Resilient Coral Reefs Successfully Adapting to Climate Change

—

A Research Portfolio

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GREAT BARRIER REEF
foundation

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Foreword

The world's coral reefs are threatened by the effects of climate change.

Spread across 109 countries, the world's coral reef communities are a storehouse of tremendous biodiversity and source of life for an estimated half a billion people[1]. The coral reefs of the six Coral Triangle countries alone, upon which more than 100 million people rely directly for their food and livelihood[2], house over 75% of the world's reef-building corals and more than one-third of its fish species[3].

On a day to day basis many reefs, particularly those in the developing world, are subjected to destructive fishing practices (for example, the use of cyanide), overfishing and tourism, the effects of soil particles, pesticides and pollutants in the water, coral mining, coastal development and shipping. However, climate change looms as the largest of the threats to reefs. It compounds the effects of all these other threats and challenges management profoundly.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) predicted that by 2020, if nothing was done, as much as 60% of the world's largest coral reef, the Great Barrier Reef, would bleach every second year[4]. In 2002 when 55% of the Great Barrier Reef bleached, 5% of the affected corals died[5].

The IPCC's conclusions were a call to action. Irrespective of how successful efforts to mitigate the severity of climate change are, there must be effective adaptation to changes in the ecosystem which are already occurring and to which we are already committed.

The Great Barrier Reef Foundation (the Foundation), an Australian not-for-profit with strong links to Australian business, philanthropy, government and coral reef research and management agencies took up the baton of adaptation as a means to meet the climate change challenge.

Recognising that no one group could solve this problem alone and that such a challenge required leadership and a strong drive for innovation, the Foundation convened experts from its network to develop a Portfolio of research addressing a vision of resilient coral reefs, successfully adapting to climate change.

The research required must begin with the ability to measure, monitor and communicate the effects of climate change on coral reefs.

[1] Pomerance et al. 1999

[2] Hoegh-Guldberg et al. 1999

[3] WWF, 2009, The Coral Triangle and Climate Change

[4] M.L. Parry et al. (eds) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007

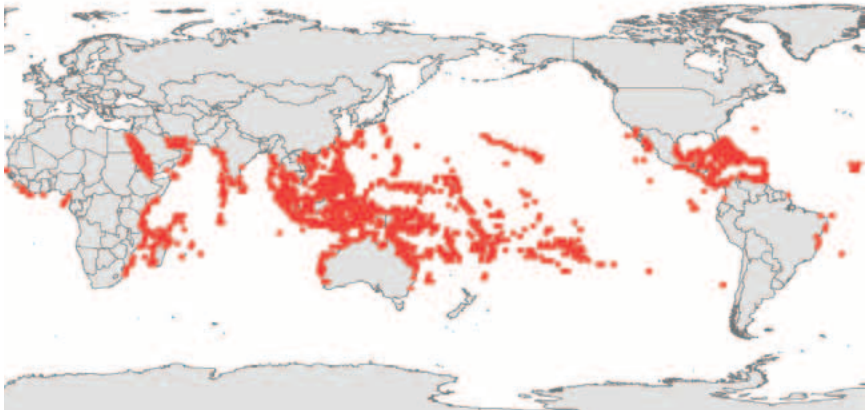
[5] Australian Institute of Marine Science, online, www.aims.gov.au

It must develop a range of adaptation options to address the effects of warming waters, more acidic oceans and organisms that are struggling to adapt. Then it must equip managers, users and policy makers with the decision making tools required to determine where, when and how to deploy these options.

This Portfolio of research seeks to do just that. It is an innovative and complex Portfolio, two years in the making and the product of more than 75 people from 15 institutions and companies.

The Great Barrier Reef (the Reef) is an ideal incubator for this research. Physically, its vast size, complexity and general good health provide the best possible conditions for developing and testing adaptation concepts at a range of scales, under variable conditions and across multiple latitudes. The Reef is situated on the edge of a developed country that has resourced its reef research and management sectors well.

Figure 1—
Global Coral Reef Distribution.
Map provided by ReefBase
(www.reefbase.org)



Its physical features and the cluster of expertise available make it an ideal location for adaptation research and base for capacity building, knowledge growth, export and transfer to coral reef communities globally.

The research delivered through this Portfolio will provide a platform for worldwide assessment of coral reef resilience to climate change, a suite of adaptation options and the means to test these innovative solutions. This will significantly advance the knowledge and tools available to coral reef managers, policy makers in Australia and ultimately could be shared with communities across the world.

The Foundation is committed to its mission of protecting and preserving coral reefs and adjoining coral coasts, for the benefit of the world community. However, the solutions to climate change on systems as beautiful and complex as coral reefs are unlikely to be found at first instance. With this in mind and with its vision firmly set, the Foundation will, alongside the delivery of this first Portfolio, continue to develop future portfolios of research.

—

Dr John Schubert,
Chairman

Mrs Judith Stewart,
Managing Director

Prof. Paul Greenfield AO,
Chairman,
International Scientific
Advisory Committee

1. Executive Summary

1.
Executive Summary

In August 2009, the Great Barrier Reef Foundation released a report by Oxford Economics into the value of the Great Barrier Reef and the economic costs of a catastrophic bleaching event on that value[6]. The report found that 73% of the Reef's assessed value of A$51.4 billion would be lost if such an event occured. The impact on key tourism and fishing regions was as high as 90%.

Less than a month later, the Reef's statutory manager, the Great Barrier Reef Marine Park Authority concluded in its Outlook Report that "despite the introduction of significant protection and management initiatives, the overall outlook for the Great Barrier Reef is poor"[7], citing climate change as the greatest risk[8] to the Great Barrier Reef ecosystem.

The effects of climate change on a fragile living ecosystem, such as the Great Barrier Reef, can be profound—warmer ocean temperatures cause coral to lose their life giving properties, more acidic waters slow the growth of the calcified structures and organisms are denied their ideal growth environment.

However, equipped with measures of how the Reef is responding to the effects of climate change, the right suite of adaptation intervention strategies and appropriate decision support and communication tools, Reef managers will be able to sustain or enhance its resilience.

Such knowledge requires innovative research of the kind contained in this Portfolio.

Expert working groups made up of eminent scientists, Australian business, government and Reef management agencies, many of whom are internationally recognised in their fields, were convened and led by the Great Barrier Reef Foundation. They came together to identify new concepts, new approaches to old concepts, strategies from other industries and sectors modified to apply to the coral reefs and new ways of thinking so that the Reef and our interactions with it can adapt to a different future.

As a result, this new Portfolio, developed by the working groups spans a large spectrum of research. It has integration as its basis, ensuring the work spans the biophysical and social, the Reef as a whole and its parts, its links to the coast and ocean and the elements of understanding, monitoring and action.

It begins with the attributes of a resilient reef successfully adapting to climate change. Understanding what constitutes a reef resilient to climate change and how it can be measured and communicated will provide the baseline and metrics for managers, policy makers and users confronting an ecosystem put directly at risk by climate change.

In parallel, it develops a suite of adaptation options which, once researched, could allow more of the Reef to adapt and survive, buying time until mitigation measures take effect. In developing these adaptation concepts, a view was taken that current and essential efforts to minimise existing stressors on the Reef and build resilience may not be sufficient to protect the Reef against climate change. Consequently, the Portfolio puts forward project proposals to examine the feasibility of minimising the effects of warmer water temperatures, reducing the effects of more acidic oceans and increasing the adaptive capacity of Reef organisms, tested in a risk-managed way. Recognising that communities, industries and Reef management too, must adapt to the effects of climate change, the Portfolio also explores complementary governance, planning, industry and community engagement strategies.

Without tools to account for the current state of the Reef, predict its future and assess the when, where and how to implement adaptation strategies, the picture remains incomplete. Consequently, the Portfolio also develops a number of integrating tools and technologies to provide the critical decision support framework for management and policy makers as the effects of climate change are felt more deeply.

The investment required to deliver this Portfolio is substantial—more than $100 million. Many different investors—corporate, philanthropic, government, science and even the financial markets—will have a role in providing this funding. The Foundation and its research partners are committed to investing their resources to deliver the vision.

We invite you too, to participate in the delivery of this innovative Portfolio by investing in the Reef's resilience and adaptation to climate change.

[6]Oxford Economics, Valuing the effects of Great Barrier Reef Bleaching, 2009

[7]Great Barrier Reef Marine Park Authority, Great Barrier Reef Outlook Report, 2009

[8]The other being catchment run off (water quality)

2.
Coral Reefs and Climate Change

2.1 Coral Reefs

2.2 The Great Barrier Reef

2.3 The Reef and Climate Change

2.4 The Great Barrier Reef Foundation

2.1 Coral Reefs

Coral reefs, frequently referred to as "rainforests of the sea", are the world's most diverse marine ecosystems. Although they form a tiny proportion of the world's ocean surface (less than 1%) they are estimated to provide a home for 25% of all marine species[9]—from hard and soft corals to fish, molluscs and mangroves, seabirds to seagrasses, turtles to dugongs.

Spanning 109 countries, these coral reefs have also shaped and formed a third of the world's tropical coastline.

As hot spots of biodiversity they provide enormous pleasure but to many, they are a source of food and income. More than 1 billion people live within 60 kilometres of a tropical coral reef and 500 million people are dependent on reefs for their food and livelihood. Reef ecosystems are conservatively estimated to provide $375 billion in direct goods and services each year[10], including 10% of the global commercial fisheries catch.

However, as a source of livelihood for so many they are also subject to significant pressures. From destructive fishing practices to overfishing, unsustainable tourism to polluted waters and coastal development to shipping, reefs are subjected to an onslaught on a daily basis. It is estimated that 40% of coral reefs are already lost or severely degraded[11].

2.2 The Great Barrier Reef

"The reefs of the Great Barrier Reef—almost 3000 in total—represent about 10 per cent of all the coral reef areas in the world. Virtually all groups of marine plants and animals are abundantly represented with thousands of different species living there." Great Barrier Reef Outlook Report 2009[12]

The Great Barrier Reef, the world's largest coral reef system, exemplifies this biodiversity and beauty.

Comprising 2900 individual reefs, the Reef spans an area of 344,040 square kilometres along 2300 kilometres of coastline, in north eastern Australia. It is home to 360 species of hard coral, 400 varieties of sponge, 5000 mollusc species and 10% of the world's fish species[13].

[9]WWF online, available from http://wwf.panda.org

[10]US Coral Reef Task Force, 2000

[11]Coral Reef Targeted Research & Capacity Building for Management Program, 2009

[12]Great Barrier Reef Marine Park Authority,Great Barrier Reef Outlook Report, 2009

[13]Great Barrier Reef Marine Park Authority, fact sheet 1 online, www.gbrmpa.gov.au

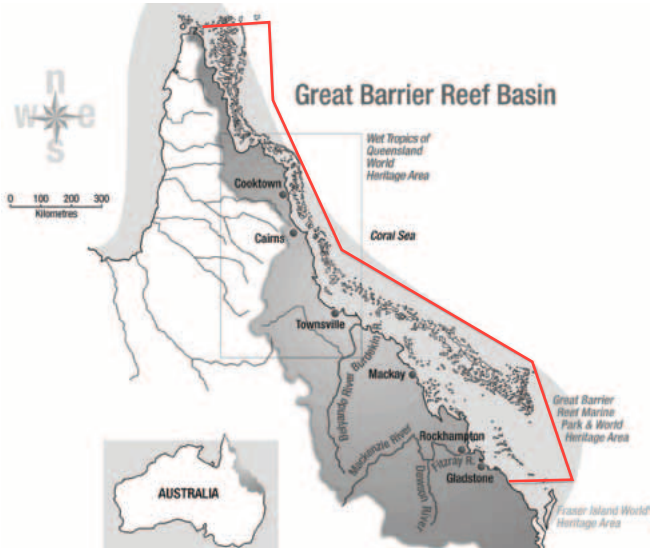
Recognising its cultural and natural value, the Australian Government established the Great Barrier Reef Marine Park in 1975. Six years later UNESCO named the Reef a World Heritage Area, stating that "The Great Barrier Reef is a site of remarkable variety and beauty".

Just as the Reef itself is complex, so too are the jurisdictions with which it interacts, the research sector dedicated to its study and the responsibilities of its management. Moreover, the Reef environment is affected by what happens in adjacent paddocks and catchments, on the coast which borders it, nearby oceans and the earth's atmosphere.

The Reef is managed and regulated by the Australian and Queensland Government through the Great Barrier Reef Marine Park Authority. A number of other regulatory bodies, at both state and national levels, also maintain a legislated interest in the Reef.

There are as many as sixteen organisations involved in scientific research on the Great Barrier Reef, including James Cook, Queensland and Sydney Universities, the Commonwealth Scientific and Industrial Research Organisation and the Australian Institute of Marine Science, to name just a few.

Figure 2—
Great Barrier Reef Region, including associated river catchments
©WWF (http://wwf.panda.org)



2.3 Climate Change places the Reef at Risk

In 2007, the Intergovernmental Panel on Climate Change (IPCC) flagged directly to the custodians of the world's coral reefs that the need to act on climate change was beyond scientific doubt, and could not wait. The message was clear—with cumulative climate change effects, such as warmer and more acidic ocean waters, already in evidence, the resilience of reefs, like the Great Barrier Reef, was already very much at risk. By 2020, if nothing is done, 60% of the Reef would bleach every second year[14]—even half this frequency of bleaching would be devastating to the Great Barrier Reef.

The Great Barrier Reef Marine Park Authority's first Outlook Report reinforced the risks of climate change stating that "Almost all the biodiversity of the Great Barrier Reef will be affected by climate change, with coral reef habitats the most vulnerable"[15].

Risks to biodiversity also have human and economic impacts. In 2009, the Foundation published a study by Oxford Economics into the economic cost of a bleaching event[16]. It found that in the event of catastrophic bleaching up to 70% of the A$51.4 billion value the Reef provides to the national economy would be lost.

One cannot diminish the overarching priority, globally, of reducing greenhouse gas emissions in order to secure the Reef for future generations. Indications are that coral reefs are in grave danger if atmospheric carbon dioxide concentrations exceed 450ppm[17].

However, it is equally important to recognise that climate change effects, in the form of warmer temperatures and more acidic oceans are already in the system and are today, impacting the resilience of the Great Barrier Reef. Indeed the Marine Park Authority's Outlook Report states that "Coral bleaching resulting from increasing sea temperature and lower rates of calcification in skeleton-building organisms, such as corals, because of ocean acidification, are the effects of most concern and are already evident"[18].

Adaptation is essential, whatever we do —to changes in the ecosystem which are in evidence and to those which current emissions have already committed us. It is this that has driven the Foundation's work on this Portfolio.

[14]M.L. Parry et al. (eds) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007

[15]Great Barrier Reef Marine Park Authority, Great Barrier Reef Outlook Report In Brief, 2009

[16]Coral bleaching occurs when the zooxanthellae that nourish the coral host giving it both life and colour are expelled from the coral, leaving the coral skeletons looking white or bleached.

[17]Hoegh-Guldberg et al., 2007

[18]Great Barrier Reef Marine Park Authority, Great Barrier Reef Outlook Report In Brief, 2009

3.
The Great Barrier Reef Foundation

3.1 The Great Barrier Reef Foundation

3.2 The Foundation's Role

3.3 Research Vision

3.1 The Great Barrier Reef Foundation

The Great Barrier Reef Foundation is an Australian not-for-profit organisation, with links to Australian business and philanthropy and the national coral reef research and management agencies. It has been raising funds from Australian business and philanthropy for the last ten years to support high priority projects on the Great Barrier Reef.

The Foundation's mission is to raise and provide funding to support research that contributes to the environmental protection, enhancement, preservation and conservation of tropical reefs (especially the Great Barrier Reef) and adjoining coral coasts, for the benefit of the world community.

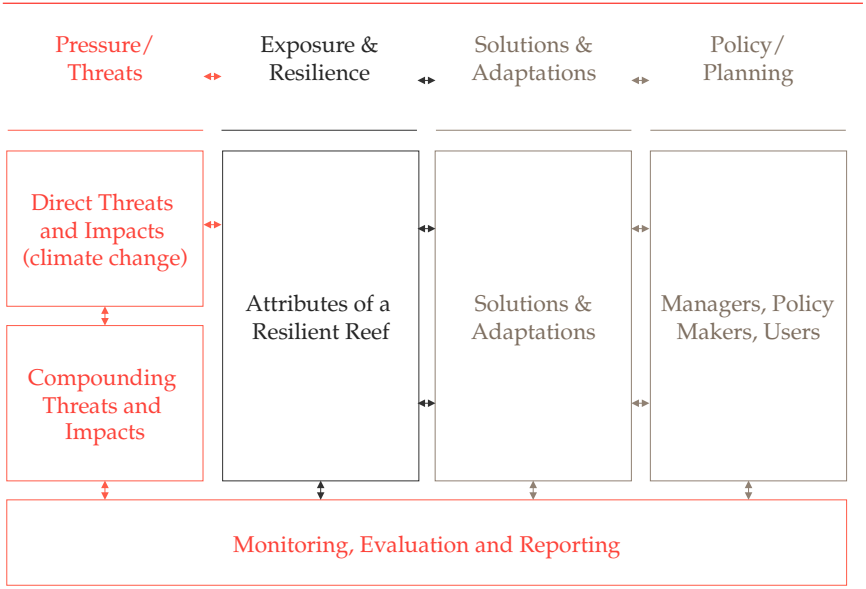
It provides an independent channel for private investment from both business and philanthropic sources, working with its partners to develop and fund the highest priority research projects on the Reef.

The Foundation's Board of Directors comprises senior representatives of the Australian business, science and philanthropy sectors. The Board's primary role is to ensure that the Foundation's activities are directed towards achieving its mission.

The Board also provides strategic advice to management on the needs and expectations of the private sector and plays an important role in engaging a wider audience about the issues facing the Reef.

The Board and management of the Foundation are directly advised by an International Scientific Advisory Committee (or ISAC). In ISAC, the Foundation assembles the most important and influential leaders of the Reef research and management sector.

Figure 3—
Research Framework



3.2
The Foundation's Role

The Foundation is devoting its resources to the climate adaptation effort for three reasons:

1. Its reach into the research, business, philanthropic and government sectors equips it to add particular value in tapping into diverse expertise and resources;
2. Its success in attracting new investment from the private sector into Reef research is the ideal basis for unlocking significant further funding from multiple sources for high priority research;
3. Its not-for-profit characteristics enable it to be both agile and provocative in seeking solutions to the seemingly unsolvable.

It is on this basis that the Foundation established its research vision and framework and led the development of a research Portfolio designed to deliver on this research vision.

This research Portfolio together with the vision and framework which underpin it, have been developed under the direction and guidance of the Foundation's International Scientific Advisory Committee. The Committee, comprising representatives of the leading Reef research bodies and Reef management has actively participated in the development of this Portfolio through attendance at working group meetings, reviews of progress, feedback into the development process and ultimately approval of the Portfolio as capable of delivering on the research vision.

Mindful that impacts of changing ocean temperature and acidity are likely to affect coral reefs everywhere, many of which are situated in the developing world[19], the Foundation will take a further role in identifying the pathways for its research findings to reach those coral reef communities.

3.2
Research Vision

In 2008, to reflect the scale and immediacy of the climate change threat to the Reef, and to focus its grant making activities, the Foundation adopted as its new research vision: A resilient Reef, successfully adapting to climate change.

For the purposes of this research Portfolio, the Foundation has adopted the following definition of resilience.

"Resilience is the ability of the Reef to resist, and recover from, disturbance."

[19]Of the 109 countries with significant coral reef communities, at least 93 are experiencing damage. The Coral Reef Targeted Research & Capacity Building for Management Program

4.
Portfolio Overview

4.1 Portfolio Elements

4.2 Attributes Projects

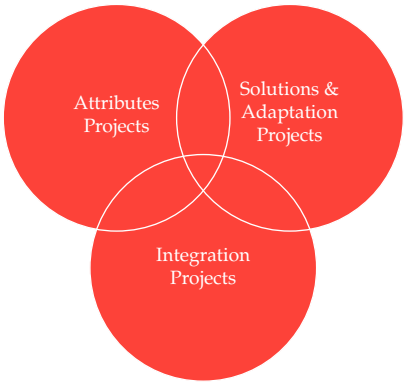
4.3 Solutions & Adaptation Projects

4.4 Integration Projects

4.5 Portfolio Deliverables

4.1
Portfolio Elements

This research Portfolio comprises three priority project groupings: Attributes, Solutions & Adaptation and Integration.



5.2
Attributes

Attributes projects focus on measuring the impacts of climate change on the key attributes of a resilient Reef. The Attributes projects extend across two streams:

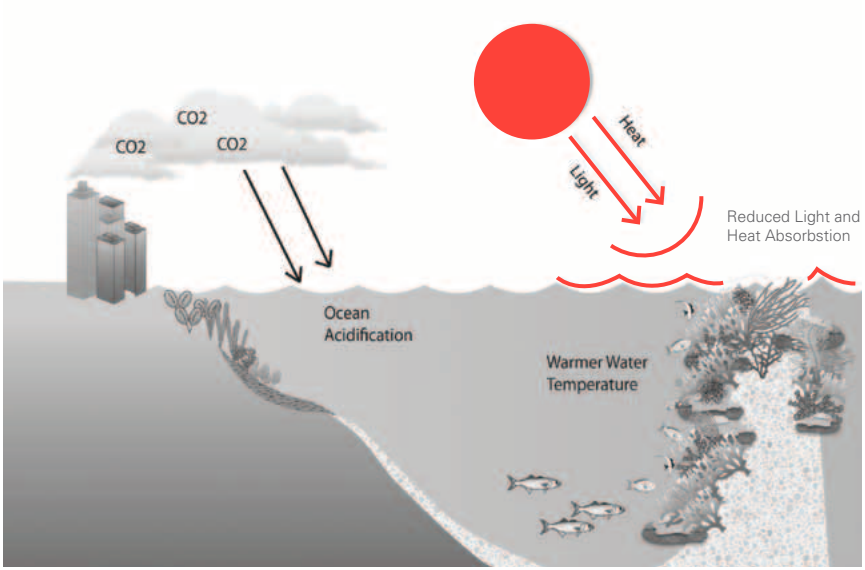
- Core coral reef systems which focus on the ecological and physical structure and integrity of the Reef, and
- Social systems which focus on the resilience of Reef-dependent communities and industries, and the governance regimes which manage the Reef.

4.3 Solutions & Adaptation Projects

Solutions & Adaptation projects address two streams of work:

- Ecological and physical solutions & adaptation strategies which directly address the primary threats of increasing water temperature and acidification. Ecological and physical strategies seek to either:
  - Reduce the effects or penetration of heat and light on water temperature;
  - Reduce the impacts of ocean acidification; or
  - Assist species and ecological communities to adapt.
- Enabling strategies address industry, community and management capacity to adapt to climate change and to adopt solutions. These initiatives are developed alongside ecological and physical strategies in order to support the socio-economic systems

Figure 4—
Solutions & Adaptation concepts seek to reduce the effects of climate change on coral reefs



4.4 Integration Projects

Integration projects have been identified and developed as the Portfolio unfolded in recognition of specific requirements to:

- Ensure the outcomes and learning from one project informs others, minimising the potential for unintended consequences;
- Span biophysical and social aspects of Reef resilience and adaptation;
- Bridge issues of spatial and temporal scale;
- Enable the modelling, visualisation and communication of results, forecasts and scenarios;
- Allow managers, users and policy makers to understand, monitor and act.

Streams of work within integration include:

- Reef Resilience Index to Climate Change;
- From Understanding to Action; and
- Decision Making and Communications Tools.

4.5
Portfolio Deliverables

This Portfolio has been designed to deliver tangible outcomes to managers, users and policy makers which will advance the resilience of the Reef in the face of the significant and impending threat posed by climate change. These outcomes include:

a) A defined set of attributes, indicators and metrics which can be employed to monitor the resilience of the Reef in relation to the threats and impacts of climate change;

b) An Index of Reef Resilience which can be applied at various scales to communicate to stakeholders how the Reef is faring in the face of climate change;

c) A suite of proven adaptation intervention concepts which can be adopted and implemented by managers and policy makers to sustain or enhance the attributes of a resilient reef to climate change;

d) A suite of tools with which managers, policy makers and Reef users can hindcast, forecast and generate scenarios and make decisions to deploy interventions and assess their effectiveness.

e) A global outreach program to share the learnings generated on the Reef with other coral reef-dependent countries.

The Foundation recognises that this first Portfolio is the beginning of a journey. Given the tight timelines facing the Reef, the Foundation has resolved to continue development of further Portfolios.

5.
Portfolio Quality Assurance and Delivery

5.1 Portfolio Governance

5.2 Quality Assurance

To provide investors with assurance as to the quality of this Portfolio and mitigate the need for investor due diligence into the quality of the process by which this Portfolio has been derived, the Foundation has drawn on a suite of governance and quality assurance processes.

Furthermore, a suite of guiding principles has driven the development of this Portfolio and will continue to guide its execution. Principles address key issues such as risk management and intellectual property, collaboration and selection processes and social license and alignment with the Foundation's research vision.

5.1 Portfolio Governance

The Foundation has established rigorous mechanisms to ensure the quality and integrity of the Portfolio as it has been developed.

These governance arrangements will also be applied to ensure that the funds contributed to this Portfolio are invested and managed.

Governance spans the Board, the International Scientific Advisory Committee, Audit and Finance Committees, the Portfolio Committee, Project Oversight Committees, Working Groups and Foundation management.

5.2 Quality Assurance

Assurance and control processes undertaken to ensure the Portfolio is of high quality include:

1. Working Group Reviews
2. Joint Working Group Reviews
3. Scientific Peer Review
4. Foundation Governance Reviews
5. Independent Portfolio Review

6.
Investing in the Portfolio

6.
Investing in the Portfolio

This Portfolio provides an overview of the projects required to deliver on the Foundation's vision. Information on projects is available on request.

However, the investment required to deliver this Portfolio is substantial. To complete the research outcomes described in section 4.4 will require an investment of more than $100 million.

All investors—corporate, philanthropic, government, science and even the financial markets—have a role in providing this funding.

The Foundation's research partners have already committed to co-invest their resources in the delivery of research.

Businesses seeking to meet their corporate social responsibility commitments, particularly those related to biodiversity and communities bordering coral coasts will see value in their commitment to the Portfolio.

Philanthropy's capacity to invest in the fundamentals that make the long term plan viable is critical.

Government's role too is important, especially in equipping managers and policy makers with the tools required to respond to climate change. Nor will this Portfolio sit proud of other government investment in reef management and research—there is simply not the time or resources to waste.

We invite you too, to participate in the delivery of this innovative Portfolio by investing in the Reef's resilience and adaptation to climate change.

Appendices

Appendices
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1. Portfolio Governance Structures
    a. Board
    b. International Scientific Advisory Committee
    c. Portfolio Committee
2. Attributes Working Group
3. Solutions & Adaptation Working Group
4. The Effects of Climate Change on Coral Reefs
5. Glossary

Appendix 1.
Portfolio Governance

a.
Great Barrier Reef Foundation Board

Name	Position	Organisation
Dr John M Schubert	Chairman	Great Barrier Reef Foundation
Judith Stewart	Managing Director	Great Barrier Reef Foundation
Ian Buchanan	Senior Executive Advisor	Booz & Co
Michael Cameron	Chief Executive	GPT Group
Geoff Dixon	Director	Great Barrier Reef Foundation
Kerry Gardner	Director	Great Barrier Reef Foundation
Prof. Paul Greenfield, AO	Vice Chancellor	University of Queensland
Amanda McCluskey	Head Of Sustainable & Responsible Investment	Colonial First State Global Asset Management
Dr John Mulcahy	Director	Great Barrier Reef Foundation
Dr Russell Reichelt	Executive Chairman	Great Barrier Reef Marine Park Authority (GBRMPA)
Michael Roux	Chairman	Roux International
Phillip Strachan	Chief Financial Officer	Rio Tinto Alcan
Keith Tuffley	Director	Great Barrier Reef Foundation
David Turner	Chairman	Commonwealth Bank of Australia
Peter Young, AM	Chairman	Queensland Investment Corporation

b.
International Scientific Advisory Committee

Name	Position	Organisation
Professor Paul Greenfield, AO	Vice Chancellor	University of Queensland
Dr Andrew Johnson	Group Executive Environment	Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Dr Russell Reichelt	Executive Chairman	Great Barrier Reef Marine Park Authority (GBRMPA)
Dr Ian Poiner	Chief Executive	Australian Institute of Marine Science
Professor Chris Cocklin	Deputy Vice-Chancellor, Research & Innovation	James Cook University
Professor Ove Hoegh-Guldberg	Director, Global Change Institute	University of Queensland
Associate Professor Eva Abal (Secretary)	Chief Scientific Officer	Great Barrier Reef Foundation

c.
Portfolio Committee

Name	Position	Organisation
Dr John Mulcahy (Chair)	Director	Great Barrier Reef Foundation
Dr John M Schubert	Chairman	Great Barrier Reef Foundation
Dr Russell Reichelt	Executive Chairman	Great Barrier Reef Marine Park Authority (GBRMPA)
Judith Stewart	Managing Director	Great Barrier Reef Foundation

Committee Coordinator: Ms Claire Hanratty, GBRF

Appendix 2.
Attributes Working Group

Name	Position	Organisation
Prof. Ove Hoegh-Guldberg (Chair)	Director, Global Change Institute	University of Queensland
Dr Natalie Ban	Postdoctoral Fellow, ARC Centre of Excellence for Coral Reef Studies	James Cook University
Dr Catherine Collier	Post Doctoral Fellow, Plant & Agricultural Sciences	James Cook University
Dr Guillermo Diaz-Pulido	Lecturer, Griffith School of Environment	Griffith University
Dr Katharina Fabricius	Principal Research Scientist	Australian Institute of Marine Science
Dr Simon Foale	Senior Lecturer, Arts, Education and Social Sciences	James Cook University
Dr Morgan Pratchett	Research Fellow, ARC Centre of Excellence for Coral Reef Studies	James Cook University
Prof. Bob Pressey	Professor, ARC Centre of Excellence for Coral Reef Studies	James Cook University

Name	Position	Organisation
Dr Cathy Robinson	Senior Research Scientist CSIRO Sustainable Ecosystems	Commonwealth Scientific and Industrial Research Organisation
Assoc. Prof. Natalie Stoeckl	Head of Discipline—Economics	James Cook University
Dr Hugh Sweatman	Senior Research Scientist & Leader of Long Term Monitoring Program	Australian Institute of Marine Science
Dr Karen Vella	Lecturer in Urban and Environmental Planning	Griffith University
Dr David Wachenfeld	Chief Scientist	Great Barrier Reef Marine Park Authority
Assoc. Prof. Michelle Waycott	Associate Professor Marine & Tropical Biology	James Cook University
Prof. Bette Willis	Professor, School of Marine and Tropical Biology	James Cook University

Attributes—
Socio-economic subgroup

Name	Position	Organisation
Dr Karen Vella (Facilitator)	Lecturer in Urban and Environmental Planning	Griffith University
Dr Allan Dale	Chief Executive Officer	Terrain NRM
Dr Nick Emtage	Research Fellow, School of Integrative Systems, Cairns	University of Queensland
Dr Margaret Gooch	Lecturer, School of Education	James Cook University
Ms Silva Larson	Research Scientist, Sustainable Ecosystems	Commonwealth Scientific and Industrial Research Organisation
Dr Kirsten Maclean	Postdoctoral Research Fellow, School of Natural and Rural Systems Management	University of Queensland
Dr Nadine Marshall	Research Scientist, Sustainable Ecosystems	Commonwealth Scientific and Industrial Research Organisation
Dr Cath Robinson	Senior Research Scientist, Sustainable Ecosystems	Commonwealth Scientific and Industrial Research Organisation
Prof. Helen Ross	Professor, School of Integrative Systems	University of Queensland
Dr Sizhong Sun	Lecturer, School of Business	James Cook University
Assoc. Prof. Natalie Stoeckl	Head of Discipline—Economics	James Cook University
Mr Bruce Taylor	Research Scientist, Sustainable Ecosystems	Commonwealth Scientific and Industrial Research Organisation

Working Group Coordinator: Dr Eva Abal (Great Barrier Reef Foundation)

Science Support: Mrs Theresa Fyffe (Great Barrier Reef Foundation

Appendix 3
Solutions & Adaptation Working Group

Name	Position	Organisation
Dr Andrew Ash (Chair)	Director, Climate Adaptation Flagship	Commonwealth Scientific and Industrial Research Organisation
Dr Hugh Bradlow	Chief Technology Officer	Telstra
Prof. Chris Cocklin	Deputy Vice Chancellor, Research and Innovation	James Cook University
Dr Allan Dale	Chief Executive Officer	Terrain NRM
Mr Shane Donohoo	Managing Consultant, Advanced Analytics Group	Worley Parsons
Mr Peter Glazebrook	Principal Advisor, Product Stewardship, Health, Safety & Environment	Rio Tinto
Mr Daniel Gschwind	Chief Executive Officer	Queensland Tourism Industry Council
Prof. Gideon Henderson	Professor of Earth Sciences	Oxford University (UK)
Prof. Ove Hoegh-Guldberg	Director, Global Change Institute	University of Queensland
Mr Adrian Jeffreys	Executive Director Environment & Resources Policy	Department of Premier & Cabinet, Queensland Government
Mr Chris Johnston	Assistant Secretary, Adaptation Innovation Branch	Department of Climate Change

Name	Position	Organisation
Mr Rob Kella	Chief Risk Officer	Qantas
Mr John Marlay	Member, Expert Committee appointed by (Cth) Minister for Climate Change	
Mr David McConnell	Manager, Advanced Technology	Worley Parsons
Mr David Mofflin	Executive Director, EcoNomics	Worley Parsons
Prof. Bob Pressey	Professor, Australian Research Council Centre of Excellence for Coral Reef Studies	James Cook University
Dr Madeleine van Oppen	Principal Research Scientist	Australian Institute of Marine Science
Dr Karen Vella	Lecturer in Urban and Environmental Planning	Griffith University
Dr David Wachenfeld	Chief Scientist	Great Barrier Reef Marine Park Authority
Prof. Jennifer Westacott	National Sustainability, Climate Change and Water Partner	KPMG
Peter Meurs	Managing Director, EcoNomics	Worley Parsons

Working Group Coordinator: Ms Claire Hanratty (Great Barrier Reef Foundation)

Appendix 4
The Effects of Climate Change on Coral Reefs

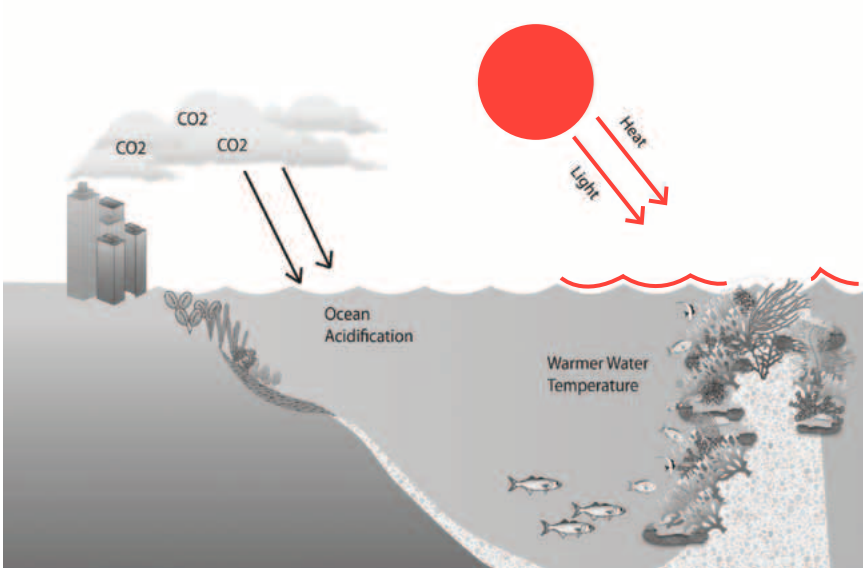
The two principal effects of climate change on coral reefs are increasing sea temperatures resulting in coral bleaching, and ocean acidification.

Coral reefs and climate change

Coral reefs like the Great Barrier Reef prosper in the shallow, warm and alkaline waters of the tropics. At the heart of these reef ecosystems, are reef-building corals which form a symbiosis with tiny plant-like organisms known as zooxanthellae. These organisms live inside the cells of the coral where they photosynthesise and trap the sun's energy. Most of this energy is transferred to the coral host, which uses the energy to grow and secrete its skeleton composed of limestone-like calcium carbonate. Over time, these coral skeletons create the three-dimensional structure of coral reefs, forming the habitat for thousands of other species.

Escalating concentrations of greenhouse gases such as carbon dioxide in the Earth's atmosphere have caused rapid increases in global temperature. These changes at the global level have resulted in steadily rising temperatures across the world's oceans. The Coral Sea is no exception and has changed by 0.8°C over the past century. At the same time, increasing amounts of carbon dioxide in the atmosphere have led to increased amounts of carbon dioxide entering the world's oceans.

Figure 5—
The principal effects of climate change on coral reefs



When in the ocean, the carbon dioxide reacts with water to create a dilute acid, significantly reducing the concentration of carbonate ions which are used by corals to form their skeletons. Since the beginning of the industrial revolution, the pH (a measure of the relative acidity or alkalinity of the solution) has decreased by 0.1 units. This decrease represents a 25% increase in the concentration of hydrogen ions and is driving decreases in the concentration of carbonate ions. These changes to the chemical and physical nature of the ocean are now beginning to affect coral reefs.

a—
Increased sea temperatures and mass coral bleaching

Increased sea temperatures have had major impacts on the viability of reef building corals, and consequently coral reefs. Since 1979, coral reefs have been experiencing mass coral bleaching events. These events occur when small increases in sea temperatures trigger the breakdown of the symbiosis between corals and their zooxanthellae.

Sea temperatures have always fluctuated from year to year—the problem now, however, is that warmer than normal years now exceed the thermal tolerance of corals, causing mass coral bleaching events. When the symbiosis between corals and their zooxanthellae breaks down, corals reject their zooxanthallae causing them to turn a brilliant white colour. Without their all-important zooxanthellae, corals are susceptible to starvation and disease.

Coral reefs can bounce back from short periods of thermal stress, but if conditions are warmer for longer, corals will die in great numbers[20]. In 1998, coral reefs all over the world experienced mass coral bleaching and around 16% of the world's corals died. In some regions, such as the western Indian Ocean, 46% of corals disappeared. In other regions, like Australia's Great Barrier Reef, conditions did not get as warm and only 5% of corals died. Over the past several decades, mass coral bleaching events have occurred repeatedly on the world's reefs, with the Great Barrier Reef experiencing two of the worst periods of bleaching over the past 12 years[21].

Reefs are devastated by these coral bleaching events and may take up to 20 years to recover—if these events continue to become more frequent, and reefs do not have time to recover in between bleaching events, then reefs will eventually lose the living corals that build and maintain them. Without corals providing the three-dimensional structure of coral reefs, many of the organisms that live in and around corals disappear. For this reason, thermal stress on coral reefs also endangers many other organisms in larger reef ecosystems; starfish and anemones, fish, turtles and sea birds, among many other species, all depend on the corals for food and protection.

[20] Hoegh-Gulberg, 1999

[21] In 2002, 54% of the Great Barrier Reef bleached, and about 5% of the reefs were severely damaged.

b—
Ocean acidification and declining reef calcification

Declining concentrations of carbonate ions in the ocean have reduced the ability of corals to form their skeletons, with recent evidence indicating that the calcification rates of corals have decreased by 15% since 1990[22]. A decrease of this size is unique in the 400 years of record examined so far.

Because coral reefs represent a balance between calcification (building their skeletons) and erosion (breakdown of their skeletons), seemingly small decreases in pH have the potential to tip the carbonate balance of coral reefs towards net erosion. Compounding this, other studies have shown that increased temperature and acidity interact to have a much greater impact on corals than either impact has on its own[23]. This means that the currently small temperature thresholds of corals are likely to be reduced even further with an acidifying ocean and will therefore bleach more readily.

c—
Compounding Pressures

The ability of coral reefs to recover from climate change disturbances depends very much on how intact they are. A healthy and resilient coral reef will recover from mass coral bleaching much faster than one that is stressed by other factors such as declining water quality and overfishing. In addition to local factors, climate change projections suggest that the future will see stronger storms and greater variability in rainfall. These changes can potentially combine with the stress of rising sea temperatures and acidities to create much greater challenges for coral reefs.

[22] De'Ath et al., 2009
[23] Anthony et al., 2008

Appendix 6— Glossary

Adaptation Strategies

Adaptation strategies seek to best manage and respond to the impacts of climate change across the biophysical, institutional and socio-economic domains.

Attribute

An attribute is a feature, either biophysical or socio-economic, of Reef resilience in the face of climate change. In the context of this Portfolio, they could be considered the 'vital signs' of Reef health under climate change.

Biophysical

This spans the physical environment of the Reef, the life forms within it and their interactions with the physical environment

Climate Change

A statistically significant variation in the mean state of the climate or its variability, persisting for an extended period, typically decades or longer. (IPCC)

Climate Change Adaptation

In general climate change adaptation involves taking action to adjust to the effects of climate change and to plan and prepare for the risk of future change.

Ecological and Physical Adaptation

Spans adaptation of Reef organisms and structures and the physical Reef environment to the primary threats of increasing water temperature and acidification.

Ecosystem

A biological environment made up of organisms and the physical environment in which they live.

Great Barrier Reef Marine Park Authority (GBRMPA)

Great Barrier Reef Marine Park Authority is the joint Federal and State agency responsible for administering the Great Barrier Reef Marine Park

Indicator

An indicator is defined as a specific measure which can be used to evaluate a given Attribute.

Integration

The approach adopted by the Foundation to the development and delivery of this Portfolio.

Intergovernmental Panel on Climate Change (IPCC)

The scientific body of the United Nations charged with evaluating the risk of climate change caused by human activity.

Metric

A metric is the quantifiable component of an indicator.

Ocean Acidification

The lowering of ocean pH levels as a result of carbon dioxide absorption.

Outlook Report

The five yearly report prepared by the Great Barrier Reef Marine Park Authority. The primary aim of the Outlook Report is to provide a regular and reliable report on the management of the Marine Park, the overall condition of the ecosystem of the Great Barrier Reef Region, social and economic factors, as well as a risk-based assessment of the longer-term outlook for the Region.

Oxford Economics

A UK based economic advisory provider of independent forecasting and analysis for policymakers and business.

Queensland

The north eastern state of Australia which the Great Barrier Reef borders

Resilience

The ability of the Reef to resist, and recover from, disturbance.

Social Resilience

The resilience of individuals and social structures to climate change on the Reef.

Solutions Strategies

Solutions seek to minimise or reduce climate change impacts on the Reef.

UNESCO

United Nations Educational Scientific and Cultural Organisation

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