} for Offshore.

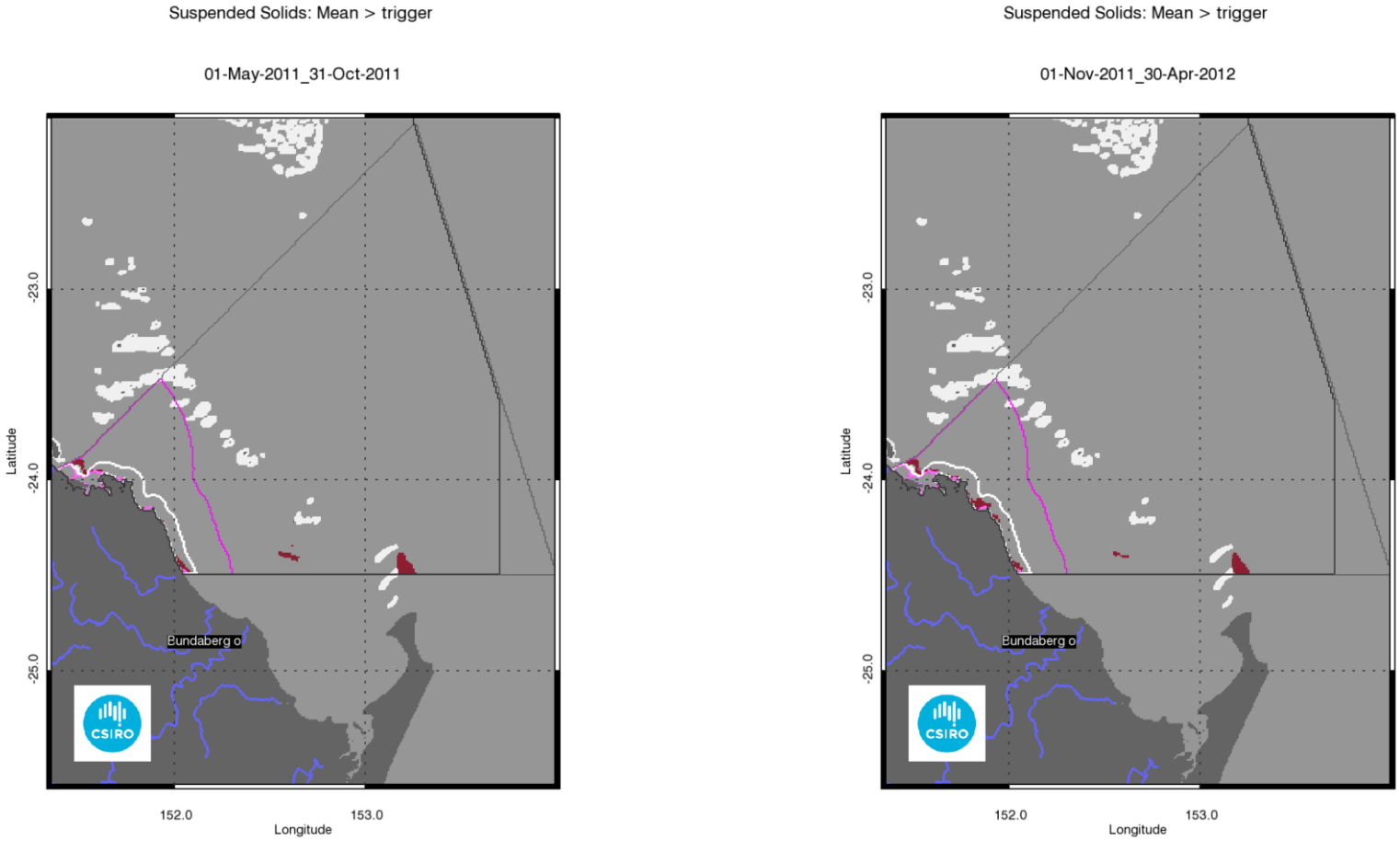


Figure 91. Non-algal particulate matter (NAP as a measure of TSS) exceedance maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance for the dry season 2011 (May - October), while the second map presents the exceedance for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

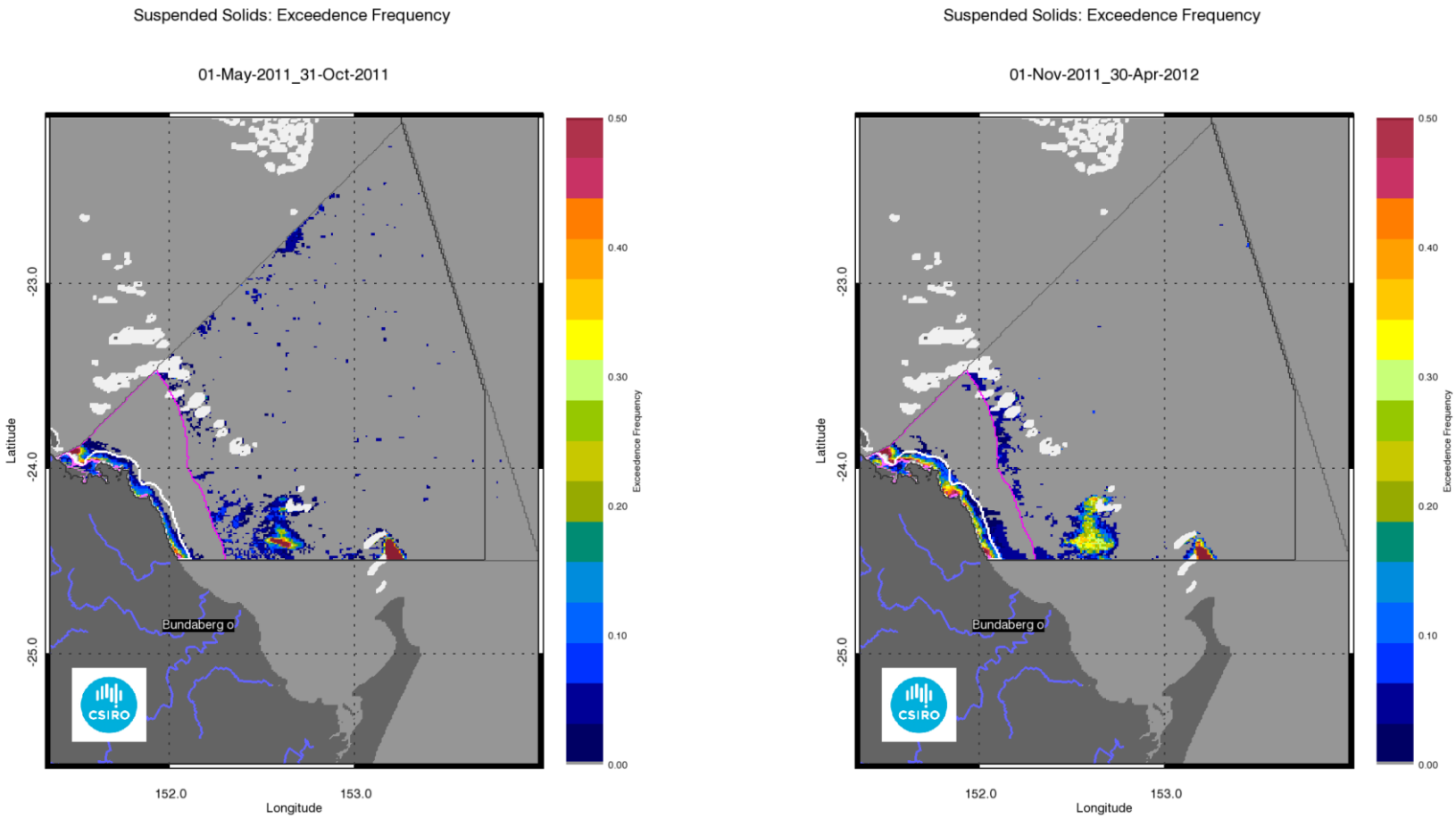


Figure 92. Non-algal particulate matter (NAP as a measure of TSS) exceedance frequency maps for the dry and wet season for the Burnett Mary region. The first map presents the exceedance frequency for the dry season 2011 (May - October), while the second map presents the exceedance frequency for the wet season 2011/2012 (November 2011 - April 2012). The seasonally adjusted Guideline values for TSS for the dry/wet season means are 1.6/2.4 mg L^{-1} for Open Coastal and Midshelf and 0.6/0.8 mg L^{-1} for Offshore.

5 CONCLUSION AND RECOMMENDATIONS

A cornerstone of the GBRWQPP and the WQIPs is the setting of water quality objectives against which to assess the success of the actions taken under Reef Rescue to mitigate the effects of nutrients and sediment from runoff and discharges. A key challenge is to detect and monitor the effect of the land management practices on the water quality in the GBR lagoon waters. In this system, the water quality is also influenced by the inter-annual weather variability induced by the *El Niño-Southern Oscillation* (ENSO) leading to large year to year variations in the distribution of rainfall events over the GBR catchments resulting in sediment laden river plumes and algal blooms.

The MMP aims are to document flood and the condition of inshore water quality to explain changes in the health of key inshore environments (coral reefs and seagrass). To address these important management questions water quality is monitored using three complementary approaches to collect data at various spatial (site, location, region, and whole GBR lagoon) and temporal (snapshot, daily, 10-minutely) scales: traditional direct water sampling from research vessels, *in situ* data loggers at a small number of selected inshore reef locations and remote sensing techniques. While data loggers provide detailed information on the local variability in water quality parameters, remote sensing observations provide extensive spatial coverage at 1 km resolution.

This report delivered management-relevant information of flood events and inshore water quality from remote sensing data to enable GBRMPA and other relevant management agencies to make more informed management decisions. Remote sensing is a suitable and cost-effective technique for the large-scale monitoring of coastal water quality because it provides synoptic views of the spatial distribution of several variables (CHL, CDOM and TSS). At present, MODIS Aqua represents a time series (November 2002 – present) of water quality estimates with spatial coverage at 1 km resolution, nominally acquired on a daily basis (except overcast days) for the whole-of-GBR lagoon. The water quality estimates were retrieved from the MODIS Aqua time series using two coupled physics-based inversion algorithms developed to accurately retrieve water quality parameters for the optically complex waters of the GBR lagoon. This was necessary because CHL concentrations retrieved with the MODIS standard algorithms provided by NASA are inaccurate up two-fold in GBR waters (Qin et al., 2007), while regionally parameterised algorithms account for the significant variation in concentrations of CDOM and TSS and achieve more accurate retrievals.

For this report the whole MODIS aqua time series was reprocessed with the most recent updates in NASA's software (SeaDAS version 6.4), incorporating the improved knowledge of instrument temporal calibration to improve temporal stability of the time series of the MODIS AQUA aging sensor. Furthermore, the parameterization of both the ANN atmospheric correction and the adaptive Linear Matrix Inversion (a-LMI) water quality algorithm were revised to improve accuracy in turbid waters and reduce over-estimates of TSS concentrations in the Midshelf. The comparison of MODIS Aqua retrievals of CHL, CDOM and NAP with *in situ* data showed that the regional algorithm coupled with the ANN atmospheric correction is more accurate than NASA's algorithms for GBR waters. The uncertainty for the retrieval of CHL, CDOM and TSS with the coupled physics-based inversion algorithms was 89%, 68% and 77%, respectively. The parameterization and validation on the remote sensing retrievals was mainly based on observations performed in coastal and lagoonal waters during the dry season between Keppel Bay and the Wet Tropics. The accuracy of the retrieval is likely to be lower in shallow and turbid water systems such as Princess Charlotte Bay, Broad Sound and Shoalwater Bay where there was no data available for parameterization and validation.

The combination of expanding catchment development and modification of land-use has resulted in a significant decline in the quality of water flowing into the reef lagoon over the past 150 years. Flood events in the wet season are the main delivery mechanism for nutrients, sediments and pesticides from the adjacent catchments into the Reef lagoon. The freshwater extent was estimated for each region from MODIS measurements within the wet season of each year by applying a threshold to maps of aggregated seasonal maximum CDOM concentrations. For this study a CDOM absorption threshold was established based a relationship between measurements of salinity and CDOM absorption (Schroeder et al. 2012). The high CDOM concentrations may also reflect other processes in occurring in near-shore waters, further work should also attempt to separate the plumes from non-plume effects.

The freshwater extent based on the CDOM maximum provides a conservative estimate of the extent as the flood plumes could have extended further in cloudy or overcast days and hence may not been captured with the satellite imagery. However as the proposed method is biased by cloud cover and quality flagging of erroneous pixels, the most comprehensive way of assessing freshwater extent into the GBR will be a combination of in-situ sampling and satellite observations (augmented by aerial surveys where and when feasible). The estimated freshwater extent for the whole GBRWHA was highly correlated to the total freshwater discharges (R2=0.835), the freshwater extent for 2011/2012 was similar in magnitude to 2007-2010 period as observed with the MODIS time series. The estimated freshwater extent for 2011/2012 was larger than in 2010/2011 only for the Burdekin and Burnett Mary regions, while for Fitzroy and the Wet Tropics it was higher than the median extents observed with the MODIS time series. These results were consistent with the results of the qualitative and quantitative flood mapping approaches carried out in the flood plumes and extreme weather monitoring activities of the MMP (Devlin et al. 2012).

The Guidelines provide triggers for management action where exceedance occurs and threshold levels for analysis of current condition as well as trend monitoring. The exceedance assessment results evaluated for CHL and TSS were presented a as maps illustrating the exceedance of the Guidelines (EG) and the exceedance frequency (EF). The spatial patterns in EG and EF were function of the coastal to offshore gradients that can be observed in the median maps and of the steep changes in trigger values between the Enclosed Coastal and Open Coastal as well as the Midshelf and Offshore areas.

The two component indicators of the Paddock to Reef marine water quality index are based on the spatial extent of non-compliance in the Inshore water body. The Inshore water body includes the Open Coastal waters and the Enclosed coastal waters that have been delineated in this report by performing a cluster analysis of the MODIS AQUA CHL time series. The proposed delineation for the Enclosed Coastal waters account for 15-30% of the Inshore water body in the NRM regions. As the guideline values for CHL and TSS for the Enclosed Coastal waters are higher than those for the Open Coastal water body, this study demonstrated that the relative area of non-compliance for the Inshore waters is over-estimated if the Enclosed waters delineation is not taken in account. Hence the proposed delineation of the Enclosed Coastal water body improved the estimates of the spatial extent of non-compliance and the Paddock to Reef marine water quality index.

It is recommended to GBRMPA that the proposed delineation of the Enclosed Coastal waters should be taken in consideration together with other data sources including the Queensland Wetlands 2009 data, depth contours, hydrodynamics and sources of freshwater input to the coast prior to selecting the final water body delineation for formal implementation in the Guidelines.

The marine water quality for this reporting year for the whole GBR was scored as “moderate”, reflecting the one “poor” and three “moderate” scores for P2R_WQI in the four reporting regions that contribute the whole of GBR score (the regional scores for Cape York and Burnett Mary are excluded from calculations of the overall GBR score for each metric as limited field information was used for the parameterization and validation on the remote sensing retrievals). The scores for the two component indicators for the whole GBR were “poor” for P2R_CHL and “moderate” for P2R_TSS, reflecting the “very poor” to “moderate” regional scores for P2R_CHL and “moderate” to “good” regional scores from P2R_TSS.

Large areas of TSS exceedance occurred in Offshore areas, particularly in Cape York, the Mackay-Whitsunday and Fitzroy reporting regions at the boundary between the Midshelf and Offshore waters. These large areas of exceedance of the mean annual TSS values may be due to either an over-estimate of the mean TSS concentrations in Offshore waters or to a low guideline threshold value for those waters as a consequence of a wrong delineation of the Offshore boundary. Future work should attempt to assess the accuracy of TSS and CHL retrieval from satellite data at a regional and seasonal scale, if enough validation data points become available. It is recommended to GBRMPA that, consistently with the adaptive monitoring paradigm (Lindenmayer and Likens 2009), a re-assessment of the Guidelines threshold values, the delineation of the reporting boundaries, as well as the regional and seasonal adjustments, is carried out as part of the Guidelines review cycle.

The number of available observations was significantly lower in the wet season than the dry season in all regions. This was mainly due to the higher cloud cover and aerosol concentration in the wet season. It is possible that cloud cover introduces a bias in the sampling if the remote sensing imagery does not effectively capture the extreme values in concentrations of CHL and TSS during and following flood events. The estimate of the mean values for the wet season, and to a lesser extent for the whole year, are more likely to be affected than the estimate of the median values by the "non-sampling" of the higher values due to cloud cover. In an attempt to address this issue, in this report the exceedance of the Guidelines for CHL and TSS was evaluated by comparing the mean as well as the median values of the variables to the appropriate seasonal and regional values, even if the mean values are identified in the Guidelines. Also, the effect of calculating a mean value for a given location based on 6-8 samples in a year or 100-200 values is quite different from a statistical sampling design perspective, as the distribution of the effective sampling due to the cloud cover may bias the estimate of mean values. These implementation issues should be included by GBRMPA in the scope of a review of the Guidelines.

To documents the condition of inshore water quality in the GBRWHA, the current design of MMP relies on three complementary approaches to collect data at various spatial (site, location, region, and whole GBR lagoon) and temporal (snapshot, daily, 10-minutely) scales. Comparison of the remote sensing based water quality monitoring with other MMP components like the site-specific inshore water quality monitoring shows some level of disagreement for regions, mainly due to the differences in the temporal and spatial scales of the data collection. The interim site specific water quality index proposed in Schaffelke et al. (2011 and 2012) provides a detailed, albeit site-specific, assessment of inshore water quality for twenty fixed sampling locations across the Open Coastal and Midshelf water bodies in the GBRWHA. The index aggregates scores given to 4-year running means of four indicators in comparison to the GBR Water Quality Guidelines (i) a combined score for suspended solids concentrations in water samples, Secchi depth and turbidity measured by *in situ* loggers and scores for (ii) chlorophyll, (iii) particulate nitrogen and (iv) particulate phosphorus concentrations in water samples.

The interim site-specific water quality index (Schaffelke et al. 2012) may suggest at first glance an higher rate of compliance than the remote sensing based assessment of this study for the inshore waters. For example, the site-specific assessments for the Wet Tropics Region found that six of the eight sites in the inshore region had a total score of "poor" or "moderate" for the 2009-2012 period, consistently with the four "poor" P2R_WQI scores for the same reporting years (2008/09 – 2011/12). Also, all four Midshelf sites were rated as "very good" from 2005-2008 to 2009-2012. This was consistent with EG result the Midshelf water body for CHL and TSS presented in this report for the last ten years, where the annual mean values of CHL were above the guideline in 15-20 % of the area while the annual mean values of TSS were above the guideline in less than 10 % of the area. In the Fitzroy region the site-specific assessments from 2007-2010 to 2009-2012 show that the two sites in the Open Coastal water body scored as "poor" and "moderate" and the only site in the Midshelf water body was compliant to the Guidelines (Schaffelke et al. 2011). These results appear in close agreement with the remote sensing based estimates for P2R_WQI scores from 2007 to date of "poor" for this region and REEG lower than 10% for both CHL and TSS for the Midshelf water body.

Given the spatial and temporal complexity of the water quality in the GBR lagoon, the development of an integrated assessment and reporting framework is needed to provide a comprehensive and more easily interpretable assessment of GBR water quality. A separate research project carried out with Reef Rescue Research and Development funding for 2011-13 will further develop the exceedance/compliance metrics and identify how to combine the assessment over more variables to provide a high degree of confidence in these results. This will enable these datasets to meet the requirements of the reasonable assurance statements and the monitoring and modelling strategies for the Paddock to Reef reporting.

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APPENDIX 1 DETAILS OF ALGORITHM THEORETICAL BASIS FOR THE REGIONALLY VALID RETRIEVAL OF WATER QUALITY FROM SATELLITE IMAGERY

6.1 Regionally valid retrieval of water quality parameters from satellite imagery

Based on studies conducted in the Fitzroy Estuary (Brando et al. 2006, Oubelkheir et al. 2006) and the Mossman –Daintree (Steven et al. 2007), it has been demonstrated that the NASA standard global Ocean Colour algorithms are inaccurate in nearshore GBR waters (Qin et al. 2007). Subsequently, there has been considerable effort in developing regionally appropriate algorithms for these optically complex GBR waters. Studies commissioned by GBRMPA on water quality monitoring (Schaffelke et al. 2006) and optical characterisation of coastal waters (Blondeau-Patissier et al. 2009) have also been undertaken and contributed to the development of regionally appropriate algorithms using a semi-analytical physics-based approach parameterised and validated with local measurements.

In this work we coupled two physics-based inversion algorithms with the objective to improve the accuracy of CHL and IOP estimates from MODIS Aqua data in GBR Lagoon coastal waters. In a first step, an atmospheric correction algorithm based on inverse modelling of radiative transfer simulations and Artificial Neural Network (ANN) inversion derives the remote sensing reflectance at mean sea level (Schroeder et al. 2008). Then, the inherent optical properties and the concentrations of the optically active constituents (CHL, NAP and CDOM) are estimated using an enhancement of the Linear Matrix Inversion (LMI, Hoge and Lyon 1996) that incorporates regional and seasonal knowledge of specific IOPs (Brando et al. 2008, Brando et al. 2012, Schroeder et al. 2012).

As the ANN atmospheric correction uses as input MODIS Top-Of-Atmosphere radiance spectra, the MODIS aqua time series is first processed with NASA's software (SeaDAS), and then with CSIRO's coupled physics-based inversion algorithms.

6.2 Atmospheric correction

The atmospheric correction algorithm applied in this report was developed by inverse modelling of radiative transfer (RT) calculations within a coupled ocean–atmosphere system by utilizing artificial neural network (ANN) techniques. The algorithm was implemented similar to an approach developed by Schroeder et al (2007) for MERIS, but with a different inverse model capable of generating more complex network architectures (Schroeder et al. 2008). Within this model-based approach, ANNs were found to be well suited models to deal with optically-complex coastal waters because multilayer feed-forward networks with nonlinear transfer functions, as implemented for this report, are known as universal function approximators (Hornik et al. 1989).

By utilizing an established and validated radiative transfer code as a forward model (Fischer and Grassl 1984, Fell and Fischer 2001), a large data base of azimuthally resolved upward radiances in the MODIS channels at the Bottom-Of-Atmosphere (BOA) and at the Top-Of-Atmosphere (TOA) was generated for a variety of sun and observing geometries as well as different types of atmospheric and oceanic constituents. Different inverse models (ANNs) were trained under a supervised learning procedure by applying a non-linear optimisation routine on the basis of a randomly selected data

subset of 100.000 spectra taken from the simulated data base. A detailed description of all inputs to the RT model can be found in Schroeder et al (2007). The learning was stopped for all networks after 1.000 iterations with the full subset of 100.000 simulated input vectors. A single input vector contained the complete MODIS TOA reflectance spectrum of the bands 8-16, the sun and observing geometry and the surface pressure. The associated output vector consisted of the reflectance spectrum at mean sea level (MSL) for the MODIS bands 8-15 (412-748 nm). At the end of the training phase inverting "real-world" MODIS data and comparing the outputs against concurrent in-situ observations accessed the accuracy of the networks. Therefore, a match-up database was compiled containing *in-situ* above water reflectance measurements collected by the German GKSS Institute for Coastal Research and the Belgian Management Unit of the North Sea Mathematical Models (MUMM) during various field campaigns in North Sea turbid waters and by CSIRO in coastal waters of the GBR. The reflectance spectra were measured according to the REVAMP protocols (Tilstone et al. 2004) using Trios RAMSES and SIMBADA spectrometers. From the processed MODIS imagery 3x3 pixels were extracted at the location of the ground observations and the median satellite reflectance was compared with the in-situ measured reflectance within a maximum time window of ±3 hours to the satellite overpasses.

The performance of the ANN approach was also compared against three SeaDAS v6.1 implemented atmospheric correction methods. The implementation of these algorithms is the same in SeaDAS v6.4, hence the results presented in this section are still current as the in situ data were collected before 2010. In detail, we compared ANN with the SeaDAS standard near-infrared (NIR) algorithm (Gordon and Wang 1994, Gordon 1997), the shortwave-infrared (SWIR) algorithm (Wang and Shi 2005, Wang 2007, Wang et al. 2009) and the near-infrared shortwave switching (NISW) algorithm(Shi and Wang 2007, Wang and Shi 2007) Spectrally averaged match-up results for all four methods applied to the same data set of 49 spectra are shown in Figure 93 as scatter plots of *in-situ* reflectance versus satellite retrieved median reflectance.

With a Mean Absolute Percentage Error (MAPE) of 70% the SWIR atmospheric correction performed overall less accurate compared to the rest of the methods. The SWIR outputs appear noisy, which can be seen by the large standard deviation within some of the match-up areas of the scatter plot. Larger SWIR errors also affected the NISW algorithm with a spectrally averaged MAPE of 50%. Overall best performance was achieved by the ANN method followed by the NIR algorithm, showing retrieval errors of 24% and 34% respectively. All three SeaDAS algorithms showed over-correction for some spectra and consequently retrieved non-physical negative reflectance values mainly in the blue (412 nm) and NIR (748 nm) spectral region. The ANN algorithm was designed to output reflectance on logarithmic scale to eliminate this problem.

The associated spectrally resolved error statistics are presented in Figure 94 Larger relative errors can be observed from all algorithms especially in the blue and near-infrared spectral region as a consequence of the generally low absolute reflectance signal. The analysis showed that errors exceed 90% for the SWIR and NISW algorithms at 412 nm, while the NIR method produced better results with errors that exceed 50%. Most accurate results were obtained by the ANN method with errors of about 25% at 412 nm.

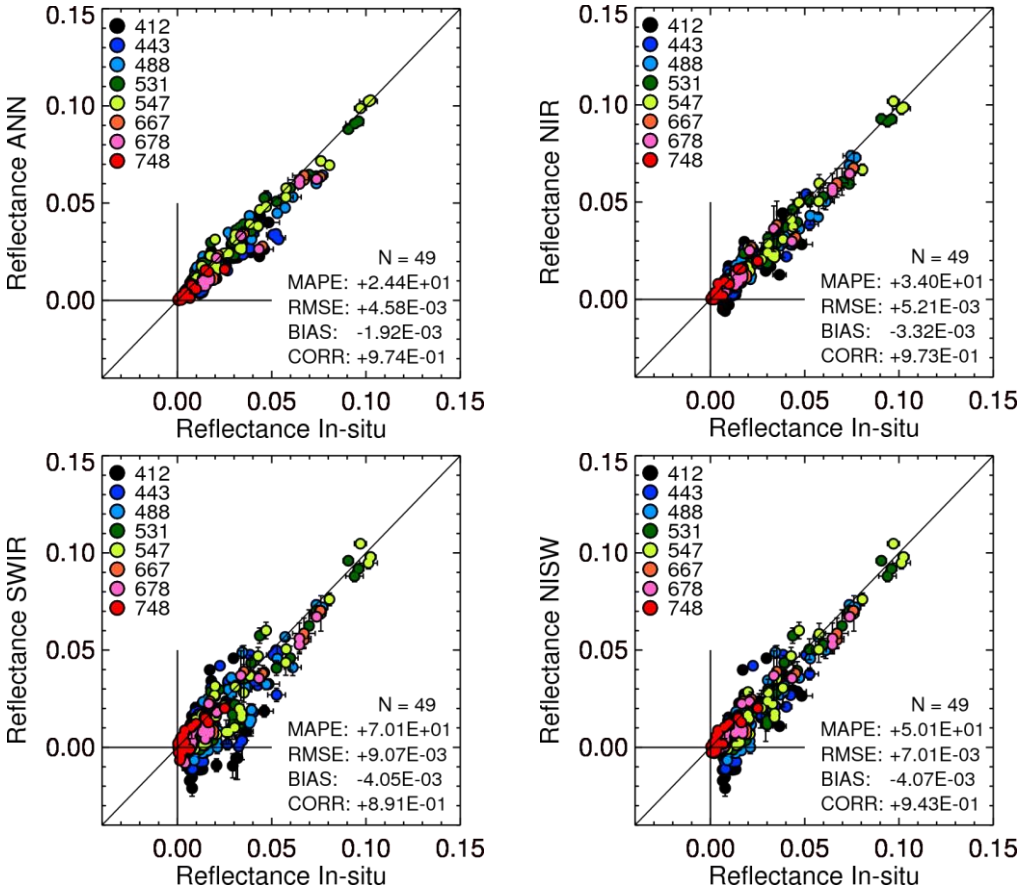

Figure 93: Scatter plots of in-situ versus satellite estimated median reflectance spectra for the ANN (top left) and three SeaDAS v6.1 implemented atmospheric correction methods.

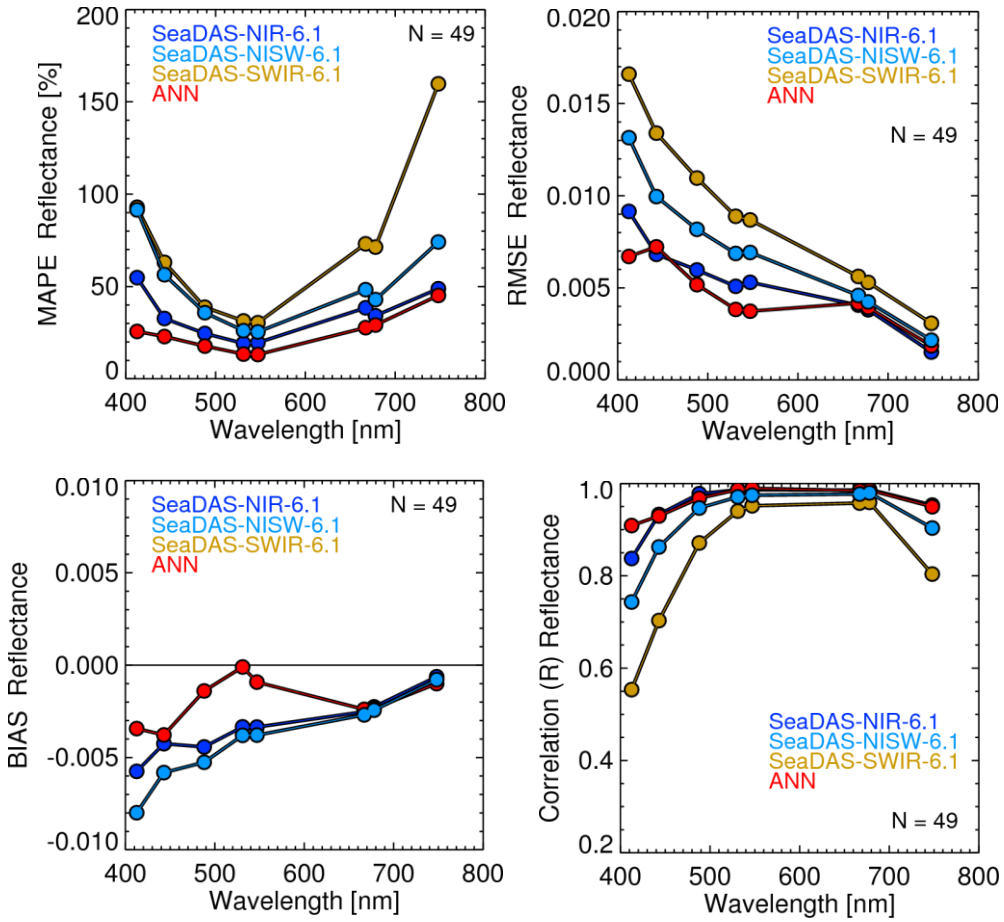

Figure 94: By comparison with *in-situ* reflectance measurements derived spectral slopes of RMSE (left) and MAPE (right) for the MODIS standard Level2 product generated with SeaDAS v6.1 and the proposed ANN algorithm.

Selected match-up spectra over the GBR region are presented in Figure 95 for waters with different turbidity levels. The NIR, SWIR and NISW methods generally underestimate the in-situ observations and in one instance atmospheric correction failure can be observed for the SWIR method retrieving negative values.

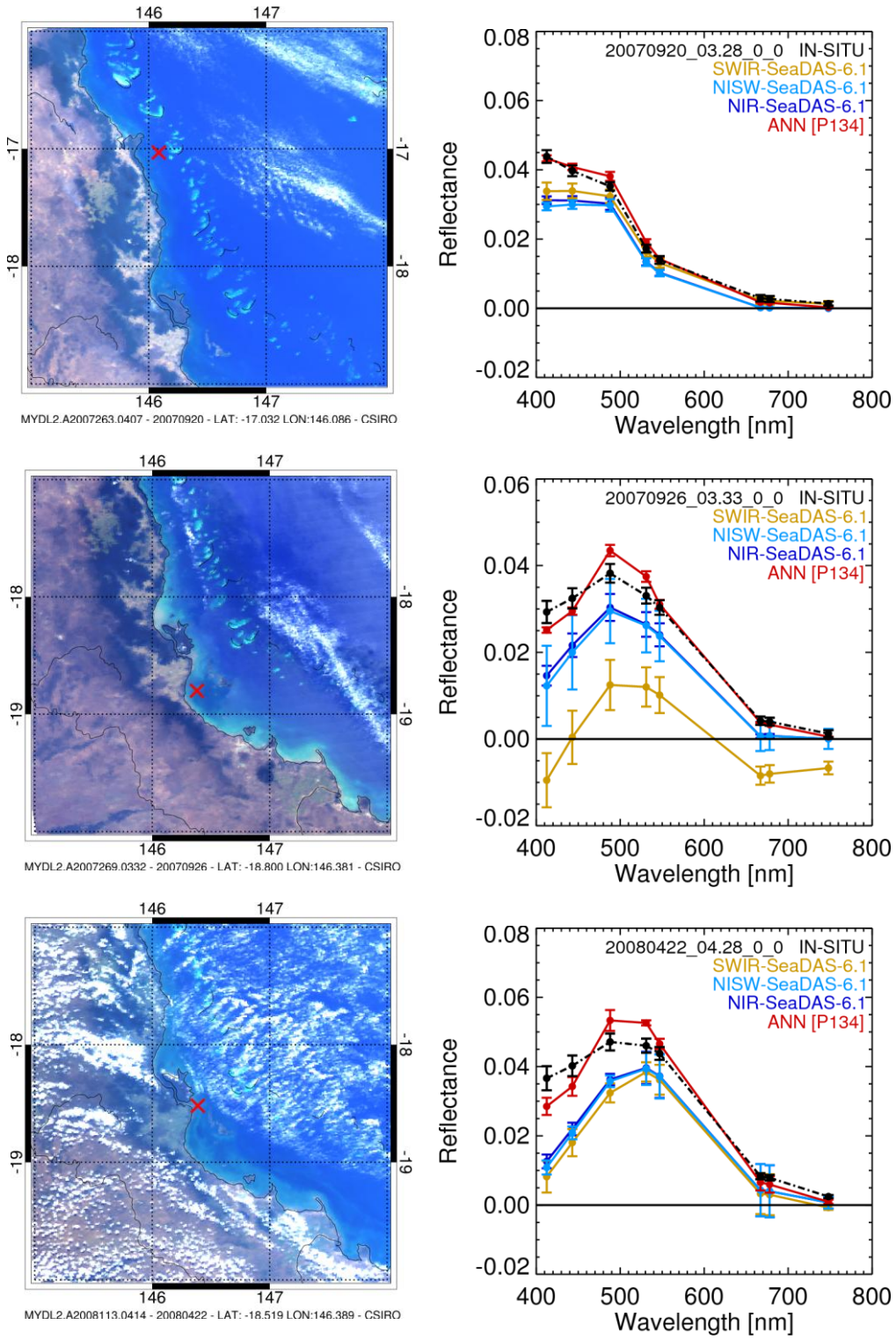

Figure 95: Selected in-situ (black) and associated atmospherically corrected spectra for illustrating the performance of the ANN and SeaDAS v6.1 implemented atmospheric correction methods over the GBR.

Recently the performance of CSIRO's ANN algorithm was compared to the SWIR, NISW and NIR methods based a different validation data set from Aeronet-OC (Goyens et al. 2013). Using data collected in large diversity of coastal water types from moderately turbid waters to very turbid waters, this study confirmed the results of Figure 93 and Figure 94: for water masses mainly influenced by

detrital and mineral material the CSIRO's ANN algorithm performed the best at all wavelengths. Future work for the validation of the atmospheric correction scheme in the GBR will rely on the match-up analysis of the normalized water-leaving radiances data-stream acquired on a daily basis at the Lucinda Jetty Coastal Observatory (LJCO).

6.3 Optical water quality retrieval

Previous studies in the GBR have shown that the spatial and temporal variability in the composition and concentration of particulate and dissolved matter is translated into significant variability in the shape and amplitude factors controlling the inherent optical properties (IOP) of water masses (Oubelkheir et al. 2006; Blondeau-Patissier et al., 2009).

Furthermore, it has been demonstrated that in the GBR near-shore coastal waters, as in several other coastal systems in the world, the NASA standard global Ocean Colour algorithms are inaccurate because of the large variability in IOP spectral shapes (Brando et al. 2006; Qin et al. 2007). These algorithms are work well for open ocean waters but have not been designed for optically complex coastal waters (IOCCG, 2000).

The accuracy of CHL retrieval for the seven NASA global CHL algorithms implemented in SeaDAS generally degraded rapidly with increasing CDOM and NAP concentrations (Qin et al. 2007). The level of disagreement was at least twofold for CHL concentrations above 2 µg L^{-1}. The gsm01 (Maritorena et al. 2002) algorithm was shown to work relatively better in the widest range of CDOM and NAP concentrations, while the Carder (Carder et al. 2003) algorithm has the highest accuracy for low CDOM and NAP concentrations. For the retrieval of bulk IOP, Qin et al.(2007) found that the three semi-analytical algorithms Carder, gsm01 and QAA seem unable to break down the total absorption coefficient, a, into its components, a_{ph} (phytoplankton) and a_{dg} (CDOM + NAP). This is probably because the three algorithms used a_{dg} slopes (QAA: 0.015, gsm01: 0.0206 and Carder: 0.0225) that are different than the values of S_{NAP} and S_{CDOM} found in the GBR coastal waters. (Brando et al. 2008) have shown that considerable differences in optical properties and concentrations are found between the dry and wet season for the GBR lagoonal waters.

6.3.1 IOP and concentrations retrieval – a-LMI

To improve the accuracy of CHL, CDOM, NAP and IOP estimates from MODIS Aqua data in GBR Lagoon coastal waters, in this project an adaptive implementation of the Linear Matrix Inversion (LMI, Hoge and Lyon 1996) was used to incorporate regional and seasonal knowledge of variability in the specific inherent optical properties for concentration, specific light absorption and scattering encountered in GBR coastal waters (Brando et al., 2010; Brando et al., 2012). The adaptive implementation of LMI (a-LMI hereafter) used in this study estimates simultaneously the IOPs and concentrations of chlorophyll-a, total suspended sediment and CDOM from atmospherically corrected spectra (Brando et al., 2012).

LMI has been already successfully applied to retrieve the concentrations of the optically active constituents in inland and coastal waters with hyperspectral data (Hoogenboom et al. 1998, Brando and Dekker 2003, Giardino et al. 2007). This algorithm was adapted to MODIS for the Fitzroy River Estuary Keppel Bay (southern GBR) (Brando et al. 2006, Brando et al. 2007) and applied to the MODIS Aqua data for the whole GBRWHA (Brando et al. 2006, Schaffelke et al. 2006).The a-LMI

method as outlined here uses the below-water remote sensing reflectance spectrum of the eight MODIS bands 8-15 (412-748 nm) as input to a semi-analytical model developed by Gordon et al. (1988) to simultaneously derive the three optically active constituents in an algebraic manner.

One of the major weaknesses of the LMI is the difficulty of parameterising a stable spectral shape for each SIOP to reflect the natural variability (Lyon and Hoge 2006). To overcome this, Wang et al. (2005) made use of an over-determined system (3x4, λ=410, 440, 490 and 550 nm) to explore the observed range of variability of the IOP shape factors. In a-LMI, to incorporate regional knowledge of specific IOPs, the imagery inversion is performed while varying the SIOP shape parameters through a through a small group of predetermined combinations, i.e. the candidate model parameter sets (Brando et al., 2012). Each candidate model parameter set corresponds to a naturally occurring set of SIOP shape and amplitude parameters ($a^*_{phy}(\lambda)$, S_{CDOM}, $a^*_{\mathrm{NAP}}(440)$, S_{NAP}, $b^*_{b\mathrm{phy}}(555)$, γ_{phy}, $b^*_{b\mathrm{NAP}}(555)$, γ_{NAP}) estimated from a suite of *in situ* measurements and samples collected concurrently at a sampling station during a field campaign, hence each of these model parameter sets is time, location and water-type specific. By performing the spectral inversion only for a limited number (L, Figure 96) of naturally occurring model parameter sets, unnatural (or highly unlikely) combinations of the SIOP shape and amplitude parameters are avoided (Brando et al., 2012).

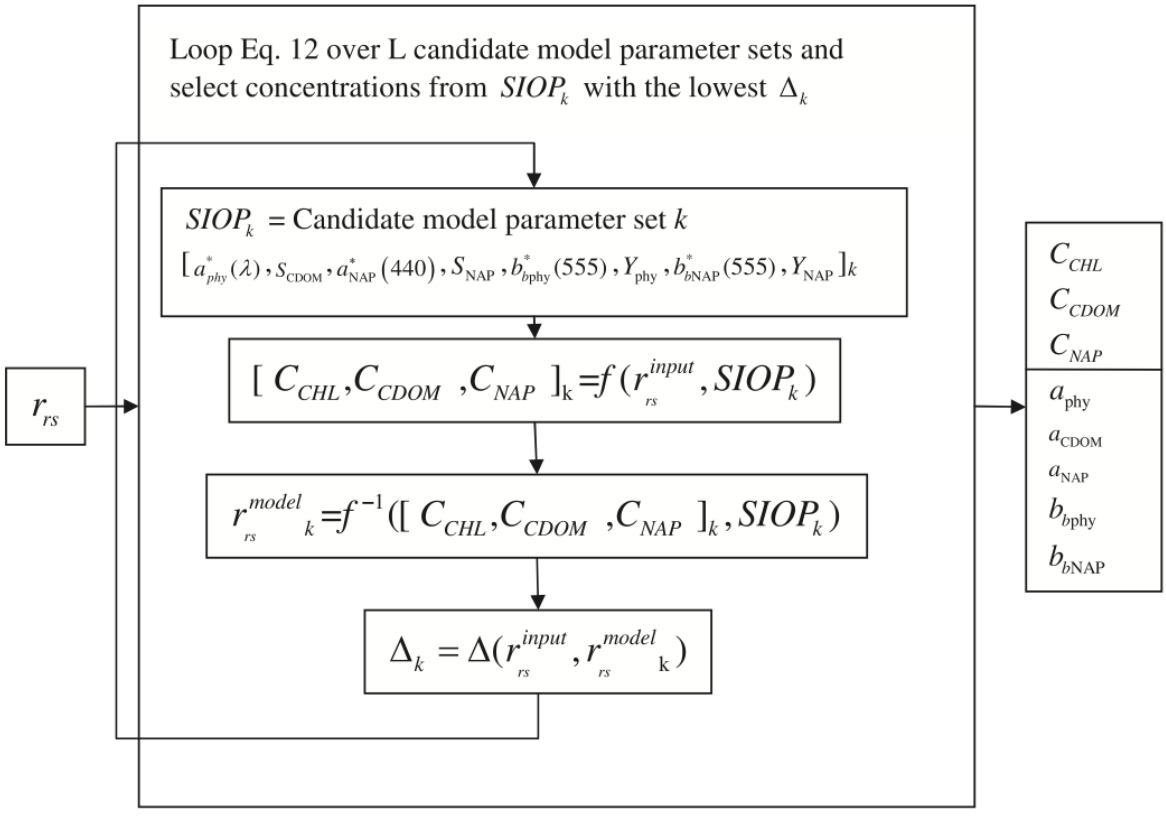

Figure 96. Conceptual diagram of the adaptive Linear Matrix Inversion approach adopted for the retrieval of Chlorophyll-a and IOPs from MODIS Aqua data (reproduced from Brando et al. (2012).

In a-LMI the model parameter set, the IOPs and concentrations values associated with the best optical closure $\Delta(r^{input}_{rs}, r^{model}_{rs})$ are retained as the optimal solution for each inverted spectrum (Figure 96). With this approach, no *a priori* assumptions are made on the occurrence of a specific water mass at

any given location during the inversion of satellite imagery. A more detailed description of the algorithm is provided in Brando et al. (2012).

6.3.2 Parameterization of a-LMI for the GBR

The original selection of the candidate model parameter set is described in the MMP 2006 report (Appendix 1 pages A40- A-57, Schaffelke et al. 2006). This parameterization was based the in situ datasets over the period 2002-2005 to adequately represented the full range of SIOPs measured from Cape Tribulation down to Port Curtis. The variability in this data set is described in (Blondeau-Patissier et al. 2009). The parameterization of a-LMI for the GBR has then evolved in the over the years as result of continuous QA/QC of the bio-optical data used as input and of the accuracy assessments carried out each year.

For this report, after the full reprocessing of the MODIS time series with the SEADAS version 6.4 and the subsequent ANN and ALMI processing, an analysis of the SIOP occurrence maps identified that two of the ten candidate parameter sets in LMI_CLU4 were leading to over-estimates of NAP retrievals in lagoonal waters. Hence those two candidate sets were removed and the revised version of the LMI adaptive parameterization composed of eight candidate parameter sets was labelled LMI_CLT4.

For this report, after the full reprocessing of the MODIS time series with the SEADAS version 6.4, an analysis of the SIOP occurrence maps was carried out and two of the ten candidate parameter in LMI_CLU4 were removed as they were leading to over-estimates of NAP retrievals in lagoonal waters. This revised version of the LMI adaptive parameterization composed of eight candidate parameter sets was labelled LMI_CLT4. Table 42 and Figure 97 present the sets of SIOP shape and amplitude parameters currently used to parameterize the a-LMI algorithm to estimate simultaneously the concentration of Chlorophyll-a, total suspended sediment, and CDOM.

The effect of these changes in the parameterization to the accuracy of the retrievals of TSS will be presented in section 6.5.

Table 42 The SIOP shape and amplitude parameters for the candidate model parameter set in the adaptive parameterization LMI_CLT4.

Cluster	Site	bb_phy_slope	Bb_phy_555nm	a_cdom_slope	a_tr_slope	a_tr_440nm	bb_tr_slope	bb_tr_555nm
1	AS05_WQN026	0.6649	0.0006	0.0336	0.0115	0.0188	0.6649	0.0064
2	MD 7D	0.7735	0.0006	0.0171	0.0119	0.0401	0.7735	0.0084
3	FK35	0.421	0.0006	0.0116	0.0099	0.0281	0.421	0.0063
4	FK2-30	0.6065	0.0006	0.0181	0.0148	0.0271	0.6065	0.0128
5	FK2-23	0.8579	0.0006	0.0192	0.0118	0.0438	0.8579	0.0145
6	MD 15D	0.8393	0.0006	0.0144	0.0115	0.0266	0.8393	0.008
7	AA05_WQS015	0.6003	0.0006	0.0105	0.0119	0.0057	0.6003	0.0028
8	AO02_SAT0021	1.3086	0.0006	0.0145	0.0124	0.0118	1.3086	0.0049

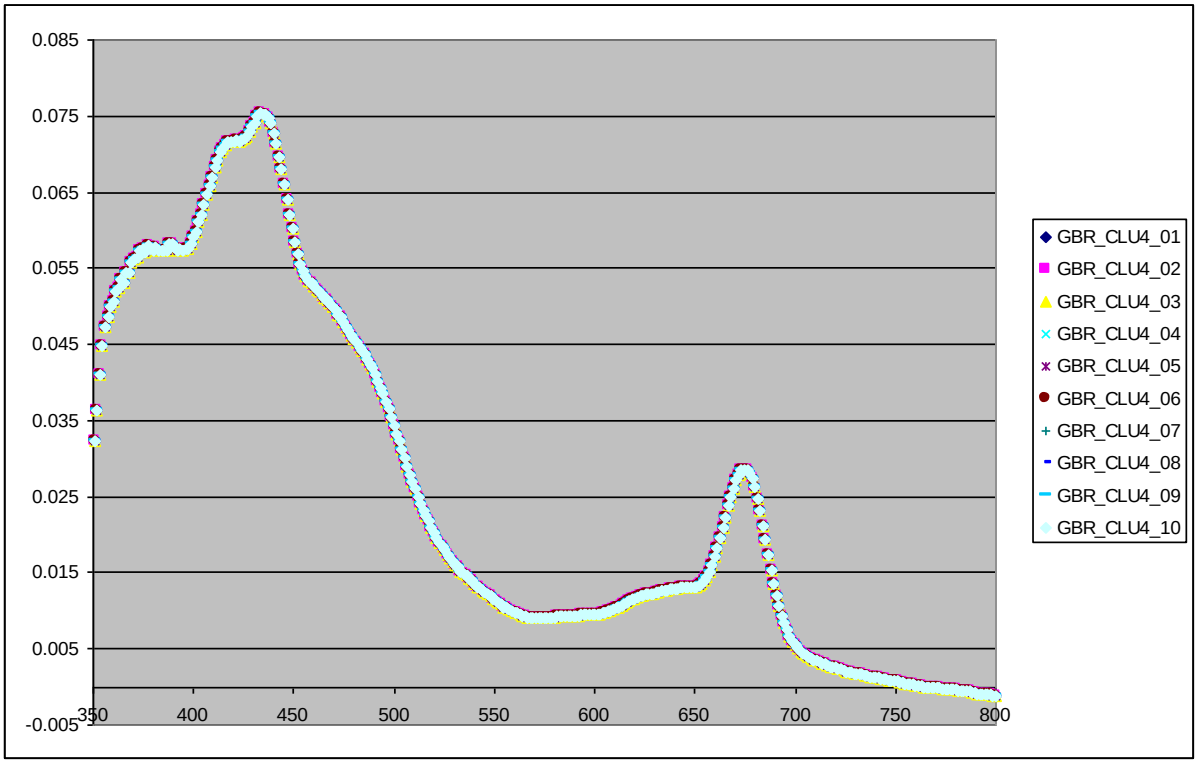

Figure 97. a_{phy}* spectra for LMI inversion adopted in the 2008 MMP version of the parameterization (LMI_CLU4).

6.4 Algorithm validation

In the remote sensing literature *validation* refers to the independent verification of the physical measurements made by a sensor as well as of the derived geophysical variables. Validation allows for the verification and improvement of the algorithms used (e.g. for atmospheric correction and retrieval of water quality variables). To achieve this, conventional, ground-based observations are required using calibrated and traceable field instrumentation and associated methods.

The match-up data base included ~2000 data points measured by 5 institutions, mostly only chlorophyll. The validation database is based on several sources of in situ observations:

- The GBR Long Term Monitoring Program (GBR-LTMP) dataset. The GBR- LTMP dataset includes Chlorophyll-a measurements going back as far as 1992 (thus including the start of the first contemporary ocean colour sensor SeaWiFS, launched in 1997). This monitoring program was designed to monitor water quality status at regional spatial scales (Brodie et al. 2007). The sampling stations for GBR-LTMP were situated some distance (~1-2 km) from the edge of nearby reefs to avoid confounding influences from biological activity on the reef itself (Brodie et al. 2007) Chlorophyll-a and phaeophytin concentrations were determined fluorometrically, and a suite of site variables (water depth, presence of Trichodesmium and weather conditions) was measured to aid interpretation of the Chlorophyll-a a data (Brodie et al. 2007).

- CHL data from the Cairns transect collected by Miles Furnas and co-workers (AIMS) between 1988 and 2006.
- CDOM, TSS and CHL data collected by Michelel Devlin and co-workers (JCU-ACTFR) during flood monitoring projects
- CDOM, TSS and CHL data collected by CSIRO during several optical characterization projects.
- CHL data collected at the IMOS National Reference Station moored at the Yongala wreck.

The measurement campaigns for GBR-LTMP, AIMS and ACTFR data sets were not designed for remote sensing validation purposes and thus the sampling protocols do not follow remote sensing validation guidelines (i.e. minimum distance of 5 km from land or islands, sampling time planned in function of satellite overpass, etc.). Hence during the matchup-analysis the number of available observation is dramatically reduced (Table 43).

The CHL, TSS (or NAP) and CDOM measurements of the combined validation database were used to assess the accuracy for the retrieval of these water quality variables as retrieved with the algorithms implemented in SeaDAS v6.4, i.e. the up-to-date version of NASA's processing software for MODIS imagery, and by the regionally parameterized algorithm (LMI_CLT4) coupled with the Artificial Neural Network atmospheric correction. For this comparison, we extracted from the remote sensing data the average value of the nine pixels (a square of 3x3 pixels) centred at the GPS location of the in situ measurements, for each available date, if at least 5 of the nine pixels passed the quality control flags. Only the measurements collected within ±3 hours of the satellite overpass were used in this analysis. Quality flags were checked and masks applied for land, glint, cloud, atmospheric correction failure and for solar zenith and observer zenith above a maximum of 60 degree. The number of data points for this analysis is different between CSIRO and NASA algorithms for the three variables as CSIRO's internal quality control for the Atmospheric correction is more stringent than NASA's standard.

The *in situ* Chlorophyll-a data were used to evaluate the Chlorophyll-a retrievals by the LMI_CLT4 and gsm01 algorithms, as the gsm01 (Maritorena et al. 2002) algorithm was shown to work relatively better in the widest range of CDOM and NAP concentrations for these coastal waters (Qin et al. 2007). Figure 98 presents the results of the MODIS Aqua Chlorophyll-a retrieval comparison with *in situ* data in logarithmic scale. LMI has lower MAPE, RMSE and bias than gsm01 (Table 43). These results are consistent with the findings of the sensitivity analysis carried out for these coastal waters (Qin et al. 2007).

The *in situ* TSS data were used to evaluate the NAP retrieval by LMI_CLT4 (as a measure of TSS) and the Clark algorithms, as it is the only one currently implemented in SEADAS for the retrieval of TSS. Figure 99 presents the matchup for MODIS Aqua TSS retrieval versus *in situ* data: a-LMI shows a lower bias and MAPE that Clarks algorithm (Table 43). Please note that in the GBR coastal waters NAP accounts for 95-99 % of TSS, as NAP is the concentration of Total Suspended Solids minus the dry weight of algal particles (Blondeau-Patissier et al. 2009).

The *in situ* CDOM data were used to evaluate the CDOM retrieval by LMI_CLT4 and the QAA algorithms, as the QAA algorithm was shown to work relatively better than others for these coastal waters (Qin et al., 2007). Figure 100 presents the matchup for MODIS Aqua $a_{CDOM}(443)$ retrieval vs. *in situ* data: the number of matchups is 18 for $a_{CDOM}(443)$ and 27 for $a_{dg}(443)$. QAA's $a_{dg}(443)$

overestimates CDOM in *situ data* as it provides an estimate of the absorption due to CDOM and NAP (Table 43).

It should be noted that most of this matchup analysis is based mainly on dry season observations, but the high concentrations of TSS and CHL measured in flood appear to skew the results (Figure 98, Figure 99). If the data points collected by ACTFR during flood monitoring are excluded from the validation statistics, the uncertainties were reduced significantly for a-LMI as well as NASA's algorithms (Table 44).

The comparison of MODIS Aqua retrievals of CHL, CDOM and NAP with *in situ* data showed that revised parameterization of regional algorithm coupled with the Artificial Neural Network atmospheric correction led to lower uncertainties than the NASA standard processing for the full MODIS AQUA time series that was reprocessed consistently with the latest SEADAS version 6.4. The results of the matchup analysis for Chlorophyll-a, CDOM and TSS are consistent with the findings of the sensitivity analysis based on radiative transfer modelling that was carried out for these coastal waters (Qin et al., 2007).

These results are not directly comparable to the accuracy assessments of previous reports, as they are based on a different number of matchups.

Table 43 Validation statistics for the measurements collected with 3 hours of the overpass. RMSE is the root mean square error, MAPE the mean absolute percentage error.

Variable	Algorithm	N	RMSE	MAPE	Bias
Chlorophyll-a	a-LMI	266	0.85127	88.91%	0.07716
Chlorophyll-a	GSM	366	7.08165	252.4%	1.01867
TSS (NAP)	a-LMI	114	8.47601	68.60%	-3.6495
TSS	Clark	162	58.4155	246.2%	4.95825
CDOM	LMI	18	0.08183	77.13%	-0.0017
a_{dg} (CDOM + NAP)	QAA	27	0.95100	233.6%	0.32437

Table 44 Validation statistics for the measurements collected with 3 hours of the overpass. RMSE is the root mean square error, MAPE the mean absolute percentage error. Statistics excluding the data points collected by ACTFR during flood monitoring projects are reported.

Variable	Algorithm	N	RMSE	MAPE	Bias
Chlorophyll-a	a-LMI (no flood)	211	0.73652	75.19%	-0.0274
Chlorophyll-a	GSM (no flood)	318	2.27157	166.3%	0.36061
TSS (NAP)	a-LMI (no flood)	66	1.08602	66.85%	-0.5695
TSS	Clark (no flood)	91	2.83893	301.1%	-1.0968

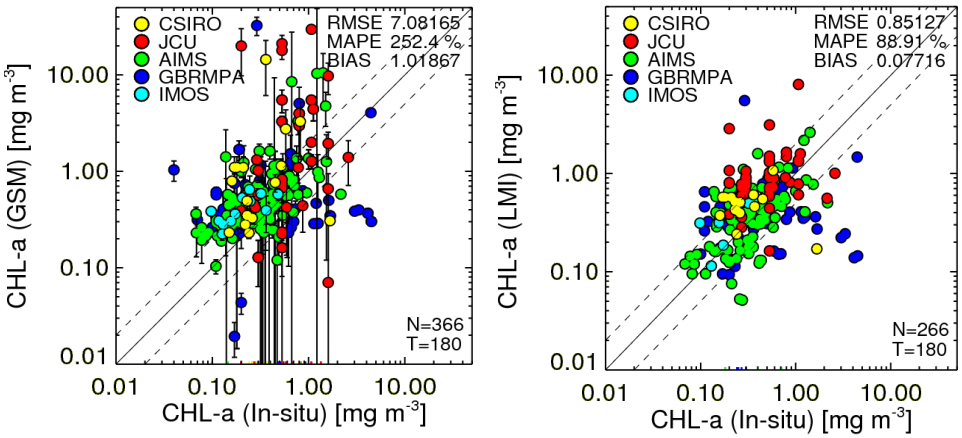

Figure 98: MODIS Aqua Chlorophyll-a retrieval versus *in situ* data. The dashed lines present an over or underestimate of 100%. Only the measurements collected within ±3 hours time difference to the overpass were plotted. Number of matchups is 266 for a-LMI and 366 for gsm01.

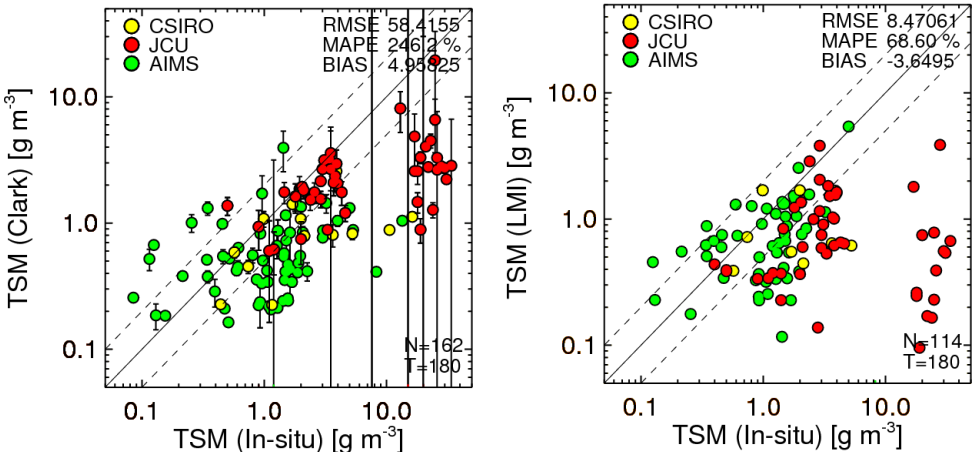

Figure 99: MODIS Aqua TSS retrieval versus *in situ* data. The dashed lines present an over or underestimate of 100%. Only the measurements collected within ±3 hours time difference to the overpass were plotted. Number of matchups is 114 for LMI and 162 for Clark.

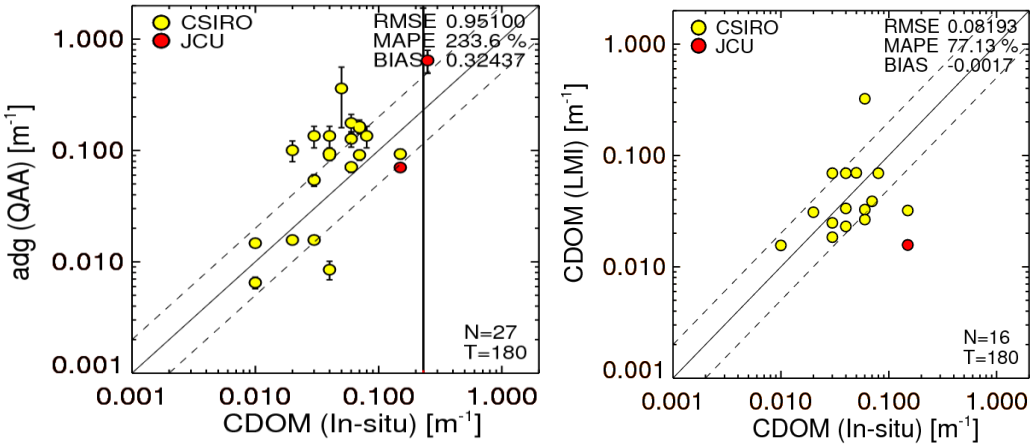

Figure 100: MODIS Aqua a_{CDOM} (443) and a_{dg}(443) retrievals versus *in situ* data. The dashed lines present an over or underestimate of 100%. Only the measurements collected within ±3 hours time difference to the overpass were plotted. Number of matchups is 16 for LMI and 27 QAA.

6.5 Accuracy assessment for the superseded parameterization

As mentioned in section 6.3.2, for this report two of the ten candidate parameter set in the LMI_CLU4 parameterization were removed as they were leading to over-estimates of NAP retrievals in lagoonal waters. Figure 101 presents the matchup for MODIS Aqua TSS retrieval versus in situ data using a-LMI (with the LMI_CLU4 parameterization). In the range 0.1-2 mgL^{-1} there are more than ten data points over-estimating more than 100%, i.e. appear above the upper dashed line. Most of these of these data points were closer to the 1:1 line when using the revised version of the LMI adaptive parameterization composed of eight candidate parameter sets (LMI_CLT4) presented in Figure 99.

Overall the summary statistics (Table 45, and Table 46) show that the accuracy of TSS retrieval improved with the revised parameterization (Table 43 and Table 44), particularly if the data points collected by ACTFR during flood monitoring are excluded from the validation statistics: 5 The accuracy for the retrieval of CHL and CDOM was similar for both parameterizations.

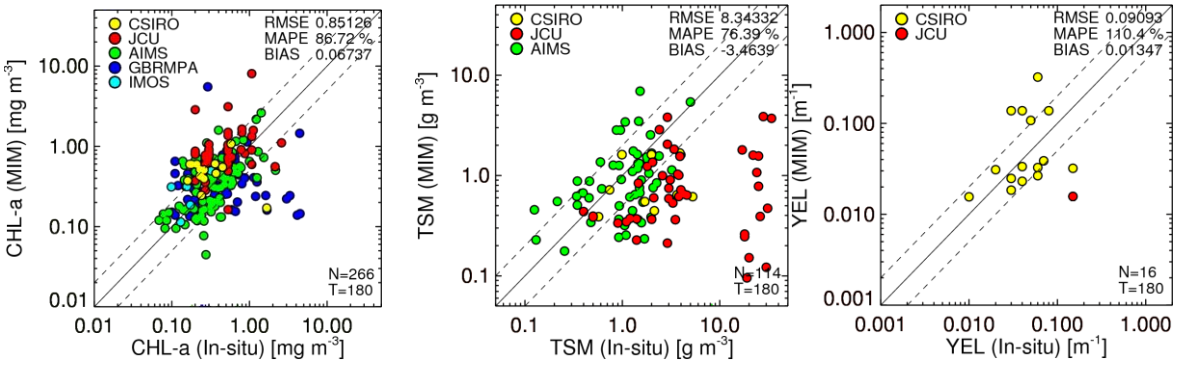

Figure 101: MODIS Aqua scatter plots for the superseded LMI_CLU4 parameterization. The dashed lines present an over or underestimate of 100%.

Table 45 Validation statistics for the measurements collected with 3 hours of the overpass for the superseded parametrization LMI_CLU4. RMSE is the root mean square error, MAPE the mean absolute percentage error.

Variable	Algorithm	N	RMSE	MAPE	Bias
Chlorophyll-a	a-LMI (LMI_CLU4)	266	0.85126	86.72%	0.06737
TSS (NAP)	a-LMI (LMI_CLU4)	114	8.34332	76.39%	-3.4639
CDOM	a-LMI (LMI_CLU4)	18	0.09093	110.4%	-0.01347

Table 46 Validation statistics for the measurements collected with 3 hours of the overpass for the superseded parametrization LMI_CLU4. RMSE is the root mean square error, MAPE the mean absolute percentage error. Statistics excluding the data points collected by ACTFR during flood monitoring projects are reported

Variable	Algorithm	N	RMSE	MAPE	Bias
Chlorophyll-a	a-LMI (LMI_CLU4) (no flood)	211	0.73981	73.35%	-0.0381

TSS (NAP)	a-LMI (LMI_CLU4) (no flood)	66	1.3451	78.70%	-0.2689
CDOM	a-LMI (LMI_CLU4) (no flood)	18	0.08728	111.8%	-0.02333

APPENDIX 2. LIST OF SCIENTIFIC PUBLICATIONS, SCIENTIFIC PRESENTATIONS AND COMMUNITY SEMINARS ARISING FROM THE MONITORING PROGRAM

Journal Papers

Peer-review papers describing outcomes of this project:

- Kennedy, K., T. Schroeder, M. Shaw, D. Haynes, S. Lewis , C. Bentley, C. Paxman, S. Carter , V. Brando, M. Bartkow, and J. Mueller, *Long term monitoring of photosystem II herbicides – Correlation with remotely sensed freshwater extent to monitor changes in the quality of water entering the Great Barrier Reef, Australia.* Marine Pollution Bulletin, 2012. **65**(4-9): p. 292-305.
- Schroeder, T., M.J. Devlin, V.E. Brando, A.G. Dekker, J.E. Brodie, L.A. Clementson, and L. McKinna, *Inter-annual variability of wet season freshwater plume extent into the Great Barrier Reef lagoon based on satellite coastal ocean colour observations.* Marine Pollution Bulletin, 2012. **65**(4-9): p. 210-223

Peer-review papers describing the remote sensing methods used in this project:

- Brando, V.E., A.G. Dekker, Y.J. Park, and T. Schroeder, *Adaptive semianalytical inversion of ocean color radiometry in optically complex waters.* Applied Optics, 2012. **51**(15): p. 2808-2833.
- Goyens C., C. Jamet, T. Schroeder , *Evaluation of four atmospheric correction algorithms for MODIS-Aqua images over contrasted coastal waters, Remote Sensing of Environment, 2013,* 131: 63–75
- Werdell P. J , B.A. Franz, S.W. Bailey, G.C. Feldman, E. Boss, V.E. Brando, M. Dowell, T.Hirata, S.J. Lavender, Z.P. Lee, H. Loisel, S. Maritorena, F. Melin, T.S. Moore, T.J. Smyth, D. Antoine, Emmanuel Devred, O. Hembise Fanton d'Andon, and Antoine Mangin, *A generalized ocean color inversion model for retrieving marine inherent optical properties*. Applied Optics, 2013, 52 (10) p 2019

Book Chapters

- Devlin, M., T. Schroeder, L. McKinna, J. Brodie, V. Brando and A. Dekker (2012). Monitoring and mapping of flood plumes in the Great Barrier Reef based on in-situ and remote sensing observations. Advances in Environmental Remote Sensing to Monitor Global Changes. N.-B. Chang. P 147-188

Conference presentations

- Blondeau-Patissier D. , Dekker A. G. , Brando V. E. , Phinn S. R. , Weeks S. J. , Phytoplankton bloom dynamics in the Great Barrier Reef derived from satellite data, 12th International Coral Reef Symposium, 9-13 July 2012, Cairns, Australia.
- V Brando, T Schroeder, A Dekker, B Schaffleke, M Devlin, Assessing GBR water quality compliance using earth observation data, 12th International Coral Reef Symposium, 9-13 July 2012, Cairns, Australia.
- K Martin, C Chinn, B Schaffelke, K Kennedy, A Thompson, L McKenzie, M Waycott, M Devlin, V Brando, J Brodie, H Yorkston, Assessing the effectiveness of water quality

management of the GBR, 12th International Coral Reef Symposium, 9-13 July 2012, Cairns, Australia

APPENDIX 3. SUMMARY OF THE EXCEEDANCE OF ANNUAL MEAN VALUES FROM 2002/03 TO DATE

This appendix provides the summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) values for all reporting periods from when MODIS AQUA data is available (i.e. 2002/03 to present)

For this report the whole MODIS aqua time series was reprocessed with the most recent updates in NASA's software (SeaDAS version 6.4), incorporating the improved knowledge of instrument temporal calibration to improve temporal stability of the time series of the MODIS AQUA aging sensor. Furthermore, the parameterizations of CSIRO's atmospheric correction and water quality algorithm were revised to improve accuracy in turbid waters and reduce over-estimates of TSS concentrations in the Midshelf.

In this appendix the REEG values for CHL and TSS (REEG_CHL, REEG_TSS) are presented within each reporting region as separate values for the newly delineated Enclosed Coastal, as well as the Open Coastal, Midshelf, and Offshore water bodies for all reporting years. Also a summary of all P2R scores for all reporting year is provided, based on the REEG values for the Inshore water body (i.e. the Enclosed Coastal and the Open Coastal waters). "To compute the REEG values for the whole Inshore region, pixels in the enclosed coastal areas are compared to the guidelines values for Enclosed coastal waters and only the pixels lying in the Open Coastal are compared with the guideline values for Open coastal waters."

All the results presented in this appendix supersede the exceedance assessments and the P2R scores presented previous reports.

Table 47. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2002/03 reporting period (1 May 2002 – 30 April 2003) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS).. Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0203	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	15	39	32	8	0	33	15	20	5	8
Wet Tropics	78	72	73	14	0	81	31	39	4	2
Burdekin	47	55	54	3	0	15	30	28	0	0
Mackay Whitsunday	16	26	24	6	3	45	28	32	17	13
Fitzroy	71	53	57	5	0	56	26	33	2	1
Burnett Mary *	16	60	51	3	0	0	2	1	0	0

Table 48. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2003/04 reporting period (1 May 2003 – 30 April 2004) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0304	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	17	60	47	13	0	48	35	39	7	6
Wet Tropics	73	88	85	21	0	76	54	58	7	0
Burdekin	55	55	55	4	0	13	40	36	0	0
Mackay Whitsunday	20	26	25	4	1	52	32	36	8	8
Fitzroy	76	45	52	3	0	67	29	37	2	1
Burnett Mary *	22	50	44	3	0	0	3	2	0	0

Table 49. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2004/05 reporting period (1 May 2004 – 30 April 2005) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0405	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	14	44	35	7	0	36	18	24	2	7
Wet Tropics	73	77	76	14	0	75	36	41	4	1
Burdekin	43	58	56	3	0	8	32	29	0	0
Mackay Whitsunday	16	19	19	4	0	39	21	25	8	10
Fitzroy	68	43	48	3	0	59	27	34	2	1
Burnett Mary *	18	36	33	2	0	0	1	1	0	0

Table 50. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2005/16 reporting period (1 May 2005 – 30 April 2006) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value.* Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0506	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	14	72	54	19	0	27	18	21	3	7
Wet Tropics	50	80	75	14	0	66	36	40	3	1
Burdekin	54	53	53	3	0	19	32	30	0	0
Mackay Whitsunday	15	20	19	5	0	45	17	23	9	8
Fitzroy	69	42	48	4	0	63	28	36	2	1
Burnett Mary *	11	42	36	2	0	0	2	1	0	0

Table 51. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2006/07 reporting period (1 May 2006 – 30 April 2007) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0607	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	27	75	60	17	0	57	31	39	5	8
Wet Tropics	84	90	89	21	0	77	49	53	5	2
Burdekin	54	55	55	4	0	18	36	33	0	0
Mackay Whitsunday	20	30	28	5	0	50	33	36	8	6
Fitzroy	71	44	50	4	0	63	27	35	2	1
Burnett Mary *	9	41	34	2	0	0	1	1	0	0

Table 52. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2007/08 reporting period (1 May 2007 – 30 April 2008) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value.* Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0708	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	13	55	42	11	0	31	10	17	1	5
Wet Tropics	56	79	76	16	0	66	23	30	3	0
Burdekin	45	63	61	5	0	8	25	22	0	0
Mackay Whitsunday	21	32	30	4	0	45	19	24	8	6
Fitzroy	65	58	59	5	0	56	32	38	2	0
Burnett Mary *	14	59	50	4	0	0	3	2	0	0

Table 53. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2008/09 reporting period (1 May 2008 – 30 April 2009) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value.* Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0809	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	18	60	48	13	0	46	28	33	5	7
Wet Tropics	81	88	87	22	0	71	31	37	3	0
Burdekin	61	69	68	8	0	12	27	25	0	0
Mackay Whitsunday	19	37	33	7	1	44	24	28	9	9
Fitzroy	75	57	61	5	0	66	32	40	3	1
Burnett Mary *	15	56	48	4	0	0	2	1	0	0

Table 54. Summary of the exceedance of mean annual Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2009/10 reporting period (1 May 2009 – 30 April 2010) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
0910	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	14	54	42	11	0	31	12	17	4	7
Wet Tropics	65	85	82	21	0	63	33	38	4	0
Burdekin	61	69	68	6	0	17	31	29	0	0
Mackay Whitsunday	17	34	30	7	2	46	27	31	10	16
Fitzroy	77	67	69	7	1	64	28	36	3	3
Burnett Mary *	17	81	68	6	0	0	3	2	0	0

Table 55. Summary of the exceedance of annual mean values of Chlorophyll-a and non-algal particulate matter (as a measure of Total Suspended Solids) for the 2010/11 reporting period (1 May 2010 – 30 April 2011) for the Enclosed Coastal, Open Coastal, Inshore, Mid-shelf and Offshore water bodies (EC, OC, IS, MS, OS). Cells are shaded in gray when more than 50% of the area of the water body exceeds the Guideline value. * Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals.

	Chlorophyll-a: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value					Total Suspended Solids: Relative area (%) of the water body where the annual mean value exceeds the WQ Guideline value				
1011	EC	OC	IS	MS	OS	EC	OC	IS	MS	OS
Cape York*	5	78	61	25	0	45	26	32	5	6
Wet Tropics	76	94	92	32	1	72	34	39	4	0
Burdekin	63	69	68	12	0	11	30	27	0	0
Mackay Whitsunday	27	63	56	10	0	56	37	40	8	7
Fitzroy	86	76	78	8	0	65	32	40	2	1
Burnett Mary *	24	92	78	8	0	0	9	7	1	0

Table 56 Summary table for Paddock to Reef marine water quality index (P2R_WQI) for all reporting periods. Cells are shaded to reflect the colour coding of the P2R reporting scheme from red to green in

steps of 20%.* Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals. The regional scores for Cape York and Burnett Mary are excluded from calculations of the overall GBR score for each metric.

P2R_WQI	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
Cape York*	73	56	70	62	50	70	59	70	53	62
Wet Tropics	44	28	41	42	28	47	38	40	34	33
Burdekin	59	54	57	58	56	58	53	51	52	50
Mackay Whitsunday	72	69	78	79	67	72	69	69	52	59
Fitzroy	55	55	58	57	57	51	49	47	41	38
Burnett Mary *	73	76	83	81	82	74	75	64	57	53
GBR	**59**	**55**	**61**	**61**	**56**	**58**	**54**	**53**	**45**	**46**

Table 57 Summary table for the Paddock to Reef marine water quality component scores (P2R_CHL and P2R_TSS) for all reporting periods. Cells are shaded to reflect the colour coding of the P2R reporting scheme from red to green in steps of 20%.* Caution should be used when interpreting the results for the Cape York and Burnett Mary regions as limited field information was used for the parameterization and validation on the remote sensing retrievals. The regional scores for Cape York and Burnett Mary are excluded from calculations of the overall GBR score for each metric.

P2R_CHL	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
Cape York*	67	52	65	45	39	57	52	58	39	47
Wet Tropics	27	14	23	24	10	24	13	17	8	9
Burdekin	46	44	44	46	44	39	32	32	32	34
Mackay Whitsunday	75	74	81	81	72	70	66	69	44	58
Fitzroy	42	48	51	51	49	40	38	30	21	19
Burnett Mary *	48	55	67	63	65	50	52	31	21	15
GBR	**50**	**50**	**54**	**55**	**49**	**46**	**41**	**39**	**28**	**32**
P2R_TSS	0203	0304	0405	0506	0607	0708	0809	0910	1011	1112
Cape York*	79	60	76	78	60	83	66	82	68	76
Wet Tropics	61	42	58	59	46	70	63	62	60	57
Burdekin	72	64	71	69	67	77	74	70	72	65
Mackay Whitsunday	68	64	75	77	63	75	72	68	59	60
Fitzroy	67	62	65	63	64	62	60	64	60	58
Burnett Mary *	98	97	99	98	99	97	98	98	93	92
GBR	**68**	**60**	**68**	**68**	**62**	**70**	**67**	**66**	**62**	**60**

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