2017 Scientific Consensus Statement

LAND USE IMPACTS ON GREAT BARRIER REEF WATER QUALITY AND ECOSYSTEM CONDITION

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Contents

1. Introduction

The 2017 Scientific Consensus Statement reviews and adds to the scientific knowledge of water quality issues in the Great Barrier Reef from the 2013 statement. It draws heavily on the regional water quality improvement plans and supporting studies, specific research and monitoring results as well as published science to date related to ecological processes operating in the Great Barrier Reef.

This Scientific Consensus Statement applies a risk management framework based on the ISO 31000 (AS/NZS, 2004) shown in Figure 1.

Chapter 1 describes Great Barrier Reef marine and coastal aquatic ecosystem status and condition, identifies the primary drivers, pressures and threats to these systems and the known effects of land-based pollutants based on understanding derived through monitoring and modelling (Schaffelke et al., 2017).

Chapter 2 describes the sources of pollutants, considered as the hazards to Great Barrier Reef ecosystems (Bartley et al., 2017).

Chapter 3 applies the risk assessment components of the framework by evaluating the likelihood, consequences and quantified risk to the Great Barrier Reef coastal aquatic and marine ecosystems, particularly from different nutrient species, suspended sediment (including different size fractions) and pesticides (Waterhouse et al., 2017).

Chapter 4 considers management of the risks (Eberhard et al., 2017).

Chapter 5 presents an overall synthesis and draws on the previous chapters to present a management prioritisation and discussion on management implications of the new knowledge (Waterhouse et al., 2017). It also identifies uncertainties and where there remain differences in the interpretation of the scientific evidence (identified in Chapters 1 to 4).

The scope of the 2017 Scientific Consensus Statement was expanded from 2013 to include additional sections to align with the water quality theme of the Reef 2050 Long-Term Sustainability Plan (Reef 2050 Plan). It covers all land-based pollutant sources including urban diffuse, point source and industrial discharge. The Reef 2050 Plan water quality theme has an additional focus on improving water quality from all sectors including marine-based impacts, such as from dredging, which remain outside the scope of the Reef 2050 Water Quality Improvement Plan 2017-2022 (previously the Reef Water Quality Protection Plan).

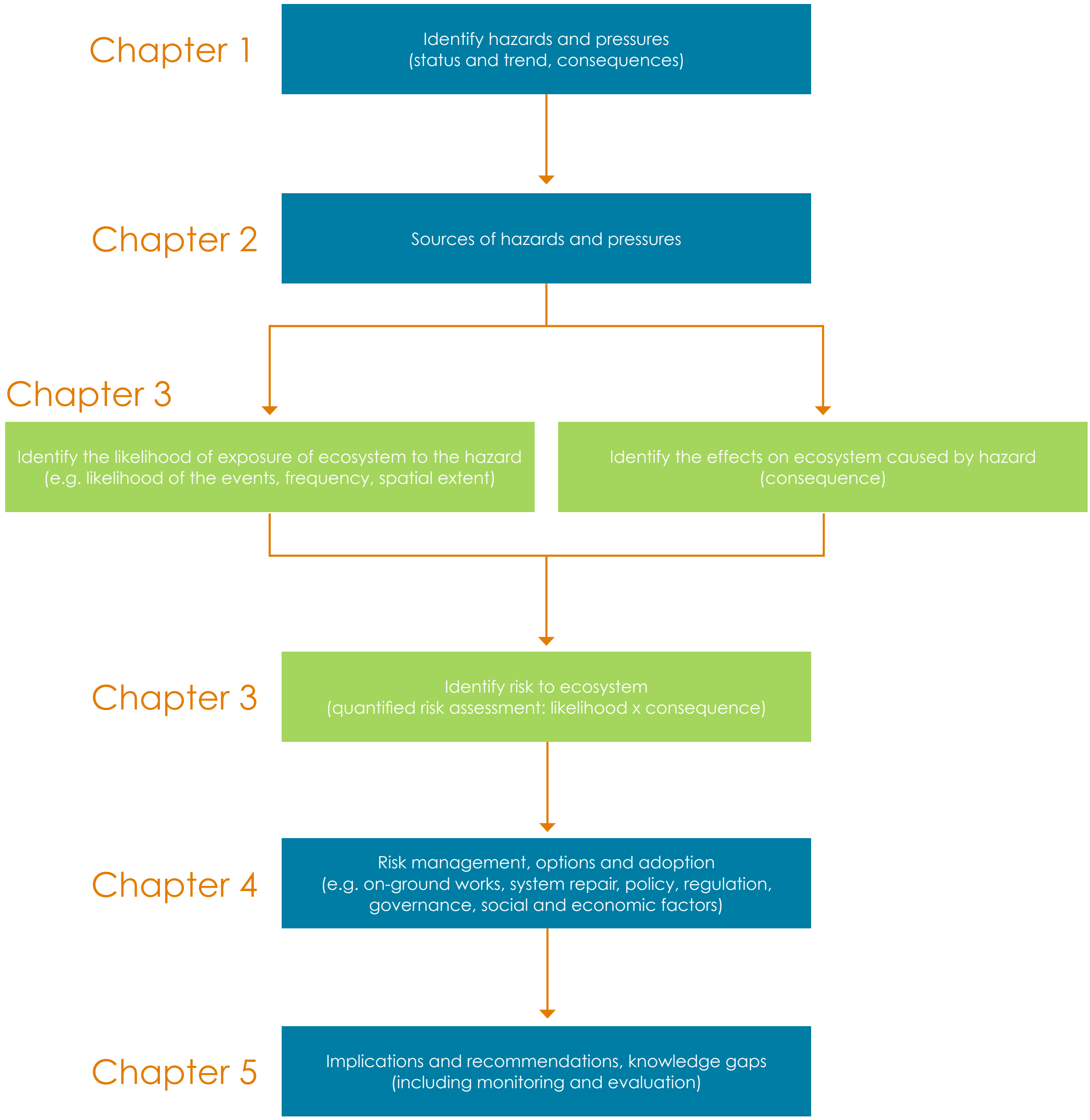
While all land-based pollutant sources have been considered as part of this Scientific Consensus Statement, the emphasis is on the agricultural diffuse sources of pollutants as the dominant contributor of land-based pollutant loads at a regional and Great Barrier Reef-wide scale. Evidence about the effectiveness of water quality management in the Great Barrier Reef reflects the focus on agricultural industries. Chapter 4 highlights there is little direct Great Barrier Reef evidence about the effectiveness of urban water quality management, wetland and treatment systems, and the social, economic and governance literature in this chapter deals almost exclusively with agricultural practice change.

The Reef 2050 Plan also links the ecosystem health theme to the water quality targets under the actions of protecting and restoring, reducing impacts and monitoring and reporting. Accordingly, new sections have been added to the Scientific Consensus Statement to cover coastal aquatic ecosystems in terms of status and water quality impacts, relative risk and management options. For some aspects of these new sections, where there is limited specific knowledge for the Great Barrier Reef, it has been necessary to draw on national and international literature. These aspects are highlighted as knowledge gaps in Chapter 5.

The primary ecosystems considered include coastal wetlands and floodplains, estuaries, marine waters and benthic marine ecosystems with a focus on coral reefs and seagrass. The geographic scope is extended to include reference to the Torres Strait and Hervey Bay. Information is reported at the scale of the six natural resource management regions, 35 main catchments and additional management units in the Burdekin and Fitzroy natural resource management regions (see Figure 2).

The primary source of information in the 2017 Scientific Consensus Statement is published, publicly available information that has undergone a peer review process.

Figure 1: Risk management framework adopted for the 2017 Scientific Consensus Statement showing how each chapter maps into the framework. Derived from AS/NZS (2004).



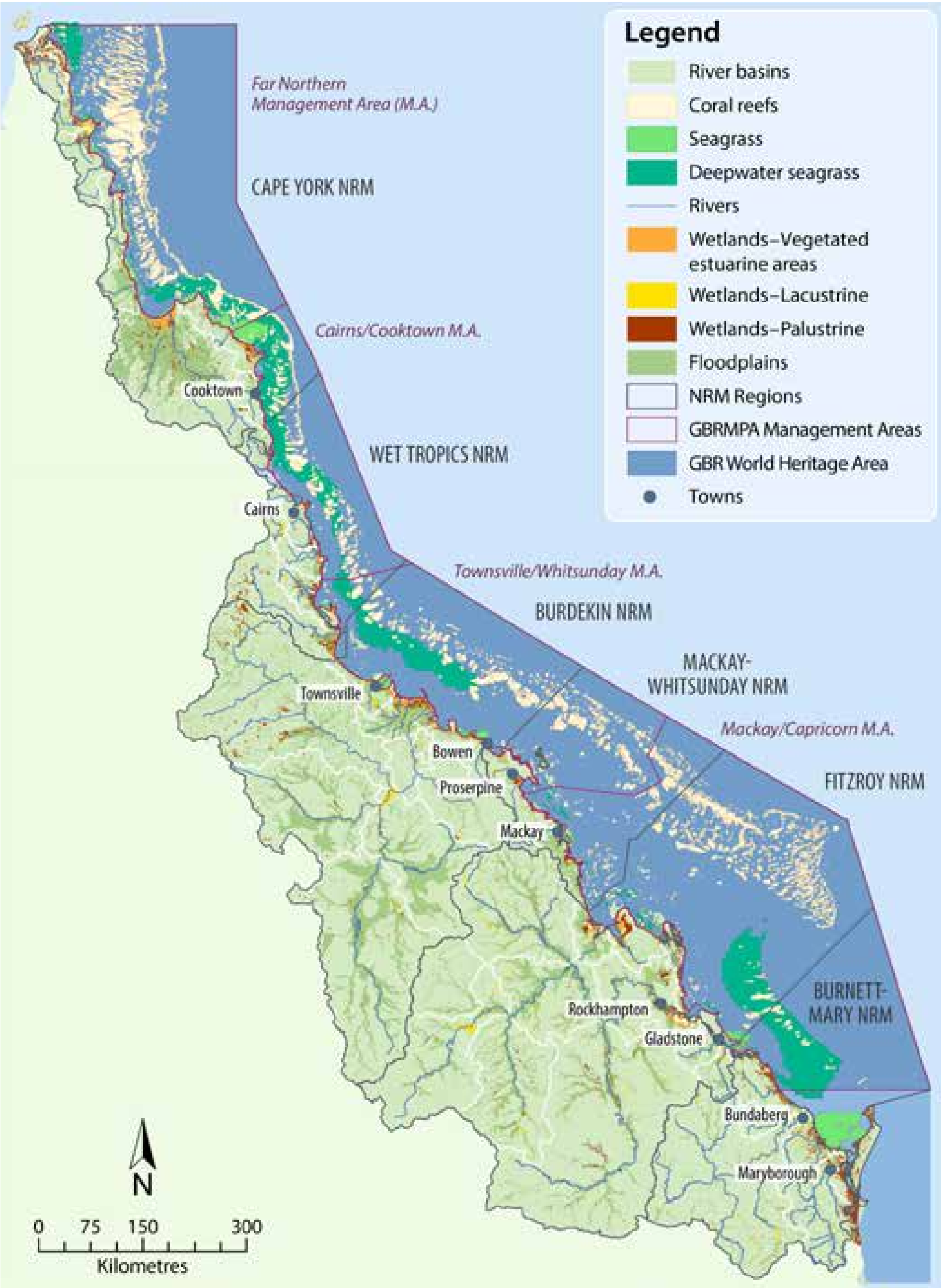
2. Background

The Reef 2050 Water Quality Improvement Plan 2017-2022 is a joint commitment of the Australian and Queensland governments. The plan is a collaborative program of coordinated projects and partnerships designed to improve the quality of water flowing to the Great Barrier Reef. The 2017 Scientific Consensus Statement is a foundational document which provides the scientific understanding underpinning the design and implementation of the Reef 2050 Water Quality Improvement Plan.

The Scientific Consensus Statement has been prepared by a panel of scientists with expertise in Great Barrier Reef water quality science and management. They have reviewed and synthesised the significant advances in scientific knowledge of water quality issues in the Great Barrier Reef from the 2013 Scientific Consensus Statement. The evidence reviewed is summarised in the next section.

In parallel to the update of the Scientific Consensus Statement in 2017, new catchment-based pollutant load reduction targets were developed for the Reef 2050 Water Quality Improvement Plan (Brodie et al., 2017).

Figure 2: Map of the marine natural resource management (NRM) boundaries, coastal aquatic and marine habitats, NRM regions and catchment boundaries included in the 2017 Scientific Consensus Statement. Map prepared by D. Tracey, James Cook University.



3. Scientific Consensus in 2017

This report provides the 2017 Scientific Consensus Statement for the Great Barrier Reef – a review of the *significant advances* in scientific knowledge of water quality issues in the Great Barrier Reef to arrive at a consensus on the current understanding of the system. The consensus statement was produced by a multidisciplinary group of scientists, with oversight from the Reef Independent Science Panel, and supports the development of the Reef 2050 Water Quality Improvement Plan 2017-2022.

The overarching consensus is:

Key Great Barrier Reef ecosystems continue to be in poor condition. This is largely due to the collective impact of land run-off associated with past and ongoing catchment development, coastal development activities, extreme weather events and climate change impacts such as the 2016 and 2017 coral bleaching events.

Current initiatives will not meet the water quality targets. To accelerate the change in on-ground management, improvements to governance, program design, delivery and evaluation systems are urgently needed. This will require greater incorporation of social and economic factors, better targeting and prioritisation, exploration of alternative management options and increased support and resources.

The evidence base supporting this consensus is provided in a series of four supporting chapters. The main conclusions were:

1. The decline of marine water quality associated with land-based run-off from the adjacent catchments is a major cause of the current poor state of many of the coastal and marine ecosystems of the Great Barrier Reef. Water quality improvement has an important role in ecosystem resilience.
2. The main source of the primary pollutants (nutrients, fine sediments and pesticides) from Great Barrier Reef catchments is diffuse source pollution from agriculture. These pollutants pose a risk to Great Barrier Reef coastal and marine ecosystems.
3. Progress towards the water quality targets has been slow and the present trajectory suggests these targets will not be met.
4. Greater effort to improve water quality is urgently required to progress substantial pollutant reductions using an expanded scope of tailored and innovative solutions. Climate change adaptation and mitigation, cumulative impact assessment for major projects and better policy coordination are also required to protect the Great Barrier Reef.
5. There is an urgent need for greater investment in voluntary practice change programs, the use of regulatory tools and other policy mechanisms to accelerate the adoption of practice change, and robust monitoring and evaluation programs to measure the rate and effectiveness of adoption.
6. Strengthened and more effective coordination of Australian and Queensland government policies and programs, further collaboration with farmers and other stakeholders, and strong evaluation systems are critical to the success of Great Barrier Reef water quality initiatives.
7. Priorities for reducing pollutant loads are now established at a catchment scale, based on the exposure of coastal and marine ecosystems to land-based pollutants, and should be used to guide investment.
8. A greater focus on experimentation, prioritisation and evaluation at different scales, coupled with the use of modelling and other approaches to understand future scenarios, could further improve water quality programs.

4. Independent Science Panel remarks

The Independent Science Panel (the panel) was established in 2009 to provide multidisciplinary scientific advice to the Australian and Queensland governments on the implemention of the Reef Water Quality Protection Plan. In this role, the panel has reviewed the 2013 and 2017 Scientific Consensus Statements.

After reviewing the 2017 Scientific Consensus Statement, the panel agreed:

1. **There has been significant progress since the 2013 Scientific Consensus Statement in understanding sediment, nutrient and pesticide delivery from Great Barrier Reef catchments and their mitigation through improved land management practices.** The new eReefs biogeochemical model tracks sediments and nutrients in the marine environment and connects the impact of these pollutants to water clarity and indicators of ecosystem health. The increased capability of terrestrial and marine models to evaluate processes in the catchments and receiving waters must be supported by additional investment in the in-situ monitoring of coastal water quality. This monitoring will also benefit regional report cards partnerships.
2. **The cumulative effects of multiple pressures substantially reduce the health and resilience of the Great Barrier Reef** including the combined impacts of extreme weather events, climate change and historical developments. In the past four years, a fourth outbreak of crown-of-thorns starfish occurred, originating from reefs impacted by river flows from the Wet Tropics region. In addition, unusually warm sea temperatures in the northern Great Barrier Reef resulted in widespread coral bleaching in 2016 and 2017. However, later low rainfall and run-off has shown the ability of seagrass ecosystems to recover from the acute impacts of run-off. Reducing land-based pollution will improve the resilience of the marine ecosystems to cope with a changing climate.
3. **The robust risk-based approach to land-based pollutants implemented in the 2017 Scientific Consensus Statement represents an improvement** of the risk assessment in the 2013 Scientific Consensus Statement and has allowed high risk pollutants and catchments to be identified. The panel notes that point sources (e.g. urban, industrial and ports) and other pollutants (e.g. marine debris/microplastics, antifouling paint components and personal care products) are included in the 2017 Scientific Consensus Statement, but require more information to understand the level of risk. The panel reaffirms the focus of the Reef Water Quality Protection Plan 2013 and updated plan on diffuse pollution from agricultural sources.
4. **The Paddock to Reef Integrated Monitoring, Modelling and Reporting Program catchment models include more robust estimates of the effectiveness of improved land management practices** as defined by the water quality risk frameworks. The rates of adoption have slowed after a period of early uptake, challenging expectations of meeting the water quality targets entirely from voluntary reforms. In addition to continuous improvement and innovation, the panel believes that transformational change will be required to reach the targets.
5. **Further consideration of economic and social dimensions is needed** in the development and implementation of programs to improve reef water quality.
6. **There is a need for a mechanism of ongoing evaluation of the reef water quality program to inform future program design** because regionally specific feedback on design and delivery can be available before it is published and/or fully evaluated by the consensus process. Future scientific consensus statements could elevate the economic and human dimensions of program design and better communicate the achievement of outcomes for improved reef water quality.
7. **Coordination and collaboration** across all sectors (particularly among levels of government responsible for managing development pressures) is needed **to reduce land-based impacts** on inshore marine water quality. It is clear that the health of the Great Barrier Reef and its catchment ecosystems are linked and need to be improved together. This will require appropriate risk assessments in the planning of all future developments in Great Barrier Reef catchments.
8. **The 2017 Scientific Consensus Statement is currently the best and most authoritative source of information to support evidence-based decisions for better water quality within the Great Barrier Reef World Heritage Area. The panel supports the general findings, conclusions and recommendations of the updated statement.**

5. Summary of evidence to support the 2017 Scientific Consensus Statement

Condition of coastal and marine ecosystems

The decline of marine water quality associated with land-based run-off from the adjacent catchments is a major cause of the current poor state of many of the Great Barrier Reef coastal and marine ecosystems. Additionally, coastal ecosystems have been highly modified and continue to be exposed to a range of pressures from catchment development. The resilience of marine ecosystems was indicated by their ability to at least partially recover from previous losses during periods of low disturbance and reduced catchment pollutant loads. The systems have been severely impacted by a number of recent events—including prolonged periods of extreme sea surface temperatures, tropical cyclones and the progression of the fourth wave of crown-of-thorns starfish population outbreaks. Climate change is predicted to increase the frequency of large-scale bleaching events and the intensity of extreme weather events.

Summary of evidence

- The Great Barrier Reef marine ecosystems and their associated catchments are part of a dynamic, interconnected system. The condition of all parts of the system, including the catchment, is important for the long-term health of the Great Barrier Reef. Each part has its own inherent ecosystem and biodiversity values and provides ecosystem services such as water quality improvement and carbon storage that benefit the receiving marine environment.
- Coastal freshwater wetlands continue to be affected by a range of chronic and acute pressures such as excess nutrient, sediment and pesticide loads; loss of connectivity; changes in hydrology and invasive species.
- Poor marine water quality associated with pollutant run-off from the adjacent catchments, especially during major floods, affects the condition of many of the key marine ecosystems of the Great Barrier Reef.
- Inshore seagrass meadows and coral reefs continue to recover from previous losses due to major run-off events and cyclones, but remain in moderate to poor condition.
- Periods of reduced catchment run-off associated with low rainfall demonstrate the inherent ability of inshore reef communities to recover from acute disturbances. This provides a strong case for reducing the pollutant loads being delivered to the Great Barrier Reef.
- Mid-shelf and outer shelf reefs in the southern half of the Great Barrier Reef have shown the capacity to rapidly recover from previous disturbances; however, a severe mass thermal coral bleaching event in 2016 resulted in significant coral mortality, especially north of Port Douglas.
- Ongoing, warmer-than-average sea temperatures resulted in a further widespread mass coral bleaching event in 2017 which was most intense on reefs between Cairns and Townsville. In addition, a severe Tropical Cyclone Debbie affected reefs in the Mackay Whitsunday region and subsequent flooding also affected the Fitzroy region. Impacts of these events have yet to be quantified.
- Climate change is predicted to increase the intensity of extreme weather events, which are significant in driving impacts to coastal and marine ecosystems.

Recommendations

- **Implement measures to better anticipate and respond to future changes including climate change, coastal urban growth, and agricultural expansion and intensification. This will require: (a) developing a coherent climate adaptation strategy for the Great Barrier Reef catchments; (b) modified water quality planning and delivery approaches; (c) strategies to manage unforeseen impacts of future land use change (e.g. coastal development or land retirement) including offsets or strict conditioning; (d) future scenario modelling; and (e) better standards for cumulative impact assessment including climate scenarios for environmental impact assessment of development proposals in the Great Barrier Reef catchments.**
- Undertake urgent action to maintain and improve the resilience of the coastal and marine ecosystems of the Great Barrier Reef through implementing more intensive management of catchment water quality and other local pressures, active landscape protection and restoration approaches to maintain as many biodiversity and ecosystem functions as possible, and more effective global climate change mitigation measures. A stronger knowledge base about the role of extreme events and a changing climate on end-of-catchment pollutant loads is essential for developing achievable water quality targets.
- Implement a more holistic and coordinated approach to managing wetlands (including rivers) and floodplains and their connections to the Great Barrier Reef by embedding the protection of catchment, estuary and floodplain functions and connectivity in Great Barrier Reef policy. This should also include increased efforts to understand how multiple and cumulative environmental pressures (including water quality) affect recovery processes, to help refine predictions of future condition and resilience of coastal and marine ecosystems.

Risk to coastal and marine ecosystems

The greatest water quality risks to the Great Barrier Reef and coastal ecosystems are from discharges of: (a) nutrients, which are an additional stress factor for many coral species, promote crown-of-thorns starfish population outbreaks with destructive effects on mid-shelf and offshore coral reefs, and promote macroalgal growth; (b) fine sediments, which reduce the light available to seagrass ecosystems and inshore coral reefs; and (c) pesticides, which pose a toxicity risk to freshwater ecosystems and some inshore and coastal habitats.

Summary of evidence

A combination of qualitative and semi-quantitative assessments were used to estimate the relative risk of water quality pollutants to Great Barrier Reef coastal aquatic and marine ecosystem health.

- Increased loads of fine sediments, nutrients (nitrogen and phosphorus) and pesticides were all found to be important at different scales and different locations in the Great Barrier Reef. However, the risks differ between the individual pollutants, source catchments and distance from the coast.
- Exposure to fine sediment is most significant for areas with shallow seagrass and coral reefs on the inner shelf adjacent to basins with high anthropogenic fine sediment loads. The greatest coral reef and seagrass exposure to fine sediment is from the Burdekin, Fitzroy, Mary, Herbert, Johnstone and Burnett catchment areas. The Burdekin and Fitzroy catchments also contribute the greatest fine sediment risk to seagrass ecosystems.
- Exposure to dissolved inorganic nitrogen is most significant for all inner shelf areas and the mid-shelf area between Lizard Island and Townsville adjacent to catchments with high anthropogenic dissolved inorganic nitrogen loads. The relative importance of dissolved inorganic nitrogen to seagrass ecosystems is still uncertain, but it may influence light availability for deep water seagrass in areas deeper than 10 to 15 metres due to increased phytoplankton growth.
- The greatest coral reef and seagrass exposure to dissolved inorganic nitrogen is from the Herbert, Haughton, Johnstone, Mulgrave-Russell, Tully, Plane and Murray catchment areas. The Herbert, Johnstone, Mulgrave-Russell and Tully also contribute the greatest dissolved inorganic nitrogen risk to coral reefs and primary crown-of-thorns starfish outbreaks. Anthropogenic particulate nitrogen is also likely to be of some importance in the same catchment areas, as well as the Fitzroy; however, our knowledge on the bioavailability of particulate nitrogen to the marine ecosystems in relation to that of dissolved inorganic nitrogen is limited.
- Anthropogenic phosphorus loads are considerable from many catchment areas. Knowledge of the relative importance of nitrogen and phosphorus is limited, but nitrogen is considered to be the limiting nutrient and, hence, more important in any form than phosphorus.
- Pesticides pose the greatest risk to ecosystems closest to the source of the pesticides; i.e. freshwater wetlands, rivers and estuaries; followed by coastal ecosystems, seagrass and coral. Catchments within the Mackay Whitsunday region and the Lower Burdekin present a very high to moderate risk to end-of-catchment ecosystems from pesticides, with diuron presenting the highest risk.
- Marine plastic pollution was found to be the highest priority among emerging pollutants. This is particularly an issue in the Cape York region due to exposure to oceanic and local shipping sources. Additionally, chronic contamination of water and sediments with antifouling paints, and exposure to certain personal care products, has been assessed as a risk in regions south of Cape York. All other emerging contaminants were assessed as relatively low risk, with some minor differences between regions.

Recommendation

- Use the Great Barrier Reef catchment-specific pollutant load reduction targets to guide actions to minimise water quality risks to the Great Barrier Reef.

Image: © Tourism and Events Queensland

Sources of land-based pollutants

The main source of excess nutrients, fine sediments and pesticides from Great Barrier Reef catchments is diffuse source pollution from agriculture. Other land uses, including urban areas, contribute relatively small but concentrated pollutant loads, which may be important at local scales.

Summary of evidence

- Water discharged from the catchments into the Great Barrier Reef lagoon continues to be of poor quality in many locations. Knowledge of the major sources and processes contributing to these river pollutant loads has significantly improved due to better modelling and monitoring.
- Sugarcane areas are the largest contributors of dissolved inorganic nitrogen and pesticides, while grazing contributes the largest proportion of sediment and particulate nutrients to the Great Barrier Reef primarily through sub-surface (gully, streambank and rill) erosion. Contributions from other land uses, including urban, are relatively minor in comparison to agriculture but can be important locally.
- At the regional scale, the Wet Tropics, Burdekin and Fitzroy regions contribute most of these river pollutant loads. However, at the catchment scale, areas within the Mackay Whitsunday and Burnett Mary regions are also important contributors, illustrating the value of identifying management priorities at the catchment or finer scale.
- Catchment modelling shows that mean-annual fine sediment, nutrient and pesticide loads delivered to the Great Barrier Reef lagoon have increased substantially since pre-development conditions. They include an: approximate 5.0 fold increase in fine sediment for the entire Great Barrier Reef catchment (range 3.0 to 8.0 fold depending on the region); approximate 2.0 fold increase in dissolved inorganic nitrogen (range 1.2 to 6.0 fold, with the exception of Cape York); approximate 1.5 fold increase in particulate nitrogen (range 1.2 to 2.2 fold) and approximate 2.9 fold increase in particulate phosphorus (range 1.2 to 5.3 fold).
- The mean-annual loads of prevalent pesticides (ametryn, atrazine, diuron, hexazinone, tebuthiuron and simazine) are estimated (modelled) to be around 12,000kg per year across the Great Barrier Reef. The measured pesticide data suggests that most pesticides are found in all regions, even though some are in very small quantities. The catchments that contribute the most pollutants have remained reasonably consistent over the past 10 years.
- Expansion of agriculture in the Great Barrier Reef catchments (e.g. under the Northern Australia Development Plan), major development projects and anticipated growth in coastal populations adjacent to the Great Barrier Reef will increase pollutant loads delivered to the Great Barrier Reef.

Recommendation

- **Continue to prioritise agricultural sources of pollutants in Great Barrier Reef catchment management. Information on the pollutant contributions from non-agricultural sources (e.g. urban, industrial and ports) and other pollutants should be compiled as a priority to support whole-of-catchment management approaches**.

Progress to targets

Progress towards the Reef Water Quality Protection Plan 2013 targets has been slow and the present trajectory will not meet the targets. This puts the Outstanding Universal Value of the Great Barrier Reef under increasing pressure, especially in the context of other pressures such as climate change. Greater effort to improve reef water quality is urgently required to restore and protect the Great Barrier Reef ecosystems.

Summary of evidence

- The Reef Water Quality Protection Plan 2013 included land and catchment management targets to address improved agricultural management practices and the protection of natural wetlands and riparian areas. These targets were based on the conceptual understanding of the link between land condition, management practice standards and water quality outcomes.
- The annual Great Barrier Reef Report Card details progress against the Reef Water Quality Protection Plan targets, with the most recent report card providing 2014-2015 data. Most of the indicators are reported annually, except for the wetland and riparian extent indicators, which are reported every four years (the last report was in 2014).
  - » The overall condition of the inshore marine environment (water quality, seagrass and coral) remains poor, and has not changed greatly since Report Card 2011.
  - » While there has been good progress in adopting improved management practices across the agricultural industries in the Great Barrier Reef catchments, a large proportion (in some cases, up to 77%) of agricultural land is managed using practices which are below best management practice for water quality. This demonstrates the challenges associated with facilitating the adoption of improved (lower water quality risk) land management practices, and highlights the limited progress towards achieving the management practice adoption targets since 2009.
  - » An analysis of the Great Barrier Reef Report Card data indicates the rate of progress towards the targets is slowing and it is unlikely the targets will be met on the current trajectory.
  - » Catchment condition targets are tracking positively, with very good, good and moderate scores for ground cover, wetland loss and riparian extent, respectively.
- The adoption of existing best management practices for agricultural land will not be sufficient to achieve the water quality targets and additional management options need to be urgently trialled and validated in the Great Barrier Reef context and then implemented.

Recommendations

- The recommendations for these findings are combined with those for 'Efforts to improve Great Barrier Reef water quality'. The key message is **that there is a need to urgently implement more targeted and substantial effort to improve water quality in the Great Barrier Reef.**

Image: © Tourism and Events Queensland

Efforts to improve Great Barrier Reef water quality

Current management options to reduce pollutant run-off to the Great Barrier Reef provide a solid foundation for program implementation, but an expanded scope of tailored and innovative solutions is urgently required to progress the substantial pollutant load reductions required to meet the Reef 2050 Water Quality Improvement Plan targets by 2025. There is an urgent need for greater investment in voluntary practice change programs, the use of regulatory tools and other policy mechanisms to accelerate the adoption of practice change, and robust monitoring and evaluation programs to measure the rate and effectiveness of adoption.

Summary of evidence

- There is very high confidence in the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program water quality risk frameworks which are used to assess the effectiveness of agricultural practices for water quality. New research has highlighted the benefits of lower fertiliser (nitrogen) application rates, and site and season-specific fertiliser recommendations, in reducing water quality risk. In grazing, land cover management has been found to be effective at generally reducing erosion. However, gully and streambank erosion remains a major problem and remediation has become a higher priority.
- The adoption of new agricultural practices depends on many factors including individual goals and circumstances, local context, perceived profitability and risk and ease of management. Farmers are diverse, with different goals, motivations and information sources. Conflicting messages about Great Barrier Reef health, blaming farmers and the over-emphasis on science (to the exclusion of local or industry knowledge) have been found to contribute to low acceptance of environmental responsibility.
- Collaborative processes to deliver interventions and improve trust in decisions and data are essential. Local, trusted intermediaries and flexible incentives need to be fostered to improve participation in reef water quality programs.
- Wetland and floodplain protection, management and restoration, as well as engineered treatment systems are required to complement on-farm practices to reduce nutrient, sediment and pesticide run-off.
- Changes in land use to less intensive options (such as from sugarcane to grazing, wetlands or conservation) warrants further consideration to accelerate pollutant load reductions. There is currently limited investigation or evidence of these options in the Great Barrier Reef catchments.
- Additional water quality benefits can be achieved from non-agricultural lands such as urban areas and ports, although our understanding of the effectiveness of different practices for water quality in the Great Barrier Reef is limited.
- Large variations exist in the costs of improving water quality between natural resource management regions, programs and industries. Investments can be better prioritised to improve the efficiency and effectiveness of practice change programs. The costs of meeting the water quality targets has been shown to be very high; much higher than previously thought. As the water quality targets are approached, the costs of additional actions are likely to rise sharply.
- Better prioritisation of investments should take into account the cost-effectiveness of agricultural management options including adoption rates, costs, time lags and climatic influences, as well as risks to the marine environment. The areas where the most cost-effective management options can be achieved are not necessarily the areas that generate the most pollutants.

Recommendations

- **Develop and implement cost-effective techniques to manage gullies and riparian erosion; further develop and implement new approaches to fertiliser management in cropping lands (including the use of enhanced efficiency fertilisers, site-specific fertiliser management, and considering seasonal climate forecasts); and investigate methods to reduce catchment run-off as a result of extreme climatic events.**
- **Introduce tailored practice change programs that target different groups of landholders and involve collaboration with landholders, industry organisations and service providers to design and deliver programs. Include programs that involve knowledge exchange between farmers, scientists and others; address perceptions of risk; provide trusted and diverse advisory services; and deliver adequate financial, cultural and social rewards.**
- **Develop and implement a broader range of management options for pollutant reduction from all land uses considering costs, water quality benefits, other trade-offs and policy instruments. In particular: (a) test and validate the water quality effectiveness of wetland and treatment systems in specific locations to support their broader application; (b) review options for voluntary land use change to less intensive uses which support water quality improvement; and (c) incorporate total water cycle management in expanding urban areas and quantify benefits at local scales. Encourage adoption of proven applications.**
- Undertake a more comprehensive and systematic evaluation of existing and proposed policies and programs to improve their effectiveness in accelerating adoption. Additionally, ensure that an economic assessment of projects, in terms of public costs and private benefits, is undertaken to better judge cost-effectiveness and likely adoption before proceeding.
- Implement regulatory and market mechanisms to favour selection of lower cost projects and faster practice change, supported by voluntary approaches to meet the pollutant reduction targets. A variety of regulatory tools already exist, and others e.g. 'smart regulation' should be considered.

Governance and program delivery arrangements

Great Barrier Reef water quality governance requires a commitment to adaptive, participatory and transdisciplinary approaches, and better use of social, economic and institutional research. There is strong evidence to show where aspects of current water quality management programs can be strengthened. Risks including climate change, major development projects and related policy areas, such as agricultural intensification and coastal development, need to be addressed more directly. Strengthened and more effective coordination of Australian and Queensland government policies and programs, further collaboration with farmers and other stakeholders, and strong evaluation systems are critical to the success of Great Barrier Reef water quality initiatives.

Summary of evidence

- Overall, the governance of the Great Barrier Reef is inherently complex. Coordination between governments and government programs is critical to provide clear policy signals and ensure effective management actions.
- There has been a lack of systematic evaluation of program design and implementation, and limited use of social, economic and institutional research to find and test new solutions and improve program delivery.
- Great Barrier Reef governance requires adaptive, participatory and transdisciplinary approaches:
  - **Adaptive** approaches use modelling and other tools to build system understanding, encourage experimentation and evaluation, and tailor solutions to regional variations. A greater focus on experimentation and evaluation of on-ground works and program delivery would strengthen the adaptive capacity of Great Barrier Reef programs. Current governance arrangements have not effectively supported a culture of innovation for water quality outcomes.
  - **Participatory** approaches can bring more knowledge to the debate about solutions, garner support, coordinate effort and reveal value conflicts. Participation and collaboration are features of Great Barrier Reef policy, planning and implementation. Collaboration between natural resource management organisations and industry peak bodies has facilitated coordinated program delivery. Regional capacity is, however, fragile with changes to natural resource management programs, capacity and funding commitments.
  - **Transdisciplinary** approaches use natural and social sciences and stakeholder knowledge to test and evaluate innovative solutions.
- Climate change, the cumulative impact of major development projects and uncoordinated policies represent critical risks to Great Barrier Reef health.
- Intergovernmental coordination and policy alignment must be improved as they affect all aspects of program design and delivery. Related policy areas, such as agricultural intensification, drought relief and water resource development, and poor alignment with other regional planning and management efforts can have perverse impacts on Great Barrier Reef water quality outcomes.

Recommendations

- **Evaluate the effectiveness, efficiency and outcomes of Great Barrier Reef programs and share learnings at Great Barrier Reef and regional levels to drive improvement in program governance, design, delivery and implementation. Incorporate learnings from social research and international case studies, and commission locally relevant research, to support formal Great Barrier Reef policy review cycles.**
- **Address the significant risks to Great Barrier Reef ecosystems from other policy areas by implementing measures to reduce greenhouse gas emissions, assessing the cumulative impacts of major projects on the Great Barrier Reef, and influencing related policy areas such as agricultural intensification and coastal development that may increase risks to the Great Barrier Reef.**
- Develop stronger alignment between Great Barrier Reef management programs, wetland and floodplain management, and other regional planning and management activities such as land use planning, development assessment and floodplain management.
- Encourage and invest in core natural resource management activities such as local partnerships, planning and community engagement to strengthen the regional, catchment and property-scale delivery network. Longer term funding commitments tied to performance outcomes will provide flexibility to tailor approaches to local contexts.
- Encourage experimentation and innovation by scientists working with local stakeholders to develop, test and evaluate potential new solutions.
- Strengthen intergovernmental coordination to ensure effective management of the Great Barrier Reef. The Reef 2050 Long-Term Sustainability Plan needs greater authority and investment, clearer strategies and better stakeholder engagement.

Catchment-scale management priorities

Several catchments contribute to the highest exposure of coastal or marine ecosystems to pollutants, and are considered a high priority for water quality improvement. These include the Mulgrave-Russell, Johnstone, Tully, Herbert, Haughton, Burdekin, Pioneer, Plane, Fitzroy and Mary catchments. Social and economic information is required to prioritise efforts within catchments.

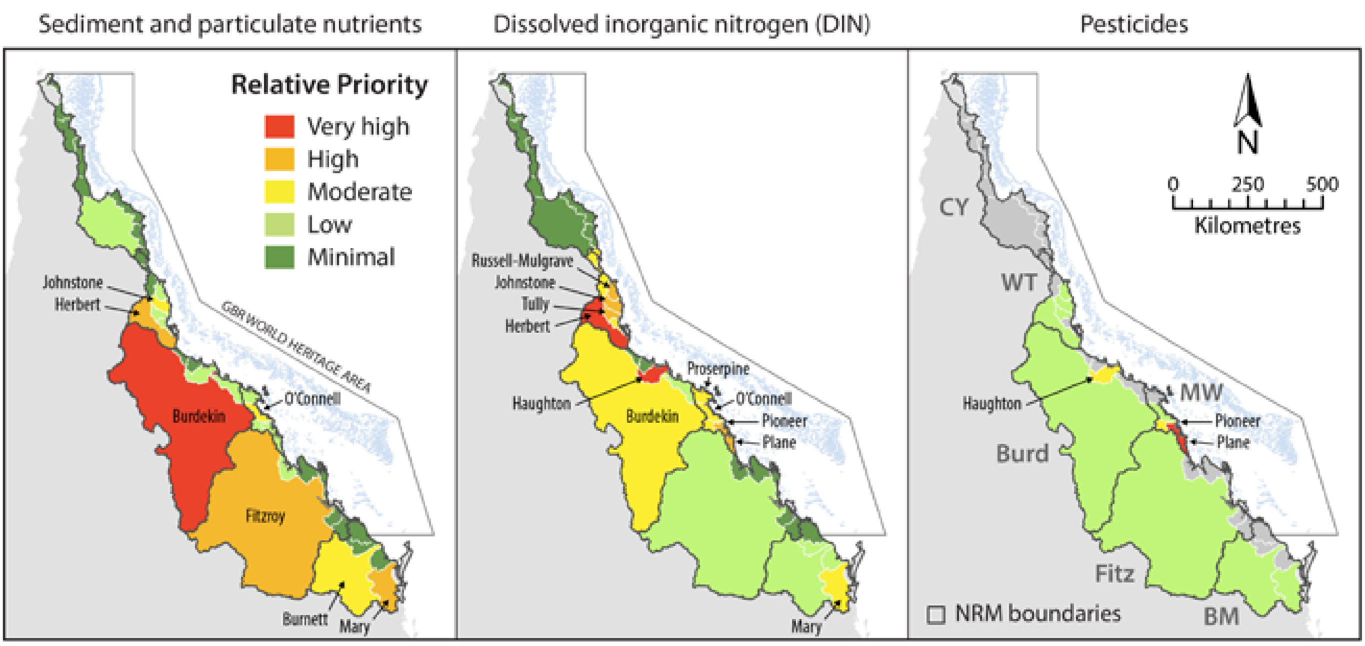
Summary of evidence

- The highest priority areas for reducing fine sediments, dissolved inorganic nitrogen and pesticides loads delivered to the Great Barrier Reef are shown in Figure 3. They are:
  - Fine sediment and particulate nutrients: Burdekin, Herbert, Fitzroy and Mary catchments.
  - Dissolved inorganic nitrogen: Herbert, Haughton, Mulgrave-Russell, Johnstone, Tully and Plane catchments.
  - Pesticides: Plane, Pioneer and Haughton catchments.
- The Cape York catchments could also be a priority for protection and for maintaining current water quality given their relatively low risk contributions and relatively good condition of the adjacent marine ecosystems.
- Comparing the highest priority catchments for pollutant reduction against those with the most cost-effective management options (in $/tonne) shows:
  - The Mary, Herbert, Fitzroy and Burdekin catchments offer the most cost-effective management for sediment, while actions in the Burdekin, including the Bowen-Broken-Bogie catchment, provide larger scale reductions at higher cost levels.
  - The results are less clear for dissolved inorganic nitrogen due to limited data availability across the Great Barrier Reef but indications are the Plane, Herbert, Tully and Johnstone catchments are the most cost-effective for reducing dissolved inorganic nitrogen loads through improved sugarcane management.

Recommendations

- **Develop a detailed, comprehensive and costed water quality management plan, drawing on the existing regional water quality improvement plans, to guide strategic investment in priority areas and ensure the water quality targets for the Great Barrier Reef are achieved.**
- **Undertake finer scale spatial prioritisation of management and allocate resource effort across and within the Great Barrier Reef catchments, using (a) biophysical catchment characteristics and the likelihood of exposure of coastal and marine ecosystems to pollutants to identify priority areas at a catchment scale, supported by (b) current practice adoption, and social and economic factors to inform the most cost-effective areas for increased management effort and the choice of policy mechanisms and (c) a range of agricultural management practice, landscape remediation and/or land conversion management scenarios. Incorporate risks to landholders and partners, climate, markets and time lags. Industries such as horticulture and broadacre cropping require further attention as they present an opportunity for cost-effective outcomes in short timeframes.**
- Target funding for improved land management and remediation to the priority catchments identified in the 2017 Scientific Consensus Statement. Areas of lower priority for remediation need to be maintained or improved.

Figure 3: Map illustrating the relative spatial priorities for water quality improvement in the Great Barrier Reef catchments based on the assessment of pollutant exposure and risk to coastal and marine ecosystems. Note this is a result of the biophysical assessment only, and results for particulate nutrients have been extrapolated from the fine sediment assessment and were not considered independently. Social and economic factors should determine priorities within catchments.



Monitoring and modelling

Monitoring and modelling of the Great Barrier Reef ecosystems is a strength of the Reef Water Quality Protection Plan 2013 and its programs, with some spatial limitations. However, there has been limited investment in social and institutional research and monitoring, and a lack of systematic evaluation of delivery processes and governance systems. A greater focus on experimentation, prioritisation and evaluation at different scales, coupled with the use of modelling and other approaches to understand future scenarios, could further improve water quality programs.

Summary of evidence

- The Paddock to Reef Integrating Monitoring, Modelling and Reporting Program (Paddock to Reef program) commenced in 2009 and is the central program for evaluating progress towards the Reef Water Quality Protection Plan management practice, catchment condition and pollutant reduction targets, as well as marine water quality and ecosystem health condition. The scope of the program does not include social (except for management practice adoption reporting), economic or governance indicators. There is also limited marine condition assessment in the northern (Cape York) and southern (Burnett Mary) regions.
- Almost 10 years of data collected under the Paddock to Reef program provides the basis for assessing catchment management effectiveness and catchment and marine water quality and ecosystem condition.
- Regional reporting partnerships have been established involving a broad range of stakeholders. Access to monitoring data outside of the Paddock to Reef program will become more important with the scope of the Reef 2050 Water Quality Improvement Plan 2017-2022 expanded to include non-agricultural land uses.
- The ability to quantitatively attribute changes in catchment activities and end-of-catchment water quality to coastal and marine water quality and ecosystem condition remains limited due to climate variability, sparse monitoring and incomplete operational models. Overall, catchment and marine monitoring and modelling approaches to support evaluation and reporting of the progress towards targets continues to improve. There are still challenges with the lack of data for all indicators in the Cape York and Burnett Mary regions.
- There has been little investment in social, economic and institutional research, or monitoring, evaluation and reporting of indicators related to Great Barrier Reef water quality management, and this constrains the ability to improve the effectiveness of programs.

Recommendations

- Expand the scope of the Paddock to Reef Integrated Monitoring, Modelling and Reporting program to:
  - » Include condition reporting of coastal aquatic ecosystems.
  - » Address the lack of monitoring data, validation of models and the estimation of water quality risks and ecosystem condition in the Cape York and Burnett Mary regions.
  - » Incorporate a formal social and economic monitoring and modelling component.
  - » Address the lack of monitoring data from other pollutants, e.g. marine debris, microplastics, and personal care products.
- Expand and improve public reporting of water quality data from all land uses and whole-of-catchment efforts to support broader community engagement.
- Develop the capacity to model the cumulative impacts of water quality and other pressures (major projects, coastal development) under a range of climate and other scenarios to better inform policy, planning and assessment processes.
- Develop a systematic approach to program evaluations that incorporates social, economic, governance and programmatic dimensions to inform program delivery efforts and support innovation.

6. Knowledge gaps

While a great deal of evidence is available to support the 2017 Scientific Consensus Statement, there are still many important knowledge gaps that need to be addressed to improve our understanding and management of water quality issues in the Great Barrier Reef. Key knowledge gaps and areas for further research are included in each chapter, and highlighted in Chapter 5. These will be incorporated into the updated Reef 2050 Water Quality Research, Development and Innovation Strategy.

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Supporting chapters

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