remote sensing

Editorial

Special Issue Overview: Advances in Remote Sensing and Mapping for Integrated Studies of Reef Ecosystems in Oceania (Great Barrier Reef and Beyond)

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Abstract: The recent widespread and recurrent coral bleaching events over the Great Barrier Reef, the largest coral reef system on Earth and a hotspot of marine biodiversity, are a reminder of the vulnerability of reef ecosystems to human activities and a warming world. Protection of the Great Barrier Reef and similar reef ecosystems across Oceania requires a better understanding of environmental and socio-economic pressures, as well as the development of integrated management strategies. The rapid expansion of Earth Observation technologies and data has greatly advanced our capability to map and monitor reef habitats, ecological processing and exposure risk, providing spatially rich data essential to support and evaluate management and conservation strategies. However, these technologies are proportionally still under-utilized, and it is important to synthesise remote-sensing-derived tools and methods currently available for mapping reef ecosystems in Oceania to facilitate their intake in coral reefs studies. Publications in this Special Issue contribute toward filling this gap and explore recent advances in remote sensing of the Great Barrier Reef and other reef ecosystems in Oceania, from novel methodological approaches (sensors, algorithm development and improved thematic classification) to applications for environmental monitoring and management.

Keywords: habitat mapping; coral reefs; water quality; river plumes; ocean colour; bio-optics; sensors; GIS; monitoring

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1. Introduction

Coral reefs and marine ecosystems are hotspots of marine biodiversity but are under substantial pressure throughout our oceans [1–3]. In 1974, the United Nations implemented the Regional Seas Conventions and Action Plans to protect the oceans and seas at the regional level [4]. Sustainable Development Goal (SDG) number 14 explicitly states the need to conserve and sustainably use the oceans, seas and marine resources. Coral reefs, seagrasses and healthy coastal systems are vital for our oceans and communities, supporting many different types of marine species and providing livelihoods and coastal protection for millions of people [1,5,6]. Climate change and ocean acidification impact all coral reefs at different levels. Local and regional pressures are also driving negative impacts, through overfishing and improper fishing practices, coastal development, land-based sources of pollution, including nutrient over-enrichment, increases in the frequency of extreme flood events and sedimentation inputs into the coastal zone and all aspects of marine pollution [7–12]. Other threats include harmful algal blooms, dredging, invasive species, shipping, marine litter, destruction of habitat and the loss of traditional conservation practices [13–22].

Oceania consists of four sub-regions in the Pacific Ocean: Australia and New Zealand, Polynesia, Melanesia and Micronesia. While about three-quarters of its people live on the biggest islands of Australia and New Zealand, most of the countries in Oceania consist of many scattered small islands and coral atolls with varied environmental settings, cultural values and different levels of marine conservation initiatives [15,22–25]. Amongst Oceania's coral ecosystems, the Great Barrier Reef (GBR, Australia) is the largest and one of the most intensely managed marine parks in the world [26]. The recent widespread and recurrent coral bleaching events in the GBR are a reminder of the vulnerability of this unique ecosystem and of similar ecosystems in Oceania to human activities and a warming world [27,28]. The small Pacific island states of Oceania are also some of the most vulnerable countries in the world to climate change through extreme weather events, droughts and rising sea levels [29,30].

Protection of reef ecosystems requires a better understanding of environmental and socio-economic pressures [31], integration of traditional ecological knowledge [32,33] and the development of integrated management strategies [34,35] to protect these high-value environments and habitats. This requires long-term monitoring of the water quality and a holistic understanding of the impacts on vulnerable marine habitats, including seagrasses, corals, wetlands and mangroves, and the consequences of physical modification of coastal environments [14,36,37]. The data required to assess, predict and manage coral reefs need to be long term, range from local to regional coverage and be acquired on a regular or daily basis [38]. Fully integrated assessments also require access to high-resolution bathymetry and topography data, maritime surveillance information on fishing and security. All these factors, typically at a local and national level, need to be considered alongside the impact of climate change, warming waters, increasing ocean acidification and coastal flooding. The connections between impacts and pressures are convoluted and complicated, and our data collection, analysis and reporting need to provide a large array of data to better understand these complexities and interactions.

While it is widely acknowledged that several natural and anthropogenic stressors threaten Oceania's coral reef ecosystems and the people who depend upon them, observational data to determine the status, extent and condition of coral reefs and the surrounding environments are still comparatively sparse. Gaps in knowledge are caused by the large dynamic areas across Oceania's ecosystems, coupled with their remoteness and accessibility for field studies. Many of the current monitoring methodologies are not adequate or have not been tested for the specific conditions of Oceania waters, with complex spatial and temporal variability. Specific challenges in collecting data are related to several key variables, including logistical, financial, geographical and environmental, with one of the major difficulties being the size and remoteness of Oceania islands as well as the accessibility to long-term funding for marine conservation. It is important to consider how to collect evidence in a manner that is efficient, realistic and cost effective, and that is tailored to the specificities of the reef ecosystems [39]. The rapid expansion of Earth observation technologies and data has greatly advanced our capability to map and monitor such environments, providing greater coverage and essential information to support and evaluate management and conservation strategies [9,40]. Satellite images have been implemented in operational marine monitoring programs of the water quality and habitat health in the GBR [40–43]. Several recent studies have demonstrated that methods using multiple datasets, including satellite imagery, are essential in the monitoring and management of remote, large and/or data-poor marine ecosystems such as those found in Oceania [44–49].

However, despite the potential in remote sensing technologies for mapping and monitoring reef ecosystems, these technologies are proportionally still under-utilized. This is due to a range of factors, including, but not limited to, communication, knowledge and methodological issues, as defined in Table 1. It is important to synthesise remote-sensing-derived tools and methods currently available for mapping and studying reef ecosystems in Oceania to facilitate their intake in coral reefs studies.

Table 1. Challenges in implementing remote sensing techniques across Oceania.

Challenges that Hinder the Use of RS Technologies in Oceania	Definition
Communication	Disconnection between academic research on remote sensing theories and the actual application by other scientist and managers of reef ecosystems
Knowledge	General lack of knowledge on the availability, suitability, cost and resolution of the various remote sensing datasets currently available
Methodological	Including the lack of standard methodologies for mapping water quality and habitats in coral reefs regions, or limited expertise and technical skills in monitoring teams to apply or adjust existing methodologies or applications
Confidence	Issues around accuracy, specifically data retrievals in nearshore and coastal areas where shallow, highly complex waters can reduce the accuracy of the remote sensed data or a general mistrust in the scientific value of the remote sensing techniques
Local	Including site safety and accessibility as well as financial or logistical constraints. Limit accessibility to ground reference data

Publications in this Special Issue contribute to helping filling this gap. The Special Issue intends to capture the latest research advances regarding the applications of remote sensing technologies in integrated studies of reef ecosystems in Oceania, from inshore coastal ecosystems to coral reefs. It includes 10 papers authored by 47 researchers from 35 research institutions, 4 countries and 4 seas [50].

Whilst many of the papers are focused on the GBR, the Special Issue also explores other large marine data-poor regions in Australia and across Oceania (Torres Strait, Pacific and Indian Oceans), where remote sensing offers the opportunity to improve the accuracy of data collection in remote areas with limited knowledge on their marine systems (Table 2 and Figure 1). The Special Issue covers the continuous development of remote sensing algorithms and image processing methods for mapping the biodiversity in reef ecosystems [51–55] and explores new sensors and bio-optical algorithms for monitoring water quality in coastal zones [52,54]. Improvements in the accuracy of water quality algorithms in reef and coastal ecosystems are promoted through specifically designed in situ bio-optical studies [51,53,54].

The Special Issue, however, also acknowledges the difficulty in collecting field datasets in isolated places in Oceania, as well as the difficulty for monitoring teams with limited technical expertise to select appropriate remote sensing tools. It, therefore, proposes qualitative colour classification methods [56] and decision trees [39] to facilitate the inclusion of remotely sensed information in monitoring data-poor environments. The critical scales of variability, from site to basin-scale and from short-term processes to long-term trends, are also discussed [52,53]. The Special Issue also presents the development of metrics to quantify risks, changes in the receiving environment and ecosystems and tools for evaluating these results for management strategies and using these data to support longer-term scientific goals [56,57]. Finally, the Issue explores the validity of techniques developed for the GBR transferring to other temperate marine areas, where remote sensing has improved data quality and helped quantify coastal water quality processes [57].

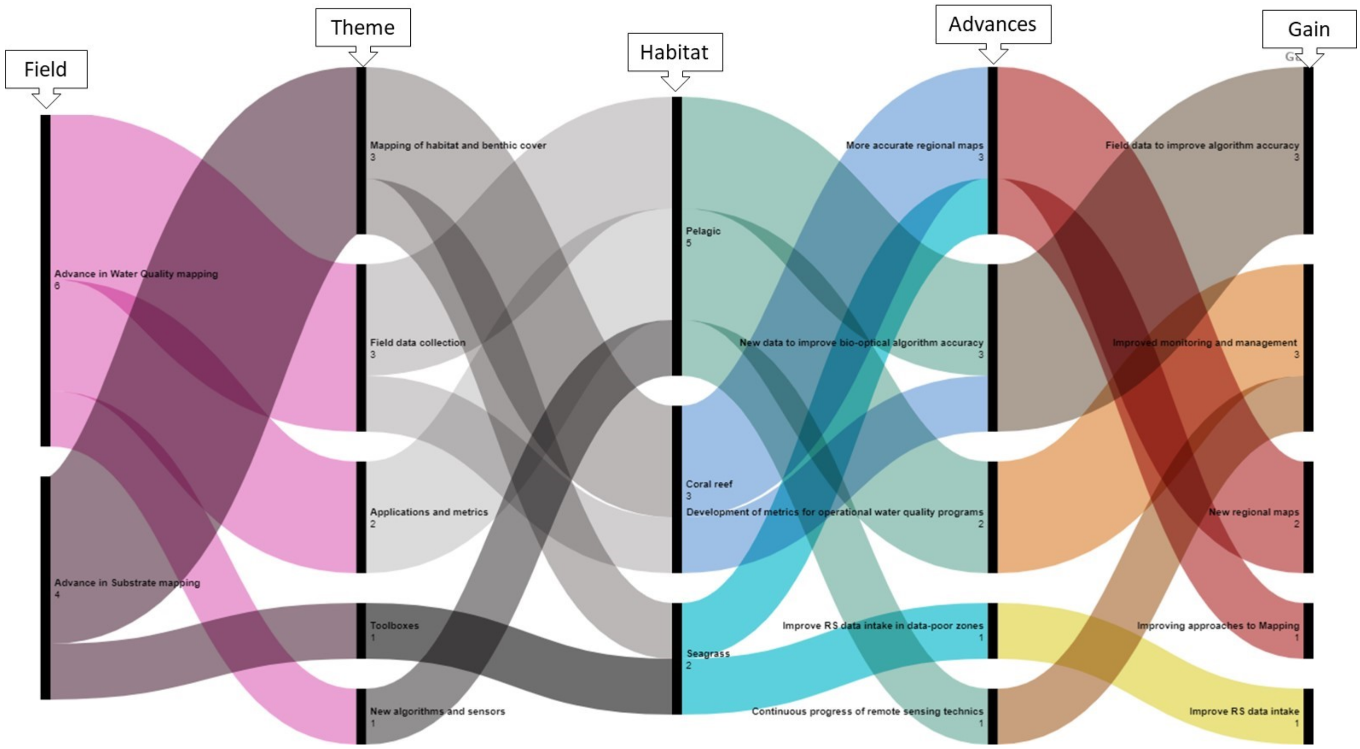

Figure 1. The Special Issue provides advances in remote sensing for Oceania and beyond over a range of ecosystems. The figure represents an alluvial graph, representing the flow between the themes, habitats, advances and gains. The different colours represent different stages of the connections between the advances presented in the Special Issue and the final gains (improvements).

Table 2. List of papers in this Special Issue.

Field	Theme	Habitats	Region	Title	Authors	Paper N^0 with Citation
Adavance in Substrate mapping (coral reefs and seagrass).	Habitat and benthic cover mapping	Coral reef	Great Barrier Reef (East Australia)	How Much Shallow Coral Habitat Is There on the Great Barrier Reef?	Roelfsema CM, Lyons MB, Castro-Sanguino C, Kovacs EM, Callaghan D, Wettle M, Markey K, Borrego-Acevedo R, Tudman P, Roe M, Kennedy EV.	1 [58]
			Ningaloo Reef (Western Australia)	Bathymetry Derivatives and Habitat Data from Hyperspectral Imagery Establish a High-Resolution Baseline for Managing the Ningaloo Reef, Western Australia	Halina T. Kobryn, Lynnath E. Beckley andKristin Wouters	2 [55]
		Seagrass	Great Barrier Reef (East Australia)	Improving Approaches to Mapping Seagrass within the Great Barrier Reef: From Field to Spaceborne Earth Observation	Len J. McKenzie, Lucas A. Langlois and Chris M. Roelfsema	3 [59]
	Toolboxes		Solomon Islands and Vanuatu (South Pacific)	A seagrass monitoring toolbox for South Pacific environments	Julie Bremner, Caroline Petus, Tony Dolphin, Jon Hawes, Benoît Beguet and Michelle Devlin	4 [39]

Table 2. *Cont.*

Field	Theme	Habitats	Region	Title	Authors	Paper N^0 with Citation
Advance in Water Quality mapping	In situ optical properties of the water column	Coral reef	Heron Island (South Great Barrier Reef) Coringa-Herald and Lihou Reefs (Coral Sea, East Australia)	Bio-Optical Measurements Indicative of Biogeochemical Transformations of Ocean Waters by Coral Reefs	Arnold G. Dekker, Lesley A. Clementson, Magnus Wettle, Nagur Cherukuru, Hannelie Botha and Kadija Oubelkheir	5 [54]
		Pelagic	Keppel Bay (inshore southern Great Barrier Reef)	Distinct Peaks of UV-Absorbing Compounds in CDOM and Particulate Absorption Spectra of Near-Surface Great Barrier Reef Coastal Waters, Associated with the Presence of *Trichodesmium* spp. (NE Australia)	Lesley A. Clementson, Kadija Oubelkheir, Phillip W. Ford and David Blondeau-Patissier	6 [51]
		Pelagic	Princess Charlotte Bay (inshore northern GBR)	Impact of a tropical cyclone on terrestrial inputs and bio-optical properties in Princess Charlotte Bay (Great Barrier Reef lagoon)	Kadija Oubelkheir, Phillip W. Ford, Nagur Cherukuru, Lesley A. Clementson, Caroline Petus, Michelle Devlin, Thomas Schroeder, Andrew D.L. Steven	7 [53]
	New algorithms and sensors	Pelagic	Great Barrier Reef (East Australia)	A Machine Learning Algorithm for Himawari-8 Total Suspended Solids Retrievals in the Great Barrier Reef	Larissa Patricio-Valerio, Thomas Schroeder, Michelle J. Devlin, Yi Qin and Scott Smithers	8 [52]
			Torres Strait (North-East Australia)	Using Optical Water-Type Classification in Data-Poor Water Quality Assessment: A Case Study in the Torres Strait	Caroline Petus, Jane Waterhouse, Dieter Tracey, Eric Wolanski and Jon Brodie	9 [56]
	Applications and metrics		Liverpool Bay (inshore United Kingdom).	Can Forel–Ule Index Act as a Proxy of Water Quality in Temperate Waters? Application of Plume Mapping in Liverpool Bay, UK	Lenka Fronkova, Naomi Greenwood, Roi Martinez, Jennifer A. Graham, Richard Harrod, Carolyn A. Graves, Michelle J. Devlin and Caroline Petus	10 [57]

2. Overview of Manuscripts Published in Special Issue

The Manuscripts published span different objectives and methodologies but can be widely grouped into two fields and five themes (Table 2).

2.1. Advances in Substrate Mapping (Coral Reefs and Seagrass)

Remote sensing techniques have been used to map and monitor coral reef ecosystems across the world, with large-scale databases now available [44,60–63]. However, the continuous development of remote-sensing technologies, including the integration of different sensors and new mapping approaches, is essential for increasing the accuracy and reliability of remote-sensing-derived maps, at both the global and local scales.

Along the GBR, an original study characterized and quantified a potential coral habitat of more than 2164 shallow offshore reefs based on depth, geomorphic and benthic composition maps [58] (paper #1, Table 2). The mapping approach combined a Sentinel-2 satellite surface reflectance image mosaic and derived depth, wave climate, reef slope and field data, and incorporated, for the first time, the 3D characteristics of the reef surface above 20 m. This resulted in detailed geomorphic zonation maps (0–20 m) and was successful in providing a new reef extent estimate and the first estimate of a potential coral habitat in the GBR based on hard substrate availability. The high-resolution maps produce key tools for supporting the management, conservation and restoration efforts for the GBR.

In the north-west of Australia, a new geomorphic layer was constructed for the Ningaloo Reef, the longest fringing reef in Australia. Benthic cover and bathymetric features were characterized for depths down to 20 m through an object-oriented classification, using an existing high-resolution airborne hyperspectral survey [55] (paper #2, Table 2). The classifications provide a useful baseline for stratifying ecological field surveys, designing monitoring programmes and assessing reef resilience from current and future threats.

While remote-sensing-derived reef maps have been successfully produced for the GBR, a comprehensive systematic review of seagrass mapping showed that there have been relatively few attempts to adopt remote sensing approaches and emerging technologies to map seagrass ecosystems within the GBR [59]. Using a series of case studies to test the power of machine and deep learning, seagrass cover was mapped in a variety of settings with PlanetScope and UAV-captured imagery (paper #3, Table 2). The mapping approach combined machine learning pixel-based classification coupled with a bootstrapping process and was able to significantly improve seagrass maps, particularly in low-cover, fragmented and complex habitats. A multi-criteria approach to semi-quantitatively score the confidence of seagrass mapping products was also introduced, enabling the upscaling of seagrass mapping for future monitoring and management [52].

Combined, these studies show that more accurate and efficient coral reefs and seagrass mapping approaches are possible, working towards overcoming methodological and confidence challenges for ecosystem mapping (Table 1). Emerging remote sensing technologies produce maps of higher confidence with greater applicability for management purposes. However, in some data-poor regions such as the Pacific Large Ocean States or some less-funded regions, managers and local end users will not have the observational data, knowledge or resources to use advanced remote sensing technologies. It is, thus, important to provide general and simple frameworks and methodologies to assist in the uptake of remote sensing tools that can inform marine conservation and build capacity [39].

A comparison of the best approaches to seagrass mapping in the data-poor South Pacific (paper #4, Table 2) identifies many of these considerations [39]. It provides a brief overview of the different groups of monitoring techniques to create a decision tree to aid in the planning for Pacific islands. The decision tree considers the scale at which data are needed, the reason that monitoring is required, the finances available, technical skills of the monitoring team, data resolution, site safety/accessibility and the location of the seagrass. It allows for selection of the most useful tools for seagrass monitoring and provides real-world case studies on the applicability of the tool in data-poor South Pacific contexts. The monitoring toolbox supports surveyors and managers in deciding on the best overall approach to collecting seagrass data, providing key tools for supporting the conservation efforts of benthic ecosystems of the Pacific. The development of a visual and accessible methodology for complex decision making works toward overcoming communication and knowledge challenges (Table 1).

2.2. Advances in Algorithms for Water Quality Measurements (from Coral Reefs and Surrounding Waters to Highly Turbid Coastal Waters)

The mapping of coral reefs or seagrass by remote sensing is constantly evolving, with improvements dependent on the accurate retrieval of the optical properties of the water column above. Whilst coral ecosystems in Oceania are generally surrounded by clear and shallow waters, they can episodically be affected by sediment-laden riverine plumes and associated land-sourced contaminants, threatening the health of coastal ecosystems and requiring remote sensing techniques to be able to map these characteristics. This is particularly well studied in Eastern Australia, where riverine plumes are the major transport mechanism for nutrients, sediments and other land-based pollutants into the GBR lagoon [41,64,65]. Remote sensing techniques have been widely used to assess variability in the bio-optical properties between the reef waters and adjacent ocean waters, to map the spatial extend of riverine plume and to monitor water quality trends and the exposure of coastal habitats to the riverine influence. However, accurate retrievals of water quality are challenging in optically complex coastal areas. The variability in the bio-optical properties between the reef waters and adjacent ocean waters has resulted in algorithms that do not fully account for the sunlight absorption along the water column, the UV radiation penetration depth, the temperature distributions and the nutrient and carbon fluxes in coral reef ecosystems. Proper parameterization for the water column effects when estimating benthic cover will improve the use of Earth observation to systematically map the differences in the water quality between reefs and the adjacent ocean. In coastal regions, the additional impact of flood events increases the complexity of bottom substrate retrievals. The continuous development of accurate estimates of water quality necessitates the integration of new field data, new sensors and improved optical algorithms to monitor risk.

The Special Issue presents three papers exploring the variability in the optical and biogeochemical properties of the water column in offshore coral reefs [54], southern GBR waters [51] and a nearshore complex coastal system following a major flood event [53]. The optical and biogeochemical properties of waters above coral reefs and in the surrounding ocean were examined across several coral reef ecosystems not influenced by land-derived run off (paper #5, Table 2). The results corrected the wrong assumption that the optical properties of on-reef waters and the adjacent ocean waters are the same and showed that ocean waters flowing onto the reef are higher in phytoplankton, whilst waters on the reef or flowing from the reefs are higher in coloured dissolved organic matter (CDOM) and non-algal particles (NAPs). The phytoplankton distributions and the ratios of photosynthetic to photo-protective pigments were also different. These differences need to be accounted for the development of more accurate regional algorithms over reef ecosystems.

In clear water ecosystems, such as coral reefs and seagrass meadows, UV radiations play a key role in the underwater light climate, phytoplankton photosynthesis and CDOM photo-degradation, but are often under-sampled and/or under-reported. Distinct UV absorption peaks were observed and described for both the particulate and dissolved fractions of water samples during a sporadic bloom of *Trichodesmium* spp. colonies in Keppel Bay (NE Australia) [51] (paper #6, Table 2). This study demonstrated that the presence of these peaks also affected the values of the light absorption coefficients of the particulate and dissolved fractions recorded at wavelengths in the visible region of the light spectrum. These, in turn, impact satellite-retrieved estimates of these parameters from standard ocean colour algorithms. In the GBR lagoon and, more widely, in tropical waters, where *Trichodesmium* spp. blooms are prevalent, this study recommends that regional ocean colour algorithms take into account the variability in the UV.

Flood events in the GBR lagoon have been studied intensively in the past and are currently integrated as a key indicator of wet season dynamics in the GBR Marine Monitoring Program [41,64,65]. However, less is known about their impact on remote inshore ecosystems and the implications in the accuracy of ocean colour remote sensing algorithms. An application for the largest estuarine system in the GBR, the Normanby–Kennedy estuaries located in the remote Cape York Peninsula (NE Australia), is presented here (paper #7, Table 2). The widespread flooding resulting from the passage of tropical cyclone Oswald in January 2013 led to rapid and drastic changes in the in situ optical and biogeochemical properties of the water column within days [53]. The Normanby and Kennedy freshwater outflows were a major source of dissolved inorganic nitrogen, suspended solids and dissolved organic matter to the coastal zone, leading to a complex bio-optical region. This study highlights the need to better quantify the spatial and temporal heterogeneity within coastal systems, the critical scales of variability and recovery times following flood events.

Such studies are essential to quantify the variability in the key relationships linking the surface water optical properties accessible by remote sensing and in situ biogeochemical quantities. Field data collection is required to increase the accuracy of ocean colour remote sensing algorithms and to allow for greater confidence and uptake of remote sensing approaches in complex oceanic and coastal systems in the GBR. Combined in situ and remote sensing approaches also provide better coverage of the critical scales of variability, in particular in highly dynamic coastal environments [51–54], and help work towards overcoming methodological and accuracy challenges (Table 1).

Remote sensing of ocean colour has been fundamental to the synoptic-scale monitoring of marine water quality in the GBR, with methods widely using medium-resolution satellite images [40,41,53,66]. However, ocean colour sensors onboard low-orbit satellites, such as the MODIS and Sentinel-3 constellation, have insufficient capability to fully resolve diurnal variability. To overcome this limitation, a physics-based coastal ocean colour algorithm for the Himawari-8 geostationary satellite was developed to use the high-frequency ocean data [52] (paper #8, Table 2). Himawari-8 offers the opportunity to estimate ocean colour features every 10 min, and the simulated data were used to develop an inverse model based on artificial neural network techniques. This high-frequency data allowed for an estimate of total suspended solid (TSS) concentrations directly from the Himawari-8 top-of-atmosphere spectral reflectance observations and validated with concurrent in situ data across the coastal GBR. The acquisition of high-frequency data can improve the understanding of short-term variability and provide important data for the monitoring and management of water quality in the GBR.

An example of satellite data application in a data-poor context is given for the Fly River in Papua New Guinea, where the input of mine-derived contaminants is of concern to Torres Strait communities [56] (paper #9, Table 2). This study used MODIS satellite time series and a colour-classification approach to map optical water types and identify downstream ecosystems that may be at risk of exposure from the Fly River runoff. The mapped area that is the most likely exposed is a relatively small proportion of the Torres Strait region but encompasses habitats of high ecological importance, including coral reefs and seagrass meadows. Satellite data showed that the period of highest risk of exposure was during the south-east trade wind season and complemented recent model simulations in the region over larger spatial and temporal frames. This study provided long-term, extensive but qualitative, baseline information needed to inform future ecological risk mapping and to support decision making about management priorities in the region.

The transfer of techniques developed previously for the monitoring of key features such as flood plumes in the GBR lagoon [9,40,41,65,67,68] to other temperate marine areas provides an opportunity to assess the applicability and usability of these mapping techniques [57] (paper #10, Table 2). The use of ocean colour classification algorithms, linked to water quality gradients, can be a useful tool for mapping river plumes in both tropical and temperate systems. This approach has been applied in operational water quality programs in the GBR to map river plumes and assess trends and ecosystem health during flood periods. In a study in UK coastal waters, the Forel–Ule (FUI) colour classification algorithm for Sentinel-3 OLCI imagery was used in an automated process to map monthly, annual and long-term plume movement in Liverpool Bay, where there are concerns of eutrophication issues and impacts [69–71]. Monthly river plume extent was compared to the river flow and in situ water quality data between 2017 and 2020, with a strong positive correlation between the river plume extent and the river flow and a strong link between the FUI-defined waterbodies and nutrients, SPM, turbidity and salinity. This work demonstrates the potential of the Forel–Ule index as a proxy for water quality in temperate waters and how it could be used in operational water quality programs to better understand river plumes and land-based inputs to the coastal zones, drawing parallels with methods that have been developed in the GBR and elsewhere [72,73]. This work provides the first insight into the systematic long-term river plume mapping in UK coastal waters using a fast, cost-effective and reproducible workflow developed for use in tropical waters.

3. Conclusions

Remote sensing methods, tools and outputs make up a fast-moving field, with many new techniques and tools available to both scientists and managers. This Special Issue explored these new advances through ongoing work to improve understanding of the source of variability in water column optical properties, remote-sensed imagery and algorithm development for Oceania waters. A large system such as the Great Barrier Reef, with its vast size and complex waters, has always been a difficult ecosystem to fully cover with traditional monitoring methods, though many valuable and long-term monitoring programs have helped resolve much of this variability [42,43]. Technological advances and the free distribution of some satellite imagery continue to make satellite data easier to access and a valuable contribution to existing monitoring programs. However, translating satellite information into relevant information for marine conservation and decision-making tools requires substantial knowledge, technical skills and observational data to use the remote-sensed data as efficiently as possible. The mix of papers focusing on many different techniques in remote sensing for Oceania and beyond provides discoveries in science, management and policy (Figure 1).

Whilst the breadth of papers ranged across Oceania and UK waters and explored several different types of ecosystems, such as coral reefs, seagrasses, flood plumes and the water column, they all showed improved approaches to the use of remote sensing. These improvements ranged from highly technical advances in algorithm development for GBR waters between coral reefs and the surrounding deep sea, to advances in our knowledge of the optical variability in both the UV and visible regions for waters impacted by *Trichodesmium* spp. blooms (a common occurrence across the GBR lagoon). Four papers explored flood plume dynamics, including an improvement in algorithms for plume mapping in the remote regions of the northern GBR, greater resolution and understanding of total suspended solid variability in the inshore waters of the GBR, the extent of flood plume waters from the Fly river and the transition of plume mapping techniques developed for tropical waters in the GBR to the temperate waters of the west coast of the UK [52,53,56,57]. More accurate retrievals and improvements in remote-sensed water quality data work toward their integration in operational monitoring programs and advances in the communication between remote sensing scientists and managers of reef ecosystems. Improvements in the mapping of key ecosystems of coral reefs and seagrass communities were also presented [39,55,58,59], adjusting algorithms to account for different water types and optical complexity [51,54].

In summary, the papers provided advances in the mapping of shallow and deep habitats, integration of machine learning and remote sensing for improved seagrass mapping, plume mapping of remote areas and water quality issues, techniques to extract high-frequency data and a toolbox to bring much of the complexity into user-friendly techniques. This provides gains that can improve our management of coral reefs, seagrasses and coastal areas. They will improve the accuracy, allow for better definition of high-value areas, improve knowledge of remote and data-poor areas and improve global and regional applicability of remote sensing for Oceania and beyond.

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