Great Barrier Reef Restoration Symposium

Program & Abstracts

16-19 July 2018

Pullman Reef Hotel Casino, Cairns

#RestoretheReef2018

#Restore theReef 2018

Great Barrier Reef Restoration Symposium

16-19 July 2018

Pullman Reef Hotel Casino, Wharf Street, Cairns

www.GBRrestorationSymposium.org

Tropical Water Quality Hub

National Environmental Science Programme

AMPTO Association of Marine Park Tourism Operators

Reef & Rainforest Research Centre

Reef Ecologic For a better planet

Reef Restoration and Adaptation Program - a collaboration:

Australian Government | Australian Institute of Marine Science

CSIRO

Great Barrier Reef Foundation

James Cook University Australia

Australian Government Great Barrier Reef Marine Park Authority

QUT

The University Of Queensland Australia

Front Cover Photo: Gary Cranitch, Qld Museum Network

WELCOME

Like many reefs around the world, the Great Barrier Reef is suffering from the combined effects of many threats and disturbances, including mass coral bleaching, pollution, storm damage, and outbreaks of pests like crown-of-thorns starfish, among others.

While some of these threats are caused or exacerbated by global issues such as climate change, others may be amenable to local- or regional-scale intervention, restoration and management. Unfortunately, we currently have limited knowledge about these options and how they might be effective on the Great Barrier Reef.

Welcome to our Great Barrier Reef Restoration Symposium, a step towards redressing this gap. This international Symposium brings together restoration practitioners, scientists, engineers, environmental managers, NGOs and industry partners together to share experiences, insights and ideas about what works, what doesn't, what may work and what more we need to know to help the Great Barrier Reef. Over the next few days, Symposium participants will present and discuss methods currently being trialled elsewhere in the world, as well as novel approaches that may be still in development; from small, local-scale approaches to large-scale projects, including engineering and oceanographic interventions.

We have actively sought participation from a wide range of disciplines, including those not normally associated with coral reef research. I'd like to extend a special welcome to our school-aged delegates attending the Young Adults Workshop. Your enthusiastic participation brings hope for the future stewardship of the Reef, and all the human communities and industries that depend upon its ongoing health.

The Great Barrier Reef Restoration Symposium is a collaborative effort between the **Tropical Water Quality Hub (TWQ) of the Australian Government's National Environmental Science Program (NESP)** and the **Reef Restoration and Adaptation Program (RRAP)**, with funding support from the **Association of Marine Park Tourism Operators (AMPTO)** and the **Reef and Rainforest Research Centre (RRRC)**. Additional partners include **James Cook University**, **Reef Ecologic** and the **Reef Restoration Foundation**.

On behalf of all our partners, thank you for helping us help the Reef.

From the organising committee

Photo Left: Suzanne Long, RRRC

Sunday 15th July

17.00-20.00 All delegates are invited to the welcome function at **Aqualuna Restaurant**, within the **Cairns Aquarium**.
This function will include drinks and canapes. Early registration will be available at the venue.

Welcome to Cairns: *Cr Richie Bates, Cairns Regional Council*
Hosted by the *Reef and Rainforest Research Centre (RRRC)*

Monday 16th July

URCHINS BALLROOM

7.30 Symposium registration desk opens

8.30 Welcome to Country
Gudjugudju - Gimuy Walubarra Yidinji; Gavin Singleton - Yirrganydji

8.50 Introduction to the Symposium from the NESP Tropical Water Quality Hub leader
Damien Burrows, Symposium convenor, RRRC/NESP TWQ/JCU

9.10 Opening address 1
The Hon Zed Seselja, Assistant Minister for Science, Jobs and Innovation

9.25 Opening address 2
Patrick Suckling, Australian Ambassador for the Environment, DFAT

9.40 Plenary – Status of the Great Barrier Reef: risks and opportunities in the 21st century
David Wachenfeld, GBRMPA

10.10 Plenary – Coastal habitat restoration past and present
Boze Hancock, TNC

10.40 Morning Tea

11.10 Plenary – Collaboration to improve efficiency and spur aggresive innovation: the Coral Restoration Consortium
Tali Vardi, NOAA

Monday 16th July *continued*

URCHINS BALLROOM

11.40 Indigenous perspectives on coral restoration in the Great Barrier Reef
Gavin Singleton, Dawul Wuru

11.55 Listening session – perspectives from diverse stakeholders about need for and scope of interventions on the Great Barrier Reef
Introduction by *Hon. Penny Wensley AC, Chair, Reef Advisory Committee*
Hear from stakeholders – Tourism, Ports, Conservation, Community, the next generation (10 mins each)

13.00 Lunch

REEF ROOM

YOUNG ADULT WORKSHOP (see p13 for more details)

13.00-15.20 Led by *Nathan Cook, Reef Ecologic*

URCHINS BALLROOM

14.00 Collaborating to create an innovative suite of tools: the Reef Restoration and Adaptation Program
David Mead, AIMS

14.15 Next generation corals for tomorrow's reefs
Line Bay, AIMS

14.30 Asking for permission? The role of social licence in coral restoration
Justine Lacey, CSIRO

14.45 New approaches, transdisciplinary work and synthesis is needed to solve GBR problems: Integrated Pest Management for COTS
Sheriden Morris, RRRC

15.00 Building reefs versus planting corals – examples from Indonesia
Frank Mars, Mars Inc

15.20 Afternoon Tea

URCHINS BALLROOM

Reef restoration

15.50 Sex, death and scaling up coral restoration
Peter Harrison, SCU

16.05 Reef to Reef: Sharing Knowledge and Resources Across the Globe with the Reef Resilience Network
Liz Shaver, TNC

16.20 Economic value and importance of geographic scale in communications around reef health
Wendy Morris, TTNQ

16.35 Tackling decision challenges for reef restoration and adaptation – what strategies will sustain reef values?
Ken Anthony et al., AIMS

MICHAELMAS CAY ROOM

Restoration – other ecosystems

15.50 Overview of shellfish restoration
Chris Gillies, TNC

16.05 Reef Aid: Innovative restoration techniques in priority catchments to improve GBR water quality
Lynise Wearne et al., Greening Australia

16.20 The potential for seagrass restoration in the GBR region
Rob Coles et al., JCU

16.35 Island restoration in the GBR: a case study of island intervention and restoration in the Great Barrier Reef – Raine Island recovery project
Tina Alderson et al., QPWS

16.50 Daily wrap-up session (Urchins Ballroom)

17.30-19.30 Please join us at the **Pullman Reef Hotel Casino, Pool Deck** for our Symposium cultural evening, including drinks, canapes and featuring local Indigenous dance & music.

Guest Speaker: *Mr Michael Healy, Member for Cairns*
Hosted by the *Reef and Rainforest Research Centre (RRRC)*

Tuesday 17th July

URCHINS BALLROOM

7.30 Symposium registration desk opens

8.30 Keynote – Is it feasible and worth altering temperature and light stress on the Great Barrier Reef?
Mark Baird, CSIRO

9.00 Engineering challenges to scaling restoration and adaptation techniques
David Mead, AIMS

9.15 Towards an integrated pest management approach to crown-of-thorns starfish on the Great Barrier Reef
David Westcott et al., CSIRO

URCHINS BALLROOM

COTS control on the GBR Session 1

9.30 The evolution of the COTS Control Program on the GBR
Darren Cameron et al., GBRMPA

9.45 Safe, efficient and effective delivery of in-water COTS control operations: a viewpoint from several decades of effort by the Association of Marine Park Tourism Operators (AMPTO)
Steve Moon, AMPTO

10.00 Crown-of-thorns starfish management: does it work and what is it good for?
David Westcott et al., CSIRO

10.15 Innovations: Ecologically-informed tactical reef scale control using the COTS Control Centre
Cameron Fletcher et al., CSIRO

10.30 Enabling targeting of effort through connectivity analyses
Karlo Hock et al., UQ

MICHAELMAS CAY ROOM

Achieving scale for restoration 1

9.30 Mass production of corals for at-scale reef restoration in the GBR
Peter Mellor et al., Worley Parsons

9.45 Exploring coral settlement on 3D objects: potential applications for improved census and post-settlement survival
Andrew Heyward et al., AIMS

10.00 The National Sea Simulator: advanced aquarium facility providing essential assistance for reef restoration research
Craig Humphrey et al., AIMS

10.15 Recruit – recovery of reefs using industrial techniques for coral spawn slick harvesting and release
Christopher Doropoulos et al., CSIRO

10.30 Opportunities for innovation in reef restoration
Mark Gibbs et al., QUT

10.45 Morning Tea

COTS control on the GBR Session 2

11.15 Ongoing COTS control effort at a high-value tourism site on the GBR: Moore Reef
Eric Fisher et al., ReefMagic/AIMS@JCU

11.30 Settlement and post-settlement movement of COTS in the central GBR
Morgan Pratchett, JCU

11.45 Using environmental DNA to inform COTS management
Sven Uthicke et al., AIMS

Achieving scale for restoration 2

11.15 Australian engineered reef substrates for habitat restoration, stabilisation, coral outplanting and improving juvenile mortality rates
Matthew Allen et al., Subcon International

11.30 Leveraging the science to position GBR restoration as the global benchmark – innovative international restoration / intervention project examples
Bobbie Corbett et al., International Coastal Management

11.45 The role of light in coral bleaching and recovery
Neal Cantin, AIMS

Tuesday 17th July *continued*

URCHINS BALLROOM

COTS control on the GBR Session 2 *continued*

12.00 Identifying fish predators to manipulate COTS predation
Frederieke Kroon et al., AIMS

12.15 Can we prevent the next COTS outbreak?
Russ Babcock et al., CSIRO

12.30 Synthesis discussion led by
David Westcott, CSIRO

MICHAELMAS CAY ROOM

Achieving scale for restoration 2 *continued*

12.00 New tools to prevent mass coral bleaching: Shading by ultra-thin surface films
Andrew Negri et al., AIMS

12.15 Regional marine cloud brightening for coral bleaching mitigation
Daniel Harrison et al., Uni Sydney

12.30 The cultivation of macroalgae to reduce nutrient loads and improve the resilience of coral reef ecosystems
Andrew Cole et al., JCU

12.45 Lunch

Effects of hydrodynamics & mixing on bleaching & recovery

13.45 Understanding the physical drivers determining the spatial variability of coral bleaching of the Great Barrier Reef
Craig Steinberg et al., AIMS/NESP TWQ

14.00 Scratching the surface: How in-water observations cast light on possibilities for small-scale engineering interventions
Dennis Stanley

14.15 Fine-scale water circulation patterns of a channel in Moore Reef on the GBR
Eric Fisher, Reef Magic

14.30 Reef Havens: an in-situ research platform for developing effective science-based local-scale interventions for the GBR
Suzanne Long et al., RRRC

14.45 Hydrodynamic drivers of restoration success using staghorn *Acropora* from Guam, Mariana Islands
Whitney Hoot et al., U of Guam

15.00 Summary panel discussion led by
Ian Poiner, RRRC

Enhancing the temperature tolerance of corals

13.45 Assessing the value of northern Great Barrier Reef bleaching survivors for selective breeding and assisted gene flow
Carly Randall et al., AIMS

14.00 Assisted gene flow: facilitating the spread of adaptive variation for coral reef restoration
Kate Quigley et al., AIMS

14.15 Evaluating adaptive potential and identifying markers of thermal tolerance in *Platygyra daedalea*
Holland Elder et al., Oregon State U/AIMS

14.30 Conditioning next generation corals to sublethal stress to enhance tolerance for reef restoration
Neal Cantin et al., AIMS

14.45 The social risk of biocontrol and synthetic biology in Australia: examples of social science in action
Aditi Mankad et al., CSIRO

15.00 Summary panel discussion led by
Line Bay, AIMS

15.15 Afternoon Tea

Tuesday 17th July *continued*

URCHINS BALLROOM

Collaborating for reef restoration

15.45 Reef Education to Sea Country connections: Innovation of co-learning for a sustainable future
Marie Taylor et al., Reef Magic & Dawul Wuru Aboriginal Corporation

16.00 Leveraging the science to position GBR restoration as the global benchmark - catalyst infrastructure
Robert Prestipino, Vital Places

16.15 Leveraging the science to position GBR restoration as the global benchmark - the academic role
Rodger Tomlinson, GU

16.30 Leveraging the science to position GBR restoration as the global benchmark – implementation
Angus Jackson, International Coastal Management

16.45 GBR Legacy's collaborative expeditions: a catalyst for the future survival of coral reefs
Dean Miller et al., GBR Legacy

MICHAELMAS CAY ROOM

Speed talks!

15.45 Reborn from the fragments: urban coral restoration in Hong Kong
Vriko Yu et al., University of Hong Kong

Scientific lessons in establishing Australia's first coral nursery
Nathan Cook et al., Reef Ecologic

The importance of farmers: how algal-farming damselfish influence reef recovery and coral restoration
Johanna Leonhardt et al., JCU

16.00 Seaweed (*Sargassum spp.*) removal on the GBR
Adam Smith et al., Reef Ecologic/JCU

The role of underwater sound in the restoration of coral reefs
Craig McPherson et al., JASCO

Exploring the potential use of chemical extracts from coralline algae for enhancing coral larvae settlement
Guillermo Diaz-Pulido et al., Griffith University

16.15 Local reef stewardship in the face of global climate change: A tourism operators' perspective
Doug Baird, Quicksilver Cruises

The power of networks – the Australian Coastal Restoration Network and its relevance to the GBR
Jemma Purandere et al., JCU

Can underwater art help reef restoration science?
Adam Smith et al., Reef Ecologic/JCU

16.30 Diversity and non-random transplanting increase growth of coral transplants following removal of an invasive corallimorpharian
Corinne Amir, Scripps Institution of Oceanography

Aggregation, allee effects and management of COTS
Jacob Rogers et al, UQ

Engaging citizens in the future of the Great Barrier Reef
Andy Ridley, Citizens of the GBR

16.45 Active localised restoration and its application in management of the Great Barrier Reef World Heritage Area
Richard Quincey, GBRMPA

17.00 Daily wrap-up session (Urchins Ballroom)

17.30-21.00 Please join us at the **Pullman Reef Hotel Casino, Pool Deck,** for our Symposium cocktail mingling function, drinks and light dinner served with entertainment by Russell Harris & Band

Guest Speaker: *The Hon Warren Entsch, Member for Leichhardt*
Hosted by the *Association of Marine Park Tourism Operators (AMPTO)* and the *Reef and Rainforest Research Centre (RRRC)*

Wednesday 18th July

URCHINS BALLROOM

8.00 Symposium registration desk opens

8.30 Scoping regulatory, institutional and governance implications of reef restoration and adaptation interventions
Pedro Fidelman et al., UQ

8.50 100x thinking: mobilising capital at scale for restoration and resilience
Rich Gilmore, TNC

URCHINS BALLROOM

Coral restoration methods

9.15 The history of reef restorers
Adam Smith et al., Reef Ecologic/JCU

9.30 Coral restoration in a changing world - a comprehensive review of coral restoration methods used by scientists, experts and managers
Lisa Boström-Einarsson et al., JCU

9.45 Investigating long-term responses of coral assemblages to coral restoration: case studies from around the world
Margaux Hein et al., JCU

10.00 A global synthesis of coral reef restoration efforts
Phoebe Stewart-Sinclair et al., UQ

10.15 Developing cost-effective coral propagation targeted to the GBR: the Opal Reef coral nursery research facility
David Suggett et al., UTS

MICHAELMAS CAY ROOM

Economic levers/investment

9.15 Developing a sustainable business model for large-scale coral restoration in the Bahamas
Sam Teicher et al., Coral Vita

9.30 Engagement at all scales: conservation activities with SMB and corporate tourism CSR partners in Thailand
Petch Manopawitr et al., IUCN

9.45 Leveraging the science to position GBR restoration as the global benchmark - raising collaborative capital
Paul Niederer, Raiseworth Capital

10.00 How to build a business case for an intervention on the reef
Patrick Silvey, VenturePro

10.15 Reef credits – a market instrument to pay for improving water quality and the improvement of reef health
Mike Berwick et al., Green Collar

10.30 Morning Tea

Learning from reef restoration experiences around the world

11.00 Key lessons learned from 30+ years of coral reef restoration
Austin Bowden-Kerby, Corals for Conservation

11.15 Establishing the first coral nursery in the GBR to regenerate high value coral reefs
Stewart Christie et al., Reef Restoration Foundation

Social licence/ politics

11.00 Is social acceptance really the end goal? Experiences and lessons for avoiding engagement mistakes of the past
Lucy Carter et al., CSIRO

11.15 Who has a stake in reef restoration? Designing stakeholder engagement and public participation in large-scale environmental interventions
Bruce Taylor et al., CSIRO

Wednesday 18th July *continued*

URCHINS BALLROOM

Learning from reef restoration experiences around the world *continued*

11.30 Putting the coral back into 'coral reef restoration': Proactive massive coral mitigation in Hawaii
David Gulko et al., Hawaii Div Aquatic Resources

11.45 Racing against climate change in the Republic of Seychelles
Louise Laing et al., People4Ocean

12.00 Validating a large-scale reef restoration project post-2016 coral bleaching in the Maldives
Tess Moriarty et al., U of Newcastle

12.15 Assessing biological diversity and richness in natural, transplanted, artificial, and "accidental" reefs in Puerto Rico
Manuel A. Nieves-Ortiz, U de Puerto Rico

MICHAELMAS CAY ROOM

Social licence/ politics *continued*

11.30 Tweeting the reef revolution: an analysis of public debates on GBR restoration
Maxine Newlands et al., JCU

11.45 Can we build community resilience to climate change through ecological restoration? The case for deliberative governance
Karen Vella, QUT

12.00 Pathways to connect citizen science with reef restoration
Richard Coleman et al., Reef Check Australia

12.15 Novel ecosystems: managing novelty in the marine realm
Marie-Lise Schläppy et al., UWA/AIMS

12.30 Lunch

REEF ROOM

WORKSHOP (see p14 for more details)

12.30-14.00 Coral-tipping, bommie-rolling & fragments of opportunity
Led by *Ian McLeod, JCU*

URCHINS BALLROOM

Decision-making approaches & tools

13.45 Evaluating GBR interventions using a Reef-wide systems model
Scott Condie et al., CSIRO

14.00 The search for a resilience network in the GBR
Donna-Marie Audas et al., GBRMPA

14.15 A resilience-based management system for the GBR
Peter Mumby et al., UQ

14.30 Habitat maps supporting the restoration of the GBR
Chris Roelfsema et al., UQ

MICHAELMAS CAY ROOM

Breeding/growing corals & other restoration methodologies

13.45 Large scale, carbon neutral coral production
Ryan Donnelly, Cairns Marine

14.00 Seeding units and floating pool devices to facilitate large scale coral restoration via sexual reproduction
Aric Bickel et al., SECORE

14.15 Scaling up coral restoration using micro-fragmentation plus sexual reproduction: Ten years' experience in Florida and Mexico
David Vaughan et al., Mote Marine Lab

14.30 Rehabilitation of coral reefs through removal of macroalgae: State of knowledge and considerations for management and implementation in GBR catchment
David Bourne et al., AIMS/JCU

Wednesday 18th July *continued*

URCHINS BALLROOM

Decision-making approaches & tools *continued*

14.45 Incorporating coral ecological services and functions valuation into coral mitigation and restoration
David Gulko, Hawaii Div Aquatic Resources

15.00 Towards pervasive monitoring of marine species physiology in coral reef ecosystems
Brano Kusy, CSIRO

MICHAELMAS CAY ROOM

Breeding/growing corals & other restoration methodologies *continued*

14.45 Restoration in highly diverse ecosystems and the roles of science, community and government
Susan Laurance, JCU

15.00 Green engineering seawalls in the GBR: a trial using plant boxes to promote biodiversity
Nathan Waltham et al., JCU

15.15 Afternoon Tea

15.45-16.15 Symposium wrap-up (Urchins Ballroom)

REEF ROOM

WORKSHOP (see p14 for more details)

16.15-17.00 What you need to know about regulations in the GBR Marine Park
Led by *Rean Gilbert, GBRMPA*

Thursday 19th July

8.30am Cairns Marina

Visit the Crown-of-thorns starfish control vessel and meet the in-water control teams

followed by

FIELD TRIPS to FITZROY ISLAND

Visit the **Fitzroy Island turtle hospital**

Examine coral nursery trees established as a coral restoration project
by the **Reef Restoration Foundation**

Snorkel fringing coral reefs

Cost $119 – various ferry transfer timing options available for a half or full day tour

Further details visit
http://www.cairnsconferences.com.au/events/gbr-restoration/

YOUNG ADULTS WORKSHOP

Monday 16th July, 13.00-15.20, Reef Room

Led by *Nathan Cook, Reef Ecologic*

Even with our best efforts today, maintaining the health of the Great Barrier Reef will be an important task for future generations.

The Great Barrier Reef Restoration Symposium will feature the Young Adults Workshop, which will include 30 primary and secondary school students, mainly from schools in North Queensland. It will take place primarily on Monday the 16th of July in the Pullman Reef Hotel Casino's Reef Room, adjacent to the Urchins Ballroom in which the plenary presentations of the Symposium will occur.

The Young Adults Workshop will guide young people to take the first steps in becoming the next generation of Great Barrier Reef stewards by opening doors into the world of Great Barrier Reef protection and management.

Students will be encouraged and challenged to brainstorm, develop and share their ideas on reef restoration.

They will work in teams to identify problems and come up with solutions during guided sessions before sharing the outcome of their discussions with the rest of the workshop.

These sessions will follow the 'RARE' formula, which emphasizes finding locally-led solutions which can then be expanded to low-cost delivery at regional scales. Importantly the formula calls for the identification of physical pilot sites where solutions can be trialed.

These ideas will be collated and used to develop a **Young Adults Blueprint for GBR restoration**.

Students will be audience members for Symposium keynote speakers David Wachenfeld (from the Great Barrier Reef Marine Park Authority) and Tali Vardi (from the US National Oceanic and Atmospheric Administration) and then be able to ask these two high-profile reef experts their own questions in a private session. They'll also hear from Molly Steer (from StrawNoMore for the GBR) and Kailash Cook (Reef Check Ambassador) who will tell their personal stories of being young adults getting into the Great Barrier Reef protection space.

This workshop is now fully subscribed, but video recordings and other media will be available after the Symposium. For more information please contact Nathan on nathan.cook@reefecologic.org.

Photos Left: Suzanne Long, RRRC and Cairns Turtle Rehabilitation Centre

WORKSHOP

Coral tipping, bommie rolling and fragments of opportunity

Wednesday 18th July, 12.30-14.00, Reef Room

Led by *Dr Ian McLeod, TropWATER JCU*

In the context of reef restoration, saving every piece of coral is critical. Physical damage to bommies and individual assemblies from events like cyclones and ship strikes is still a major cause of coral loss on the Great Barrier Reef.

The damage from these events can be mitigated afterward by physically returning overturned corals to their original or new positions so they can resume normal activity. This work is often carried out by divers, but no standardized method exists and is often undertaken in an ad-hoc manner by various organisations and individuals, sometimes without the necessary permits.

This workshop will develop some Best Practice Guidelines for physical coral repair that will be made available to reef managers both on the Great Barrier Reef and reefs elsewhere in the world.

Numbers are limited so if you wish to attend, please contact Ian on ian.mcleod1@jcu.edu.au.

WORKSHOP

What you need to know about regulations in the GBR Marine Park

Wednesday 18th July, 16.15-17.00, Reef Room

Led by *Rean Gilbert, GBRMPA*

Planning on doing a reef intervention/restoration project in the Great Barrier Reef Marine Park? Having trouble navigating through the sea of legislation and fear that you may drown in rough weather associated with permissions? Want to influence reef intervention policy? Stop splashing around in the shallows… this workshop is for you.

Navigating the legislation, regulations and permits needed to run reef restoration projects within the Great Barrier Reef Marine Park – especially as the reef restoration space rapidly grows and evolves - can be a challenge.

This workshop, led by Rean Gilbert at the Great Barrier Reef Marine Park Authority, will help reef restoration operators understand the legislative context governing potential intervention activities inside the park.

The workshop will cover several subjects including the Great Barrier Reef Marine Park Zoning Plan 2003, the Plans of Management, the draft Reef Intervention Guidelines (especially the risk ratings associated with the more common intervention concepts in the Guidelines).

Feedback from the workshop will inform the final version of the Reef Intervention Guidelines and supporting information, so this is a critical opportunity for reef restorers to have their say in this vital field going forward

ABSTRACTS

Abstracts are presented in alphabetical order by the presenting author's surname.

A CASE STUDY OF ISLAND INTERVENTION AND RESTORATION IN THE GREAT BARRIER REEF – RAINE ISLAND RECOVERY PROJECT

Tina Alderson[a], Wuthathi and Kemerkemer Meriam Nation (Ugar, Mer, Erub) Traditional Owners and Mark Read[b]

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[b] *Great Barrier Reef Marine Park Authority, Townsville, 4810, Australia*

The establishment of the Raine Island Recovery Project has enabled one of the largest intervention and restoration projects on the Great Barrier Reef. Raine Island, in the far north of the Great Barrier Reef, is the world's largest green turtle nesting site as well as being one of the most significant seabird rookeries and having great cultural significant to Traditional Owners. Long-term monitoring of turtle nesting and hatching success at Raine Island indicated there were problems with how it was functioning as a turtle rookery, and that hundreds to thousands of females were dying each year from cliff fall, getting trapped in beachrock and heat exhaustion. The decision was made to act rather than 'sit on our hands' and monitor a major decline in the northern Great Barrier Reef green turtle population. The managing agencies first implemented on-ground actions to reduce turtle mortality and then more significant works to try and address the low nesting and hatching success. These intervention works, at one of the most important sites in the Great Barrier Reef World Heritage Area, are not taken lightly with risk assessment and mitigation of impacts underpinning decision-making and actions. The intervention and restoration works represent a significant shift in management approach and thinking in the Great Barrier Reef. The Raine Island Recovery Project is a five year, $7.95 million collaboration between BHP, the Queensland Government, the Great Barrier Reef Marine Park Authority, Wuthathi and Kemerkemer Meriam Nation (Ugar, Mer, Erub) Traditional Owners and the Great Barrier Reef Foundation.

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AUSTRALIAN ENGINEERED REEF SUBSTRATES FOR HABITAT RESTORATION, STABILISATION, CORAL OUTPLANTING AND IMPROVING JUVENILE MORTALITY RATES

Matthew Allen, Vaughan Elson and Brenda Finlayson

Subcon International, Henderson, 6166, Western Australia

Habitat morphology of the Great Barrier Reef (GBR) is drastically degraded by bleaching events. Tabular and staghorn corals serve as keystone structures of the reef. The reduction of tabular and staghorn corals into a mobile rubble prevents the recovery of surviving corals, the recruitment of new coral larvae and diminishes the success of outplanting programs of heat tolerant corals. In addition, the key function of the GBR in providing fin fish habitat is immediately lost. Critical to the success of programs to mass produce heat tolerant corals and outplanting is the establishment of stable substrates. These can be designed to immediately restore the fin fish habitat functions whilst providing a secure substrate designed to promote recruitment and enhance survival rates in juvenile, out-planted corals. Juvenile survival rates, release age of juveniles and scale of deployment influence the survival cost curve. Engineered substrates positively influence all these factors and thus are critical to the success of a broad range of interventions being investigated. Fifteen national examples of reef restoration and establishment provide a uniquely Australian reference for how engineered substrates can be designed specifically to promote coral recruitment and increase the success of out-planting programs, whilst restoring finfish habitat and supporting other critical reef functions including wave attenuation and erosion control. Engineered substrates are a tool to increase vertical terrain, hard substrate accessibility, intricacy and improved anchorage habitat and feeding opportunities for epibenthic species, macroinvertebrates and fish. Increases in species richness and diversity, biomass and production of macroalgae, macroinvertebrates and fish are supported by UNSW and UWA research. This overview of the current state of the art of reef substrate design processes provides an insight to the design optimisation process for scale-ability, interconnectivity and erosion control. Engineered substrate performance criteria include optimised surface finish for larval settlement, design for outplanting and seeding, finfish habitat complexity, cyclone stability, flow modification,

surface finish, low carbon concrete, fabrication automation, carbon footprint, material selection, design life, transportation, installation logistics, reef layout, communication and erosion control. Cross-industry experience from offshore renewables, subsea and coastal industries are used to demonstrate how engineered substrates can be delivered to industrial scale and timeframes.

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DIVERSITY AND NON-RANDOM TRANSPLANTING INCREASES GROWTH OF CORAL TRANSPLANTS FOLLOWING REMOVAL OF AN INVASIVE CORALLIMORPHARIAN

Corinne Amir[a], Clinton Edwards[a], Vid Petrovic[b], Amanda Carter[a], Michael Fox[a], Maggie Johnson[ac], Stuart Sandin[a] and Jennifer Smith[a]

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Invasive and opportunistic species are known to cause turnovers in dominant biota within ecosystems, often leading to alternative stable states that dramatically change in ecosystem structure and function. Once coral reefs begin to enter an alternative stable state, it is very difficult to reverse this process even when human intervention occurs. On Palmyra, a remote atoll in the equatorial Pacific Ocean, the corallimorpharian Rhodactis howesii has dramatically increased in abundance and now dominates >3 km^2 of reef, displacing hard corals and other dominant biota in the process. To curtail further ecosystem degradation, a restoration experiment was established at the epicenter of the corallimorph outbreak. In 2014, 15 9m^2 plots were randomly chosen within areas containing >60% corallimorph cover. Treatment plots (n=12) were chosen for corallimorph removal. Nine of the treatment plots received coral transplants and the remaining three plots were designated as treatment controls. Corallimorph was removed by tenting and application of granulated bleach for 24-hours, followed by manual removal of remaining tissue fragments. Coral fragments of Acropora accuminata (n = 27), Pocillopora damicornis (n = 27), and Montipora capitata (n= 27) were collected from nearby regions of reef unaffected by the corallimorph outbreak and transplanted onto the bare CaCO3 substrate with non-toxic two-part epoxy. Fragments were transplanted in same-species aggregations, aggregations consisting of all three species, and non-aggregated arrangements to determine if interspecific aggregation impacts coral growth. As of 2017, the site has experienced nearly a 300% increase in coral cover due to growth of original transplants. An additional 100% increase in coral cover was recorded among corals that were transplanted in aggregations consisting of the three different coral species. Corallimorph reinvasion in treatment plots has been negligible. The methods used to produce this restoration experiment can be applied to other locations around Palmyra to effectively mitigate the expansion of the corallimorph throughout the atoll. Moreover, aspects of these methods, such as multi-species coral transplant aggregation and substrate preparation, could benefit coral restoration programs throughout the world to combat biological invasions by benthic sessile organisms and to enhance coral cover and diversity.

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TACKLING DECISION CHALLENGES FOR RESTORATION AND ADAPTATION – WHAT STRATEGIES WILL SUSTAIN REEF VALUES?

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Climate change poses a growing decision challenge for reef conservation, restoration and adaptation. What intervention strategies will best help sustain reef ecosystem functions, services and values in an uncertain future? What combinations and spatial configuration of interventions will deliver the greatest environmental, social and economic net benefits to society? How and when should new interventions be deployed for best effect? And perhaps most importantly, how can such decisions be communicated to stakeholders in a way

that they will not only understand, but support decisions? We present preliminary results of a decision-support framework designed to address these key questions as part of Australia's new Reef Adaptation and Adaptation Program (RRAP). We show that the effective integration of new interventions with water quality and starfish control could lead to benefits worth tens to hundreds of billions in coming decades. We use examples to illustrate how decision analyses can inform what intervention strategies might deliver maximum return on investment for multiple value streams and under different climate scenarios and socio-economic pathways. When fully developed, these decision analyses will inform the prioritisation, design and deployment of restoration and adaptation strategies to help sustain a trillion dollar ecosystem into the future.

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THE SEARCH FOR A RESILIENCE NETWORK IN THE GREAT BARRIER REEF?

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Is reef resilience the result of good fortune? Fortune is often referred to as having something that is very desirable or as the result of being in a desirable situation. Despite widespread declines in coral cover some fortunate reefs continue to retain good healthy coral cover. The focus of our work is to map how, where and why these reefs are fortunate. The Great Barrier Reef Blueprint (Blueprint) refers to resilience as the capacity of a system to resist and recover from disturbance, this project explores the use of cumulative exposure modelling such cyclones, bleaching, flood plumes, and crown-of-thorns starfish to identify fortunate reefs.

Using the best available science complemented by expert knowledge and experience we aim to identify areas in the Reef that have relatively low exposure to impacts, retain relatively higher coral cover, recover rapidly after impacts, and make relatively higher contributions to the coral larval supply. Science is at the heart of our efforts to manage and protect the Reef, mapping a resilience network will support the Great Barrier Reef Marine Park Authority to target local actions and deliver system wide benefits for the Reef.

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CAN WE PREVENT THE NEXT COTS OUTBREAK?

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It is nearly half a century since the first major outbreaks of crown-of-thorns starfish were reported on the Great Barrier Reef. Since that time systematic research efforts have made impressive progress in our ability to predict where and when outbreaks will start, as well as their progress down the reef. We also have a much better idea of the conditions that allow outbreaks to form, and have developed better tools than ever before for controlling COTS numbers. We know that these tools can be effective. We now have clear thresholds that can be used to determine when to start and stop control efforts. These advances open up the possibility of delaying or even preventing the next outbreak. Threshold densities for COTS reproductive success indicate that if we can keep COTS at densities of less than 3 ha-1 outbreaks will be less likely to form. With modern surveillance and control, we can eradicate these small aggregations of starfish before they spawn. In the past, such aggregations have been detected prior to outbreaks forming, yet because no clear plan of action existed, no action has been taken. The question then is whether we can maintain COTS control capability in the aftermath of a major outbreak, when the threat appears to have passed, in order to be in a position to control pre-outbreak populations. We have been warned more than once in the past to avoid complacency after a wave of outbreaks has passed yet we have failed to be ready when action was most needed and potentially most effective. New pro-active models for managing COTS outbreaks are required that will maintain readiness and potentially use new tools to help ecological pressure on the Great Barrier Reef.

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LOCAL REEF STEWARDSHIP IN THE FACE OF GLOBAL CLIMATE CHANGE: A TOURISM OPERATORS PERSPECTIVE

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As one of the largest and longest-established Reef tourism companies on the Great Barrier Reef, we take our responsibilities to provide leadership to the tourism community seriously. For example, our Managing Director is also the Chair of the Association of Marine Park Tourism Operators. In the wake of back-to-back bleaching and mortality on the Reef in 2016 & 2017 we acknowledge that even though these impacts are caused by global climate change, as stewards of our parts of the Reef, we need to develop effective local actions to help mitigation and adaptation. Consequently we have been amongst the first to support development of local interventions such as Reef Havens and we are also pursuing a reef rehabilitation project at our Agincourt #3 pontoon site using mineral accretion technology to assess its viability in the field of reef rehabilitation.

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IS IT FEASIBLE AND WORTH ALTERING TEMPERATURE AND LIGHT STRESS ON THE GREAT BARRIER REEF?

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The federally-funded Reef Restoration and Adaptation Program (RRAP) is considering the feasibility of environmental interventions to cool and/or shade the waters above reefs of the Great Barrier Reef (GBR). The aim is to identify interventions that are scalable to the entire reef system. This talk outlines preliminary model calculations that shed light on the scale of the task. Here we use the relocatable ocean model capability in the eReefs modelling system to nest multiple 200 m configurations of 1 – 50 km^2 scale reefs within the regional 1 km GBR-wide model. Reefs were chosen to be representative of inshore, midshelf and offshore reefs, and to have a range of residence times from hours to days. First we quantify the time-varying cooling loads (negative energy flux) of individual sites, and of entire 1 - 50 km^2 reefs, that would be required to bring the temperatures of 2016 to below 1°C above the climatological summer monthly maximum, a threshold indicated to protect against coral bleaching. This work will inform projects such as injections of cool water from the deeper ocean to reefs. Secondly, we investigate the effects of reductions in bleaching stress by reducing solar radiation. Greater uncertainty exists in assessing the benefit of solar radiation reduction interventions because the mechanism through which light is proposed to act, the symbiont photosystem, is both complex, and incompletely understood. The knowledge from these model simulations will be used by the RRAP, along with ecological, social and economic considerations, to investigate the feasibility and worth of environment interventions to improve the future condition of the GBR's coral reef systems. And it will provide innovators with a more quantitative target for proposed interventions that can change the trajectory of the GBR's state.

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NEXT GENERATION CORALS FOR TOMORROW'S REEFS

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Coral reefs are at a cross road in terms of their ecological health and management. Declines in coral cover and health, in particular from mass bleaching, have spurred a flurry of discussion around the role of restoration in the management of reefs into the future. This discussion has moved from more traditional approaches, such as coral gardening and replenishment with local coral stock to include a range of novel approaches, many of which have never before been implemented in wild ecosystems or at large spatial scales. A central aim of the Reef Restoration and Adaptation Program (RRAP) is to facilitate naturally occurring evolutionary mechanisms to facilitate coral populations becoming better able to cope with increasing temperatures. In this talk I will outline the breadth of these "assisted evolution" approaches that are currently being tested in the laboratory.

Using a series of ongoing and recently published examples I will discuss potential benefits and risks and explore the research and development required to demonstrate safety and efficacy. I will argue that while an exploration of novel reef restoration tools must not detract from a focus on addressing the root causes of reef declines, principally climate change, it is a conversation we must have. Rigorous, systematic and objective analyses of both existing and novel restoration approaches will ensure that coral reef managers and decision makers will have the best tools available to face the challenging task of conserving coral reefs in an uncertain and warming future.

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REEF CREDITS – A MARKET INSTRUMENT TO PAY FOR IMPROVED WATER QUALITY AND THE IMPROVEMENT OF REEF HEALTH

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The Reef Credit is a means paying for a measured, verified unit of water pollution reduction entering the GBR lagoon. It is an opportunity for investors to purchase a measurable outcome they can trust and for landholders to reduce pollution. It is envisaged Reef Credits will be traded in an open market modelled on the existing carbon market. Green Collar's role has been to establish a functioning market, in partnership with the two Major Integrated Projects, a complex task with many components – a Standard, Rules, Methodologies, Secretariat, Registry, and the Reef Credit Partnership. The rules, processes, procedures and accounting systems are being established in parallel, rather than sequentially, partly because each component informs the others but also to save time. The Standard and Rules are based on existing international standards like the VCS and CCB. The registry holds and trades the credits, the secretariat provides governance, approves the standard, methodologies and projects. The Partnership is the stakeholder group to which the secretariat is answerable – science, industry, conservation, government, the sectors whose endorsement provides the Reef Credit with the trust landholders need to generate them and for investors to purchase. Three pilot methodologies are being designed: a N reduction method paying farmers to reduce N application based on modelled DIN loss to the GBR, a wetland method modelling N abatement and a sediment method, modelling and measuring sediment lost from surface, gully and streambank erosion. These methods remain pilots until signed off by the secretariat. The first Reef Credit off take agreement has been signed with Qantas on a Babinda wetland project and 10 pilot cane projects have been assessed, the first expected to be signed by June. The Reef Credit was designed for water quality but in the interests of improving the health of the GBR. Whether they can be applied to reef restoration remains to be seen so any insights or ideas are therefore welcome.

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SEEDING UNITS AND FLOATING POOL DEVICES TO FACILITATE LARGE SCALE CORAL RESTORATION VIA SEXUAL REPRODUCTION

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Current outplanting technologies of propagated corals for restoration require manual transplantation of each coral-substrate-unit using adhesives, nails or cable-ties. This is labor and cost intensive, significantly limiting the scale of restoration accomplished to date. To conduct coral restoration at the needed scale, we need to reduce labor and costs, allow application of techniques in remote areas, and expand the species spectrum. We are developing approaches utilizing larval propagules that help overcome these bottlenecks. First, cultured larvae are settled on coral-substrate-units ("seeding units, SU") that are 'sowed' on the reef, without artificial attachment. Specifically designed substrates self-stabilize on the reef, allowing natural attachment while providing favorable microhabitat to enhance survival of the coral settlers. Based on initial tests with tetrapod-shaped substrates, we have developed seven new prototype substrates (3d-printed from ceramic) which are currently being

tested (coral settlement, survival and growth, and SU retention) in the field with 2-3 hermatypic coral species in Curacao, Mexico, the Bahamas, and Guam. Another approach to facilitate large-scale restoration at locations remote from land-based infrastructure aims at transferring the production process to an in situ environment. We have developed floating culture devices ("floating pools") that are placed in a sheltered area (e.g. lagoon or dock) prior to a coral spawning event. Fertilized eggs resulting from in-situ gamete collection and in-vitro fertilization are placed directly into the pools containing SUs to complete larval development, settlement, and potentially a post-settlement nursery period with minimal labor input. Lastly, upscaling is facilitated by practitioner workshops centered around coral spawning events to provide hands-on experience with these developing tools and techniques to create a community of practice and enable implementation at expanded locations.

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CORAL RESTORATION IN A CHANGING WORLD – A COMPREHENSIVE REVIEW OF CORAL RESTORATION METHODS USED BY SCIENTISTS, EXPERTS AND MANAGERS

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Coral reefs are increasingly under threat from anthropogenic disturbances, and live coral cover has been declining around the globe for the past decades. Halting this trend will require a multi-faceted approach across several scales using a wide variety of responses. Large-scale solutions like curbing climate change, improving water quality and reducing pollutants in oceans are critical for the persistence of coral reefs. However, these tend to be slow to implement and require large-scale commitment at the government level. This has led to a growing interest in direct interventions on coral reefs, in particular outside the scientific community. Citizen scientists, tourism operators and NGO's have implemented hundreds of small-scale coral restoration projects around the world's coral reefs, often with very little financial backing or scientific support. This disconnect between the scientific community and coral restoration practitioners represents a lost opportunity for both groups. To mitigate this, we reviewed the current scientific literature describing coral restoration methods, surveyed coral restoration practitioners and scoured the internet for descriptions of methods published in non-traditional channels. Here, we present the results from this comprehensive review of methods, and share technical lessons learned and key issues to look out for concerning each of the main methods. We then explain how we are using an online interactive visualisation and database to share that information in a layered approach with scientists, managers and practitioners.

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REHABILITATION OF CORAL REEFS THROUGH REMOVAL OF MACROALGAE: STATE OF KNOWLEDGE AND CONSIDERATIONS FOR MANAGEMENT AND IMPLEMENTATION

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Coral reef ecosystems are under increasing pressure by multiple stressors that degrade reef condition and function. Although improved management systems have yielded benefits in many regions, broad-scale declines continue and additional practical and effective solutions for reef conservation and management are urgently needed. Ecological interventions to assist or enhance ecosystem recovery are standard practice

in many terrestrial management regimes, and they are now increasingly being implemented in the marine environment. Intervention activities in coral reef systems include the control of coral predators (e.g. crown-of-thorns starfish), substrate modification, the creation of artificial habitats and the cultivation, transplantation and assisted recruitment of corals. On many coastal reefs, corals face competition and overgrowth by fleshy macroalgae whose abundance may be elevated due to acute disturbance events, chronic nutrient enrichment and reduced herbivory. Active macroalgae removal has been proposed and trialled as a management tool to reduce competition between algae and corals and provide space for coral recruitment, in the hope of restoring the spatial dominance of habitat-forming corals. However, macroalgae removal has received little formal attention as a method of reef restoration. This review synthesises available knowledge of the ecological role of macroalgae on coral reefs and the potential benefits and risks associated with their active removal.

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KEY LESSONS LEARNED FROM 30+ YEARS OF CORAL REEF RESTORATION

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This presentation shares 37 years of lessons learned in coral reef restoration and coral gardening in both the Caribbean and Indopacific, much of the information is either published in rather obscure places or is unpublished.

I planted my first corals in 1981 in Micronesia, scattered into a rubble field created by blast fishing in Chuuk Lagoon, and in 1989 I began experimenting with planting corals into barren sandy lagoons in Pohnpei. In 1993 I moved to the Caribbean to apply the lessons learnt to a new ocean, and was surprised at how nearly everything I had learned was transferable.

In this talk, I briefly cover the most successful methods for both for nurseries and outplanting corals back to the reef. Ecological restoration and facilitated recovery- the jump-starting of natural recovery processes is discussed, along with the various ecological challenges which were faced and their solutions. This includes encouraging complete self-cleaning of nurseries by herbivorous fish, outplanting methods that pay close attention to micro-habitat factors leading to greater success and which help prevent predation of outplanted corals, and encouraging reestablishment of sexual reproduction and larval recruitment processes.

Community participation has, from the beginning, been a similarity between the more successful coral restoration projects in both the Caribbean and Pacific, with coral restoration serving as a springboard to heightened awareness and community support for the establishment of no-take MPAs. Tourism industry support has been a key means for mainstreaming and financing the work.

Twenty years ago, the primary goals of coral restoration in the Caribbean and Pacific were quite different; endangered species restoration was the primary focus of Caribbean efforts, while the Pacific focus was primarily the restoration of reefs damaged by destructive fishing practices. However, with the emergence of climate change, a merging of realities has recently occurred, with bleaching resistance becoming a major concern in both oceans. Along these lines, early results from the Christmas Atoll, Kiribati restoration project are shared, where the reefs suffered conditions above the bleaching threshold for fourteen months running in 2015-16, with a mass die-off of >99% of branching corals.

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THE EVOLUTION OF THE CROWN-OF-THORNS STARFISH CONTROL PROGRAM ON THE GREAT BARRIER REEF

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Since the establishment of the Great Barrier Reef Marine Park, the frequency and severity of crown-of-thorns starfish (COTS) outbreaks have caused increasing concern about their impact on the Reef's resilience and overall health. There have been four documented major COTS outbreaks on the Reef; in the 1960s, the late 1970s, the early 1990s, and the current outbreak, which was first detected in 2010. Since the 1980's the Great Barrier Reef

Marine Park Authority (GBRMPA) has worked with research partners and the tourism industry to understand the dynamics and causes of COTS outbreaks, and explore potential management responses. However, the limited effectiveness and high cost of available control methods made a broad-scale management response unfeasible. Since that time, there have been advances in the science linking COTS outbreaks to human activities such as nutrient pollution and removal of COTS predators, as well as critical progress in single-shot injection techniques for COTS control. These advances paved the way for establishment of the first broad-scale COTS Control Program in the Great Barrier Reef Marine Park in 2012. In the early years of this program, the objective was the protection of coral cover at tourism sites on reefs of high economic value in order to support the Reef tourism industry. Subsequent investment in Integrated Pest Management (IPM) research through the Australian Government's National Environmental Science Program (NESP) has provided targeted science on COTS outbreak dynamics and improved strategies for their control. These scientific advances have enabled marine park managers to improve operational efficiencies and strategically target the resources of both the COTS Control Program and the Field Management Program to undertake surveillance and culling of COTS to better protect coral cover and enhance Reef resilience. The recently expanded control program will enable COTS control to be directed at a reef and regional level for the first time. The ongoing evolution and adaptive management of the COTS Control Program is underpinned by strong partnerships between governments, scientists, managers, industry stakeholders and other entities dedicated to protecting the health of the Great Barrier Reef.

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ROLE OF LIGHT INTENSITY DURING WIDESPREAD THERMAL BLEACHING EVENTS

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Coral bleaching refers to the abrupt breakdown of the typically beneficial symbiotic relationship between the coral host and the algal symbiont, *Symbiodinium* sp., which provides coral tissues with the healthy colour expected within vibrant reef habitats. Environmental stressors, individually or combined that can cause corals to bleach and turn completely white include temperature (hot or cold events), high light and low salinity from freshwater flood events. However, widespread mass bleaching events that impact large areas of reefs on regional scales consistently occur during abnormally high temperature anomalies that last for extended periods of time. Bleaching severity and mortality is enhanced with prolonged warming events that coincide with calm (low wind) conditions that increase water clarity and light intensity. The combination of accumulated heat anomalies and high light intensity reduce the photosynthetic productivity of *Symbiodinium* spp. and increase the production of toxic reactive oxygen within the tissues of the coral host, which leads to bleaching in an attempt by the animal to protect itself from the damage produced by the symbiont. Climate change continues to increase the rate of ocean warming and the likelihood of more frequent, intense thermal stress events. Strong El Nino phases, of the El Nino-Southern Oscillation, similar to the 2016 event in Australia are typically accompanied with weaker monsoon conditions, which means reduced winds, cloud cover and higher light intensity, which enhance the air-sea heat flux. This talk will discuss the role of light in relation to coral physiology, climate patterns and ocean warming to enhance interventions that seek to reduce the effect of light intensity on the coral bleaching response.

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CONDITIONING NEXT GENERATION CORALS TO SUBLETHAL STRESS TO ENHANCE TOLERANCE FOR REEF RESTORATION

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Repetitive severe coral bleaching events on the Great Barrier Reef and throughout the global tropics from 2014-2017 have escalated the concern that climate change is rapidly overwhelming the capacity of reef-building corals to adapt and survive. Successful restoration in a warming ocean will require biological techniques that go beyond coral fragmentation and juvenile recruitment; climate hardened corals able to cope with future

stress conditions for explant to degraded reef sites are urgently needed. One option we are exploring is transgenerational acclimatization, where the parental environment may influence the tolerance of the offspring. In a multi-year study, we are testing the potential to enhance the climate resilience of the reef-building coral, *Pocillopora acuta*, through conditioning of parental colonies to future temperature and acidification (pCO2) conditions. Within the AIMS National Sea Simulator, we have raised a large number of 1-year old first generation *P. acuta* offspring (F1 cohort of 6500 individuals) under experimental present day, 2050 and 2100 climate scenarios (400 ppm x Present day temperature (0.95 Degree Heating Weeks), 685 ppm *p*CO2 x +1.5 °C (2.5 DHW's) and 900 ppm *p*CO2 x 2.0°C (5.0 DHW's)). Physiological traits of tolerance including rates of metabolic respiration, photosynthesis, calcification, bleaching sensitivity, recovery and survivorship during summer heat stress exposures under future ocean acidification conditions are being measured. This ongoing experiment has identified sensitive and tolerant genotypes within the experimental population, with consistent individuals displaying bleaching resistance and growth under high temperature and 2100 acidification conditions. We seek to identify the heritability of acquired tolerance across three generations and the efficacy of transgenerational acclimatisation to develop next generation corals for reef restoration programs.

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IS SOCIAL ACCEPTANCE REALLY THE END GOAL? EXPERIENCES AND LESSONS FOR AVOIDING ENGAGEMENT MISTAKES OF THE PAST

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Emerging technologies across various application domains are continually encouraged to take account of ethical and social considerations in the planning and implementation of research.

Often narrowly defined as 'social acceptance' or 'licence to operate', ethical and social expertise is typically employed to identify and navigate barriers to acceptance and/or adoption of novel technologies. There are both conceptual and ethical reasons for science to approach the task of engagement differently.

Recent advances in gene editing and gene drives have again raised many of the same social and ethical challenges which surfaced during the GM debate of the early 2000s. Overcoming two challenges in particular appear to be critical to achieving science impact: (1) the integration of social and life sciences in the early planning and development stages of research and; (2) the effective engagement of a range of stakeholders in the governance of science.

We reflect on how these key concepts have played out in two current multidisciplinary projects: the development of a coherent synthetic biology science agenda in Australia and; the proposed release of Cyprinid herpesvirus 3 (CyHV-3) to biologically control Carp in Australian waterways. While both projects are still in early stages, we share our approach and experience so far in our attempts to avoid mistakes from the past.

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ESTABLISHING THE FIRST CORAL NURSERY IN THE GREAT BARRIER REEF TO REGENERATE HIGH VALUE CORAL REEFS

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Reef Restoration Foundation established the first pilot coral nursery project in the Great Barrier Reef Marine Park in December 2017. Numerous challenges were successfully overcome to establish the first pilot project using local and international knowledge transfer and developing innovative business models and partnerships with

the government, tourism industry, scientists, volunteers and other key stakeholders. A number of key challenges remain to enable coral restoration to realise its potential of being one of the solutions that can be deployed at sufficient scale to regenerate high value damaged coral reefs in the Great Barrier Reef Marine Park. The presenter will outline the key challenges that were overcome and potential solutions to the remaining challenges.

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THE CULTIVATION OF MACROALGAE TO REDUCE NUTRIENT LOADS AND IMPROVE THE RESILIENCE OF CORAL REEF ECOSYSTEMS

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The export of nutrients from the Queensland coastline into the Great Barrier Reef Marine Park (GBRMP) is estimated to be 37,000 T of nitrogen and 6,300 T of phosphorous each year. This has a significant detrimental effect on the functioning of this important coral-based ecosystem. Rectifying this nutrient imbalance requires both a reduction in the supply of nutrients into the coastal zone and an implementation of novel technologies that can actively recover these nutrients once they have entered the GBRMP. The Centre for Macroalgal Resources and Biotechnology has worked closely with MBD Industries, and other industry partners, to pioneer the development and implementation of the intensive land-based cultivation of marine and freshwater macroalgae for nutrient remediation. This land-based cultivation enables the recovery of nutrients from industries that create point-source discharges, prior to these nutrients entering the GBRMP. Despite this, there are many diffuse pathways where nutrients enter the GBRMP, which cannot be addressed using land-based cultivation systems. An extension of our technology is to implement the extensive cultivation of fleshy seaweeds, such as *Sargassum*, in the GBRMP. As these seaweeds grow, they continuously remove carbon, nitrogen and phosphorous from the water, converting it into algal biomass. These assimilated nutrients are then physically removed from the system and returned to land. This harvested biomass has beneficial applications as a fertilizer and bio-stimulant for cropping agriculture or as a supplement for cattle (Figure 1). The implementation of this technology would produce approximately 1,600 T dry weight of seaweed biomass per km^2, recovering between 480-550 T carbon, 25-32 T of nitrogen and 4.8-6.4 T of phosphorous each year. Completely remediating the 37,000 T of nitrogen entering the GBRMP will require an area of seaweed cultivation of approximately 0.3-0.4% of the total area of the GBRMP. Importantly, at this scale of production, the seaweed will also provide a modifying effect on the process of ocean acidification, a reduction in incident light and a localized cooling effect. The development and implementation of seaweed aquaculture would form the basis of delivering a sustainable, low-impact environmental service to support the resilience of coral reef ecosystems.

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PATHWAYS TO CONNECT CITIZEN SCIENCE WITH REEF RESTORATION

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Reef Check Australia (RCA) empowers people to champion healthy Australian reefs, through robust citizen science, inspiring educational experiences, and tangible local conservation action. Our vision is to create a world where informed, engaged and empowered communities are stewards of healthy reefs.

Our strong legacy of citizen science is based on 17 years of collaborative experience with citizens and partners in coordinating and training volunteers to undertake reef health surveys across Queensland and Western Australia. RCA provides important data on reef health which is scientifically validated and complements traditional research and monitoring. In 2015 RCA launched a Reef Ambassador community outreach program. This program provides a more holistic framework of citizen science and support to help citizen science volunteers to share information about reefs with communities. Between 2015 and 2017, 37 Reef Ambassadors were recruited and trained in reef science, science communication and event delivery and our Ambassadors

have been working locally to coordinate or contribute to community outreach events to build community awareness about local reefs, citizen science, and conservation. In 2017, RCA explored applications for citizen science in reef restoration through monitoring the impacts of a macroalgae removal intervention on Magnetic Island in partnership with Reef Ecologic.

This presentation will outline the work of Reef Check Australia in citizen science, community outreach and will discuss the potential for citizen science to support ecological restoration and stewardship outcomes. It will provide insights into how citizen science and ecological restoration science can 'join forces' – to connect restoration science to a large database of committed citizens and connect volunteers to a range of opportunities to engage in citizen science and on-ground action. This has the potential to advance thinking about reef restoration options.

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THE POTENTIAL FOR SEAGRASS RESTORATION IN THE GREAT BARRIER REEF REGION

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The Great Barrier Reef World Heritage area has in excess of 35,000 square kilometres of seagrass meadows and ~20% of the world's seagrass species. Seagrasses provide ecosystem services that include removing nutrients from the water, stabilizing sediments, sequestering carbon, reducing acidification, providing food and shelter for fish and invertebrates, and food for turtles and dugong. They are a vital part of the ecosystems that support the health of corals. Seagrass losses have occurred along the Queensland coastline, particularly adjacent to urban and industrial centres, from reduced water quality, tropical storms, and floods. There exists the potential for intervention to restore or enhance recovery. We discuss the history and experience of seagrass restoration in the GBRWHA and the roadblocks to a successful outcome. There are environmental, site, population, and species-specific parameters that should be considered before investing in seagrass restoration even at a small scale. There are also processes that support or prevent natural recovery that need evaluation before any intervention. The experience of seagrass restoration almost certainly provides lessons for the restoration of other reef systems.

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EVALUATING GREAT BARRIER REEF INTERVENTIONS USING A REEF-WIDE SYSTEMS MODEL

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The cumulative pressures of tropical cyclones, coral bleaching, and predation by crown-of-thorns starfish (COTS) on the Great Barrier Reef (GBR) are increasing with climate change and appear to be driving a long-term decline in coral cover. With many potential nonlinearities and feedback pathways associated with both ecological and human processes, evaluating intervention options requires a systems-modelling approach. The Coral and COTS Network (CoCoNet) model is a meta-community model covering the GBR domain with realistic representation of major cumulative pressures and a range of restoration interventions. We have explored scenarios for the next 10 to 50-years under changing climate, modelling interventions including COTS control, reductions in catchment discharges, artificial shading to reduce bleaching rates, and introduction of bleaching resistant strains of coral. The systems-modelling approach allows interventions to be evaluated individually or in combination. Results suggest that the most promising approaches involve cumulative interventions that combine COTS control with coral restoration strategies that can influence a large number of reefs.

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SCIENTIFIC LESSONS IN ESTABLISHING AUSTRALIA'S FIRST CORAL NURSERY

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The declining health of the Great Barrier Reef has led some stakeholders to try new techniques. Active reef restoration has been implemented in numerous locations internationally, but is rare on the Great Barrier Reef. During 2017 we provided scientific advice to the Reef Restoration Foundation on baseline, and longer-term monitoring to assist the permit application process. In December 2017 JCU/TropWATER and Reef Ecologic researchers provided scientific expertise to conduct baseline surveys of coral and fish and establish the first coral nursery on the Great Barrier Reef. The project was implemented in the shallow fringing reef around Fitzroy Island, 25 km east of Cairns. 24 partial colonies comprising four coral species were collected from two sites. Six coral nursery trees comprising 240 coral fragments were successfully deployed in a depth of 14 m. Researchers encountered a number of logistical and environmental challenges such as not impacting LTMP sites, low visibility, vessels, resources and adhesive methods. The active participation of a suite of enthusiastic volunteers to establish and maintain the coral nurseries has been a positive outcome of this project. Survival of coral is 93% after 5 months. This development and implementation represents a first step in a process to extensively utilising local-scale reef restoration projects to support the health and resilience of local reefs, tourism and stewardship across the Great Barrier Reef.

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LEVERAGING THE SCIENCE TO POSITION THE GBR RESTORATION AS THE GLOBAL BENCHMARK – INNOVATIVE RESTORATION / INTERVENTION PROJECT EXAMPLES

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Examples of innovative restoration / intervention project examples in the Middle East and Maldives by Australian companies will be presented. These projects are spinoffs from Australian research and innovation. Prevention: Open water silt curtains: Flood water plumes from rivers carrying sediment, nutrients, pollutants and debris from the mainland enter the NQ coastal zone and, at times, reach the outer reefs causing stress and mortality of corals. Silt curtains could be used to reduce silt plumes by settlement and/or flow path diversion down coast. The design considerations for the optimal configuration of the barriers include velocity of flow, wave heights, water depth and design/modelling done. The strength, durability and effectiveness in ocean conditions are concerns however recent developments address these with curtains being designed and tested for extreme conditions and offshore use such as those made by Ecocoast in collaboration with The Ocean Cleanup restoration project for the Great Pacific garbage patch. Two innovative silt curtain case studies that could be scaled up will be presented: Protection of coral reefs from silt plumes in Saudi Arabia; and Trials for the Great Pacific garbage patch. Restoration: We will present examples of reef restoration work conducted in the Arabian Gulf and Maldives, including Food web restoration for mass release of two endangered species of fish; Design, installation and monitoring of a resort sponsored endangered species habitat; Development of a sustainable and resilient regional eco-tourism strategy based on coral propagation research; multi-disciplinary artificial reef module stability project.

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EXPLORING THE POTENTIAL USE OF CHEMICAL EXTRACTS FROM CORALLINE ALGAE FOR ENHANCING CORAL LARVAE SETTLEMENT

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Coral reefs are degrading rapidly as a consequence of mass coral bleaching events, crown-of-thorns-starfish outbreaks, cyclone damage, declining water quality and overfishing. A key strategy to assist reef restoration is by means of enhancing the settlement of coral larvae from the water column to the seafloor. For reef corals,

this process usually requires the presence of crustose coralline algae (CCA), a group of marine red algae with calcifying skeletons, also key in reef building processes. Our lab at Griffith University has been investigating the role of CCA in reef recovery and coral larval settlement. We recently tested the potency of induction of coral larvae settlement by 12 species of CCA from the GBR and found that some CCA species (including *Titanoderma*) have incredible powers to induce the attachment and metamorphosis of coral larvae. This confirmed previous reports by other research groups. We then conducted a series of laboratory experiments to test whether chemicals extracted from *Titanoderma* enhance coral larval settlement. We found that *Titanoderma* extracts can induce significant levels of settlement (i.e. attachment and metamorphosis) of species of the dominant reef building coral *Acropora*. Subsequent experiments aimed at isolating and identifying the chemical compounds involved in settlement induction and this work is currently in progress. In this talk I will discuss the potential of using CCA compounds as means of enhancing coral larval settlement in situ and their potential use in restoration strategies.

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LARGE SCALE, CARBON NEUTRAL CORAL PRODUCTION

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The Queensland Coral Fishery is limited entry and quota-controlled, supplying small, brightly coloured specimens from a wide range of species for display in aquaria. Cairns Marine is the largest quota holder and has been involved with collecting and caring for all manner of marinelife since 1964. The company's owners are heavily invested in the industry and totally committed to sustainable use of the Great Barrier Reef. The bleaching events of 2016 and 2017 prompted us to bring forward existing plans to reproduce corals onshore in a controlled environment. We purchased a property at 750m above sea level and have plans before council for a network of glasshouses with a maximum floor space of more than 3,000m^2. The lower ambient temperature at elevation enables easier control of water temperature and the corals will bathe in natural sunlight. We have a research partner to help us to understand optimum conditions for reproduction and growth of a variety of species and the closed recirculation systems will be fully solar powered. We have also partnered with German chemists Triton Applied Reef Bioscience to fix water quality problems before they arise. The driver for this initiative is continuity of supply of premium quality corals for the aquarium market. However, opportunity could easily extend to collaboration on coral reef restoration. During production at our facility, the corals are immune to marine heatwaves, crown-of-thorns starfish, wild weather and parrotfish. It is a carbon neutral alternative for repopulating coral reefs.

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RECRUIT – RECOVERY OF REEFS USING INDUSTRIAL TECHNIQUES FOR CORAL SPAWN SLICK HARVESTING AND RELEASE

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Accelerating the restoration and recovery of coral populations is a global challenge that has been attempted on many coral reefs around the world. Previous approaches have shown varying levels of success at localised scales, but the comparison of cost and benefits to develop large scale restoration concepts has so far been lacking.

Here, we compare two large scale restoration approaches: the harvesting, development, and release of wild coral spawn slicks and the transplantation of fully fecund adult coral colonies. Comparisons incorporate the best available information on the demographic rates to estimate coral population growth beginning at settlement to maturity five years following deployment. Cost effectiveness is also considered in a coarse manner.

This contribution elaborates on the apparent optimal approach for large scale application in the current context of the Great Barrier Reef: coral spawn slick harvesting and release. The coral spawn slick harvesting and release approach

appears optimal because it achieves large scale restoration of coral communities with low impact technology and at lower cost per colony. Overall, it has the potential to (1) transport billions of thermally tolerant larvae up to 1000s of km's that (2) are relevant to coral restoration efforts at the geographical scales of the Great Barrier Reef while (3) benefitting from the use of technology that likely has extremely low impact on wild populations and (4) retaining the natural genetic and species diversity needed to enhance the resilience of restored coral communities. The proposed technology and application of using industrial techniques for large scale coral spawn slick harvesting and release is presented.

Our contribution also provides valuable insights into critical elements of each concept. We highlight information gaps and the relative sensitivities of different approaches to parameter uncertainties such as levels of larval retention, which could result in different assessments of cost effectiveness.

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EVALUATING ADAPTIVE POTENTIAL AND IDENTIFYING MARKERS OF THERMALTOLERANCE IN *PLATYGYRA DAEDALEA*

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Coral bleaching events resulting in subsequent coral mortality are predicted to increase in frequency and severity due to climate change. Corals must adapt to survive in these warming oceans. Selective breeding of naturally tolerant corals is one of several genetic mechanisms which could increase thermal tolerance of coral populations. However, little data is available for predicting cross generation genomic adaptive responses in coral. We need to understand which populations have the capacity to adapt to warming temperatures and which genetic variants confer increased thermal tolerance to support conventional and novel reef management actions. In this talk I will describe a laboratory based heat selection experiment where we tracked survival of individual coral larvaes to determine if survival in acute heat stress conditions could be passed from parent to offspring in one coral species. The heritability heat tolerance in *Platygyra daedalea* from the Great Barrier Reef (GBR) was 0.6 and suggests that this population has the strong capacity to adapt to increased temperatures. We identified a total of 1,069 genetic markers associated with thermal tolerance overall with 34-336 markers in each family. Two to three of these markers were identified in at least three experimental families indicating that those specific genomic regions are important for thermal adaptation of *Platygyra daedalea*. I will discuss the importance of understanding selection and the genetic architecture of selected traits both in the context of conventional and novel management actions.

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SCOPING REGULATORY, INSTITUTIONAL AND GOVERNANCE IMPLICATIONS OF REEF RESTORATION AND ADAPTATION INTERVENTIONS

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Climate change poses unprecedented challenges to the survival of coral reefs. Even if the Paris Agreement targets of stabilising mean global temperature increases below 2°C or 1.5°C relative to pre-industrial levels are achieved, coral reefs are expected to be severely degraded. If the targets are not achieved, which current carbon emissions trends indicate will most likely occur, coral reefs are expected to be largely destroyed globally. In this context, a range of interventions are currently being investigated as part of Australia's Reef Restoration and Adaptation Program (RRAP) to help the Great Barrier Reef (GBR) resist, repair and recover from climate change. Given the multifaceted social and political organisation context in which they will be implemented, RRAP interventions may entail significant regulatory, institutional and governance implications. Drawing on document analysis, scenarios

and expert elicitation, this study investigates potential regulatory, institutional and governance issues of RRAP interventions. This includes (i) mapping the existing GBR regulatory, institutional and governance landscape, (ii) establishing a systematic approach to identify and account for issues of each intervention relating to such landscape, and (iii) interrogating selected interventions to explore the regulatory, institutional and governance issues that arise. In addition, the study identifies capacity challenges to implementation and long-term monitoring and evaluation of interventions. Ultimately, it provides important insights into the feasibility and viability of reef restoration and adaptation interventions. These may prove useful to other jurisdictions, where these interventions – similar to the GBR – take place in a complex regulatory, institutional and governance context.

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ONGOING CROWN-OF-THORNS STARFISH CONTROL AT A HIGH VALUE TOURISM SITE: MOORE REEF, GREAT BARRIER REEF

Eric Fisher

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Crown-of-thorns starfish (COTS) are a coral predator and large populations on individual coral reefs ultimately reduce hard coral cover to low levels. At tourism sites in the Great Barrier Reef Marine Park, high levels of coral cover are maximised through efforts from a range of stakeholders. These efforts are not only to improve customer appreciation of a world heritage area but also participate in building a coral reef resilience network. Ongoing COTS control programs are an example of one initiative tourism operators utilise to preserve and protect live coral cover. Cairns tourism operator Reef Magic Cruises has one pontoon site situated at Moore Reef. Crown-of-thorns starfish control programmes initiated at this site in the late 90's and have been ongoing till present. Originally the programme just involved the haphazard collection or injection of adult starfish in plague numbers. Over time the program has identified key habitat areas that experience high juvenile recruitment of COTS. Today the programmes have evolved into fine scale surveys of these habitats in locating juvenile starfish and their coral preferences. The data collected may aid in answering questions on spawning frequencies, connectivity, age and growth of juvenile COTS. In the future this programme may be a useful addition to the Reef Integrated and Reporting Monitoring Programme. Reef Magic Cruises Moore Reef site and techniques could be an early warning system into predicting future out breaks in the Cairns region of the Great Barrier Reef.

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FINE-SCALE WATER CIRCULATION PATTERNS OF A CHANNEL IN MOORE REEF, A MID-SHELF PLATFORM CORAL REEF ON THE GBR

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Multiple patch reefs in the Cairns region of the Great Barrier Reef Marine Park were influenced by consecutive mass coral bleaching events in 2016 and 2017. The outcome of these events in terms of coral mortality and recovery was patchy, and possible explanations include individual coral reef configuration and how it impacts the local hydrodynamics. To investigate local scale patterns in hydrodynamics, a study site was selected on the north western side of Moore Reef, approximately 55 km east of Cairns. This area contains several passages within the reef front that connect the coral reef lagoon to the open water. Several instruments were used to evaluate hydrodynamic patterns of a passage. A total of 3,962,311 observations of current speed and direction were collected from the 9 current meter stations between 15-08-2014 and 7-12-2015. Illustrated water circulation patterns shows the restriction in water flow created by the narrow passage causes current velocity to increase, which is evidence of tidal jets. Other evidence of tidal jet phenomena was the production of a separation point towards the entrance of the seaward side of the passage and current velocity on the outer reef slope increases further away from the passage. Tidal harmonics analysis was performed on the water height data, and Moore Reef experiences a semi diurnal tidal pattern with a Form Factor ~ 0.58. Tidal changes in current direction were not in synch with changes in tidal phase, with current switching direction two hours in advance to change in tidal phase. Flood and ebb bodies of water in the passage varied in turbidity and temperature. Temperature on flood tides was 0.8°C cooler than ebb tides. Overall there was little evidence of seasonal changes in water circulation. In the passage daily average current speed ranged between 0.093 to 0.37 m/s

with regular peaks and troughs in water velocity indicating lunar periodicity. Peaks in current velocity correlated with spring tides and troughs with neaps. Daily average wind speed for this period ranged between 1.26 and 11.62 m/s and an increase in wind speed was often followed by an increase in current speed. Tidal forcing is the principal driver influencing the hydrodynamics of the channel and intermediate surroundings.

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INNOVATIONS: ECOLOGICALLY-INFORMED TACTICAL REEF SCALE CONTROL USING THE COTS CONTROL CENTRE

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Crown-of-Thorns Starfish (COTS) population outbreaks are one of the major threats to the Great Barrier Reef (GBR). They are also the threat that is most directly and immediately manageable in the short term through active control. The scale of the COTS problem, however, threatens to dwarf the resources available to combat it. It is therefore vitally important that COTS control activities are conducted as efficiently and effectively as possible.

The effectiveness of current COTS control activities can be maximised by ensuring that COTS are removed efficiently from areas of ecological or economic importance, or areas which foster the growth and spread of the population. Identifying and prioritising the areas where the greatest impact can be achieved requires knowledge of the current distribution of COTS from control and surveillance activities, and a detailed understanding of the ecology that drives the spread of their population. At the same time, it is vital that the effectiveness of control actions is monitored to ensure the desired outcomes are being achieved, and to know when the COTS population at a site has been successfully controlled and resources can be redirected to another site.

The COTS Control Centre is a tablet-based, ecologically-informed, on-water decision support system. It uses the cull and surveillance data collected by the control program, coupled with detailed ecological and management models, to recommend which sites control program staff should survey and which they should dive at, how often, and at what point they should move to the next priority site in order to achieve the greatest improvement in coral health and resilience on the GBR. It leverages advanced decision science techniques to compartmentalise the data and decisions that need to be made on-water on a daily basis from those made by program managers each month. It uses robust hierarchical decision trees to make optimal decisions under uncertainty and intermittent connectivity. It coordinates decisions across the fleet of control program vessels to optimise control strategies given current knowledge, while also generating the data required to improve our knowledge and decisions in the future.

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OPPORTUNITIES FOR INNOVATION IN REEF RESTORATION

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The scale of restoring the GBR, through altering the community structure of the GBR to a more thermally-tolerant assemblage, or other means is daunting. One approach is through using existing aquaculture approaches to develop and seed reefs and then when at-scale, rely more on natural processes to recruit more thermally tolerant individuals into other reef communities. Other approaches focus on managing the ambient environmental conditions surrounding particular reefs.

However as a result of the large spatial scales, significant innovation will be required to boost the productivity of existing aquaculture production and delivery processes, or engineering methods to alter local environmental conditions.

This talk will present an innovation framework which can be used to plan and assess innovation opportunities, along with case studies of where similar sectors have harnessed such innovation approaches to increase productivity. The framework is applied to several proposed restoration approaches to demonstrate its efficacy.

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100X THINKING: MOBILISING CAPITAL AT SCALE FOR RESTORATION AND RESILIENCE

Rich Gilmore

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The protection and restoration of important natural assets like the Great Barrier Reef at a speed and scale that matters requires a radical rethink of how philanthropic, government and private investment monies are raised and deployed. 100X Thinking challenges conservation practitioners to move beyond seeing philanthropic and government grants as the solution to environmental problems. Rather, these funding sources must be seen as levers to be pulled in order to mobilise private capital in vastly greater quantities than can be simply gifted to worthy beneficiaries by generous benefactors.

One of the challenges currently constraining the scale of conservation investments is the limited 'bankability' of existing approaches to valuing nature. According to a well-publicised 2017 report, the value of the Great Barrier Reef is more than A$56 billion dollars. But is the Reef really worth that much? If it is, an investor, acting rationally, would be motivated to invest up to that sum in its conservation and protection. Likewise, a commercial bank could secure a loan against some portion of that value and a rational insurer could write a policy covering a $A56 billion loss. Sadly, as is all too well-known, this is far from today's reality. We will address the question "How can we take the value of the Reef from the ethereal, and make it real, investable and impactful?"

We will showcase recent examples by The Nature Conservancy and others in Australia and elsewhere, that show that this can be – and is being – done. Philanthropic grants are being leveraged one hundredfold to create impact investment funds that deliver financial, social and environmental returns for people and nature at landscape and seascape scales. The world sits on the verge of a massive-scale transformation in how the world's capital markets are deployed in service of conservation. The financial tools needed to save the Great Barrier Reef already exist. Now is the time to wield them.

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PUTTING THE CORAL BACK INTO 'CORAL REEF RESTORATION': PROACTIVE MASSIVE CORAL MITIGATION IN HAWAII

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Most coral nurseries focus on in-water growing of fast-growing branching species to relatively small sizes for outplanting. The State of Hawaii has recently implemented an innovative program which combines collection of small (10cm) live massive and encrusting forms of coral colonies (mostly from within public harbours); placing them into the State's land-based Coral Restoration Nursery where they are fast-grown using advanced aquarium husbandry techniques into large-sized (40+ and 80+ cm) massive colonies in a fraction of the time it would take to occur naturally (in Hawaii, these corals grow 1-2cm/year). The resulting large colony modules are then placed onto degraded natural Hawaiian coral reefs in an effort to restore these reefs back toward their earlier ecologically-complex state. The outplanted colonies are evaluated using the State's Coral Ecological Services and Functions Tool and the resulting offset can be used by developers and Responsible Parties to pay for coral and habitat loss incurred elsewhere in Hawaii. The result is a dynamic program to put out large, live coral colonies, paid for without large expenditures of public monies, and without the extremely long natural recovery rates (one year instead of decades) for large corals normally seen in Hawaii. The program is now expanding to focus on extremely rare coral species to re-introduce them back into the wild using similar mechanisms.

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INCORPORATING CORAL ECOLOGICAL SERVICES AND FUNCTIONS VALUATION INTO CORAL MITIGATION AND RESTORATION

David A Gulko

Hawaii Division of Aquatic Resources

The State of Hawaii has developed an easily-used coral ecological services and functions tool for assessing relative and cumulative impacts and restoration targets. The global version of this tool can be used with all

coral species within the 15 recognized stony coral families worldwide and is easily adapted for any coral reef jurisdiction. The tool can be used in any country as the results given are relative ecological valuations which can be incorporated into natural resource trustee activities for evaluating impacts from human activities, and for establishing both restoration and compensatory mitigation targets.

The Global Coral Ecological Services and Functions Assessment tool itself is very simple and does not require extensive knowledge beyond inputting a few variables into commonly available versions of Microsoft Excel:

- The species of coral impacted for each colony impacted along with its dominant form and level of rarity in your area.
- The size of each colony impacted (measured by its longest diameter and within established size categories).
- The type of sub habitat (substrate) each coral colony occurs on.
- Each of these is selected from pre-provided lists of choices. The tool itself is very transparent and provides guidance along each step as to what it is doing

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COASTAL HABITAT RESTORATION PAST AND PRESENT

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Coastal habitat restoration is at an exciting and important point in its development. Much of the work since the 1980's has been focused on developing techniques and implementing proof-of-concept scale projects. In the last 5 to 10 years these have included restoration at increasing scales. The increased scale has been supported by improved ecosystem service science, partnerships between diverse groups including governments, and innovation.

Unlike the other habitats, fragmenting and propagating corals gained traction as an endangered species recovery exercise to increase the abundance staghorn coral in Florida and the Caribbean, to buy time to address the causes of the decline. Fragmentation was subsequently adapted to propagate the second *Acropora* sp. in the region, the elkhorn coral. This technique has been modified to the point where now nearly 100 species of coral are being asexually propagated in just one facility in Taiwan. The Society for Ecological Restoration (SER) has focused primarily on the restoration of terrestrial habitats and, consequently, has a much longer and denser record of projects. Their International Standards for Ecological restoration would consider such endangered species recovery as rehabilitation, though part of a continuum of activities aimed at improving potential for ecological recovery at larger scales. As other techniques that broaden the suite of coral species included in restoration are developed and tested we move closer to ecological restoration of reef habitats rather than selected species. Quantifying the services provide by the restored habitat will be a primary measure of restoration success. Examples of successful restoration at scale in other coastal marine habitats will be used to highlight similarities and themes within the field of coastal marine habitat restoration.

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REGIONAL MARINE CLOUD BRIGHTENING FOR CORAL BLEACHING MITIGATION

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Marine cloud brightening (MCB) applied regionally has been suggested as an intervention which could potentially mitigate bleaching of heat stressed coral reefs (Harrison, 2018). The proposal is that providing additional cloud condensation nuclei (CCN) in the form of nano sized salt crystals derived from evaporated sea water droplets to the marine boundary layer will increase the reflectivity of low lying marine stratocumulus clouds. By increasing the cloud albedo, incoming shortwave solar radiation reaching the sea surface is reduced,

with the integrative effect that over some days to months ocean mixed layer temperatures are lowered and coral stress due to both heat and light is reduced.

Global models of MCB, and atmospheric climatology indicate that the Great Barrier Reef is a good candidate for cloud brightening, but can it provide a tangible benefit to coral health?

A modelling study using eReefs and WRF is underway to quantify the potential benefits and physical feasibility of cloud brightening. If shown to be technically viable there are many additional aspects of feasibility which must also be considered. These include technical and engineering aspects, costs, social license, governance, and consideration of the potential for undesirable side effects. These aspects form part of a feasibility study underway in the Reef Restoration and Adaption Program.

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SEX, DEATH AND SCALING UP CORAL RESTORATION

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Successful sexual reproduction is essential for the maintenance, recovery and evolution of hermatypic coral populations that create the foundations of reef ecosystems. Increasing human impacts have decimated breeding coral populations on many reef systems globally, which threatens the integrity of reef communities and reef function. Coral populations are naturally resilient but when larval supply becomes limited, natural recruitment rates fail to restore depleted populations. Passive conservation management approaches are proving inadequate for promoting reef recovery, therefore active interventions including effective restoration techniques are needed. Most coral restoration projects have used various fragmentation, nursery rearing and transplantation approaches, but relatively few projects have been successful and most are small scale, short-term, relatively expensive and produce populations with limited genotypic diversity. Mass coral spawning events enable access to many millions of genetically diverse embryos that can be reared for large-scale larval production and settlement to enhance recruitment on degraded but recoverable reefs. Recent larval restoration field experiments in the Philippines and on the GBR have shown that supplying large numbers of coral larvae directly onto reef patches can significantly enhance larval settlement and recruitment rates, even on degraded reef systems. Post-settlement survival of settled polyps is initially low, but juvenile coral survivorship stabilises after six to nine months leading to rapid colony growth that can produce sexually reproductive adults within three years, thereby re-establishing breeding coral populations and initiating restoration of degraded reef areas. The key challenge now is to engineer coral and reef restoration processes at larger reef scales to sustain high genetic diversity and enhance evolutionary potential among surviving corals plagued by increasing climate change impacts and other chronic anthropogenic threats.

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INVESTIGATING LONG-TERM RESPONSES OF CORAL ASSEMBLAGES TO CORAL RESTORATION: CASE STUDIES FROM AROUND THE WORLD

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Coral restoration is gaining increasing attention as a reef management strategy to address dramatic declines in coral cover worldwide. However, there is often a mismatch between the objectives of coral restoration programs and measures used to assess their effectiveness. Here, we use five indicators to characterise and compare coral assemblages among restored sites, non-restored (degraded) sites, and nearby (non-degraded) control sites: hard coral cover, structural complexity, coral generic diversity, density of coral juveniles, and coral health. Surveys were conducted at four well-established coral restoration programs in Thailand, the Maldives, Florida Keys, and US Virgin Islands. Restored sites in all four regions were associated with increased structural complexity (>25%) in comparison to disturbed, unrestored sites. Moreover, hard coral cover at restored sites was double that at non-restored sites at three out of four locations. In contrast, the three other indicators

varied inconsistently among locations, highlighting differences in methodologies among restoration programs (generic diversity metric) or in the overall health state of local reefs (density of coral juveniles, coral health). We suggest that long-term objectives for coral restoration and measures of their effectiveness be better integrated into the design of restoration programs in order to maximise the resilience potential of restored reefs.

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EXPLORING CORAL SETTLEMENT ON 3D OBJECTS: POTENTIAL APPLICATIONS FOR IMPROVED CENSUS AND POST-SETTLEMENT SURVIVAL

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On the Great Barrier Reef, recruitment of newly settled corals following spawning events is a fundamental process underpinning healthy stocks. Initial settlement densities can reach thousands per square metre, based on counts from deployed tiles. However, high mortality occurs very early on after settlement, with juvenile corals of a few centimetres found at densities in the tens per square metre. Similarly, high post-settlement mortality has been recorded when recruitment has been enhanced by reef reseeding techniques. While captive and wild spawned coral larvae provide an abundant resource for generating settled corals, either directly on the reef or onto manufactured substrates, post-settlement survival represents a considerable bottleneck to restoration efforts.

Recruitment census devices such as tiles predominantly present upper and lower surfaces, which vary in both recruitment densities and subsequent survival rates. This suggests that the three dimensional aspect of natural reef substrates, at scales of millimetres to centimetres, can influence recruitment and subsequent survival. Using three species of *Acropora* larvae from the Great Barrier Reef, in annual trials between 2013 and 2017, we explored coral settlement on small three dimensional objects at the National Sea Simulator. Using both manual fabrication and 3D printing, a variety of simple and complex shapes were presented to larvae as settlement surfaces. The results indicate that coral recruits can be directed to favour specific areas on the shapes, including locations on structures designed to offer enhanced protection from predation, sedimentation or algal overgrowth. We demonstrate that low cost 3D printers are effective for rapid prototyping of shapes that can be configured to optimize production and deployment systems, as well as enhance coral settlement and survival. Prototyping in plastics such as biodegradable PLA works for short term deployment and recovery. Consequently we propose using cheap 3D printers to development a universal settlement device that may be deployed and recovered, to improve standardisation for comparative studies of coral recruitment levels on all reefs. Other shapes, prototyped with 3D printing for improved post-settlement survival, but engineered in environmentally benign materials such as ceramics or cements, may be permanently deployed to enhance early coral survival in restoration programs.

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ENABLING TARGETING OF EFFORT THROUGH CONNECTIVITY ANALYSES

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Australia's Great Barrier Reef (GBR) is a vast coral reef ecosystem consisting of 3800+ individual reefs. Ocean currents connect populations of coral and other benthic organisms by dispersing their larvae among the reefs. Connectivity is also a major driver of regional dynamics for coral-eating crown-of-thorns starfish (COTS), whose periodic population explosions have had devastating impacts on the health of the GBR. While large populations of adult starfish can devastate the coral community on a reef, dispersal of starfish larvae to other reefs leads to large-scale outbreak events and subsequent regional declines in coral cover. Efforts to control these outbreaks are exacerbated by the spatial scale of the GBR, and warrant targeted allocation of management resources at

strategic locations. Here, we first used the oceanographic models to simulate the dispersal of both COTS and coral larvae among the reefs and obtain GBR-wide connectivity patterns. We then analyzed these connectivity patterns in order to highlight reefs that will be more likely to either experience larval influx or spread the larvae to other reefs in the region. To test the capability of the connectivity models to capture the demographic processes on the GBR, we validated the model outputs against COTS field surveys, and found that the predictions of COTS larval connectivity correspond to reported adult abundances on reefs. We then used these outputs to define connectivity profiles of reefs that can then be used as a basis for designing regional control and management strategies. Importantly, in addition to identifying reefs important for COTS connectivity, this approach also identified potential sources of coral larvae that can support regional recovery processes, and do so consistently over multiple spawning seasons. Protecting these regionally important source reefs may be critical to help with the recovery of reefs that have not only already been damaged by COTS outbreaks, but also affected by other disturbances such as coral bleaching. This analysis has been designed to support on-water decision making processes, and its outputs are now being integrated into the Great Barrier Reef Marine Park Authority's expanded COTS Control Program that will guide future allocation of management resources and effort.

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HYDRODYNAMIC DRIVERS OF RESTORATION SUCCESS USING STAGHORN *ACROPORA* FROM GUAM, MARIANA ISLANDS

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Guam's coral reefs experienced widespread bleaching during four of the past five years (2013 to 2017), an unprecedented frequency that is expected to become commonplace due to accelerated ocean warming. Half of the island's staghorn *Acropora* spp. were lost due to coral bleaching in 2013 and 2014 and extreme low tides in 2015. Surveys conducted in 2017 found that five of the 21 known staghorn populations suffered 100% mortality in this short timeframe. Staghorn corals are vital to Guam's economy, culture, and reef flat communities, supporting a growing tourism industry and traditional fishing practices while providing coastal protection and nursery habitat for reef fauna. The severe, sudden deterioration of these populations indicates a need for more intensive, direct management interventions, including reef restoration. Critics of restoration argue that restoring degraded reefs in suboptimal conditions may be futile if stressors such as pollution are not first ameliorated. However, given the state of coral reefs globally, there is a need for urgent action to restore damaged reefs when possible. We are cognizant of the challenge of outplanting corals to inhospitable environments and are developing protocols for selecting appropriate sites for both in situ nurseries and outplanted coral populations. As part of this attempt, we are evaluating sites with high water flow for restoration, as our observations indicate that high flow regimes may provide refuge from warming and other stressors. We found that well-flushed staghorn patches closer to the reef crest are healthier and recover from bleaching faster than nearshore patches. Using Illumina RNAseq to study the effects of high and low flow regimes on gene expression of *A. pulchra*, we found differential gene expression of genes potentially related to heat stress in an ex situ experiment, then compared these expression trends to *in situ* flow-driven transcriptomic responses under naturally occurring heat stress and bleaching events. This research has important implications for reef restoration, indicating that *in situ* coral nurseries and outplanted populations may be more likely to withstand stressors if located at sites with high water flow regimes.

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THE NATIONAL SEA SIMULATOR: ADVANCED AQUARIUM FACILITY PROVIDING ESSENTIAL ASSISTANCE FOR REEF RESTORATION RESEARCH

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New methods for enhancing coral reef resilience, adaptation and restoration efforts are required on the Great Barrier Reef due to the unprecedented back to back bleaching events of 2016 and 2017. New experimental

systems and methods will be required to support the development of many of these lines of research. The SeaSim at AIMS is the one of the most sophisticated and technologically advanced experimental aquarium facilities in the world and can play an essential part in assisting the development of coral reef resilience, adaptation and restoration research. Sophisticated, large scale, mesocosm systems with daily, monthly and seasonal variability accurately simulate conditions found on the reef today, and expected in the future, enabling long term, multi-generational studies, allowing researchers to explore the evolutionary potential and adaptive capacity of key coral reef organisms to future climate change. Advanced and evolving capability for large scale spawning and grow out of key reef species allow for critical research to be undertaken on Crown-of-Thorns Starfish recruitment processes, Giant Triton breeding programs and sexual reproduction in corals and other reef organisms to support restoration efforts. Sophisticated systems for large scale sexual reproduction in corals opens avenues for direct restoration efforts. The ability to grow out multiple generations of reef organisms allows researchers to determine whether resilience traits are passed on to future generations. Advanced industrial scale controls systems, workshops and technical staff allow for the testing and support of large scale engineering systems. These capabilities and many others mean that the SeaSim will play a significant role in the development of science supporting reef resilience and restoration efforts.

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LEVERAGING THE SCIENCE TO POSITION THE GBR RESTORATION AS THE GLOBAL BENCHMARK – IMPLEMENTATION

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Restoration of the GBR will be a very difficult and expensive project on a scale that appears impossible. However, Project GBRR fits the definition of a moonshot project, and as an engineer I believe that the vision of restoring and protecting a resilient reef system is feasible and practical as there is a solid and steadily expanding scientific knowledge base with supporting resources and commitment.

Product, process and business model innovation are likely to be required but innovation is part of the Australian DNA and this is demonstrated by many Australian projects we will example.

Project GBRR is feasible if implemented incrementally in stages with an agile and innovative “future-back” approach. Each stage will need to include monitoring that will feed into the expanding knowledge base and the next stage(s). Innovation often takes proven solutions from one industry or discipline and applies it in a new way and a multi-disciplinary approach will help foster this.

Innovation develops skills and implementing projects will leverage the science to position the GBR restoration as the global benchmark. Moonshot projects have huge spinoffs / ROI and achieving the desired outcomes will not only have a huge significance for the Australian and Queensland economies, but it will also provide inspiration to ignite the Australian innovation ethos across a broad multi-disciplined spectrum of sectors including community, science, engineering, finance and education that would position Queensland as a leader in reef restoration and marine science research and education. A strategy should be to retain and build on the expertise developed

A brief review of the research to date on the GBR indicates that there is a sufficient data base to identify previously successful trials that can be scaled up to implement larger scale recovery projects. Using these results, further scale up and economies can be achieved. Possible areas are assisted spawning, shading, electro-accumulation, artificial reef structures and silt trap / diversion curtains.

We will provide examples of:

- Scale up opportunities.
- Examples of marine eco-engineering project examples implemented in Australia and overseas using marine biologists working with engineers that leveraged Australian innovation.
- An opportunist spin-off plan to extend the GBR southward to protect the Gold Coast from sea level rise.

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IDENTIFYING FISH PREDATORS TO MANIPULATE CROWN-OF-THORN SEASTAR PREDATION

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Population outbreaks of the Crown-of-Thorn seastar (COTS), *Acanthaster* cf. *solaris*, have resulted in a significant decline in coral cover on the Great Barrier Reef (GBR). Release of predation pressure remains one of the most likely hypothesised influences on COTS population dynamics. To inform management of COTS predators, we aim to identify fish species that predate on different life history stages of COTS on the GBR. We have developed a highly innovative and non-invasive method to identify COTS DNA in fish faeces, and successfully applied this in both laboratory and field settings. Specifically, we are applying a genetic marker, developed to identify *A.* cf. *solaris* larvae in seawater, to identify potential fish predators of COTS that may be important as natural controllers. Fish species of interests are those that may prey on larval, post settlement and adult COTS. So far, COTS eDNA has been confirmed in faecal matter of three planktivorous fish species, suggesting they may play a role in reducing larval abundance and settlement. Future work will focus on fish species that may prey on settled COTS, including species that are fished recreationally and commercially. This work will inform COTS management by recommending approaches around the use of predator manipulation in mitigating COTS outbreaks.

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TOWARDS PERVASIVE MONITORING OF MARINE SPECIES PHYSIOLOGY IN CORAL REEF ECOSYSTEMS

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Coral reefs are complex ecosystems that encompass thousands of species linked together through dynamic inter-relationships. While there has been substantial progress in monitoring the key bio-geo-chemical parameters across both local-reef and the whole-ecosystem scales, continuous long-term monitoring of health and condition of marine species is currently a challenge and beyond our technological capability.

The vision of ubiquitous and pervasive monitoring of reef environments requires improvements across sensing and communication technologies, analytical algorithms, and ecosystem modelling. Specifically, we have identified four areas of progress in support of the vision: 1) implantable physiological sensors, 2) machine learning and artificial intelligence algorithms that can run directly on low-power sensors, 3) low-cost long-range communication technology, and 4) data assimilation algorithms that can link data collected from individual animals to the whole-ecosystem coral reef models.

In this talk, we will give an overview of our recent results across the four key areas described above. Specifically, we will present three biosensor platforms that are capable of collecting spatio-temporal, environmental, physiological, and behavioural information across a range of marine species, including oysters, molluscs, and turtles. We will show examples of data collected from target species in lab and/or field trials. We have also designed a low-cost system for collecting data from coastal marine ecosystems at scale. The system was deployed over short- to mid-term in a couple of coastal areas covering tens of square kilometres and we will evaluate the system's performance in terms of radio coverage and power usage profile in relation to harvested solar energy. Finally, we will present early results from our lab and field trials of the technology, including coral trout trials at the National Sea Simulator in Townsville and oysters trials in Tasmanian coastal waters. Our main focus is on physiology models, machine learning and AI algorithms with low computational complexity and our results clearly demonstrate the potential of these new exciting technologies on monitoring animal behaviour and physiology in scale.

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ASKING FOR PERMISSION? THE ROLE OF SOCIAL LICENCE IN CORAL RESTORATION

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The development and implementation of novel technologies for coral restoration has been accompanied by the idea that successful deployment of these technologies at scale will require a 'social licence' from the Australian public. Scientists working on the development of these technologies openly acknowledge the importance of engaging with the public and talking openly to the media about their work. But does this mean that scientists are asking for permission from the Australian public to research and deploy these technologies? And is a social licence for coral restoration science and technologies what is most needed? These questions problematically presuppose there is a direct link between science values and public values, that is to say that developments in our scientific knowledge about the world will automatically deliver social progress. But this just isn't the case. Even within the scientific community, opinions and values are divided about the role of these technologies and how they might be deployed, if at all. In navigating the scientific and social uncertainty associated with these technologies, there is a need for scientists to reflect more critically on their own responsive stewardship of science and innovation. This requires that scientists can more effectively articulate their own values, motivations and responsibilities within the broader context of ethical, regulatory and societal debates posed by these novel technologies. Drawing on the lessons from documented cases of public values failures in climate science and frameworks for responsible innovation for novel technologies, this presentation argues for a shift away from seeking for a social licence to deploy technologies toward a more transparent and interactive process through which a range of societal actors mutually respond to the shared challenges of determining the ethical acceptability, environmental sustainability and social desirability of embedding these technologies in the world.

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RACING AGAINST CLIMATE CHANGE IN THE REPUBLIC OF SEYCHELLES

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Here, we describe the bleaching response observed during the 2016 El Niño at a degraded site subject to large-scale transplantation [*ref*. Reef Rescuers, Nature Seychelles] of nursery-grown corals and a naturally recovered site in the marine protected area of Cousin Island Special Reserve, Seychelles. Our analyses reveal strong differences between the transition and impact of coral bleaching at each site, suggesting that large-scale coral gardening with naturally selected bleaching surviving corals could increase the chances of reef recovery after extreme El Niño events. This presentation relates management actions taken to boost reef recovery on the site post-bleaching such as population controls of coral predators (COTS, *Drupella* spp). Finally, we describe unique post-bleaching restoration efforts through the propagation of heat-tolerant coral material by collecting naturally selected fragments of opportunity and dislodged colonies of branching corals *Pocillopora* spp. and *Acropora* spp. on selected sites a few weeks following the bleaching event. We discuss the potential benefits of using large-scale reef restoration as a MPA management tool in helping coral reefs face climate change.

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RESTORATION IN HIGHLY DIVERSE ECOSYSTEMS AND THE ROLES OF SCIENCE, COMMUNITY AND GOVERNMENT

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Restoration practices in highly diverse tropical ecosystems demonstrate significant differences to the practice and understanding in temperate regions. Instead of nurseries replicating the historic species community, the

focus is upon species selection that can capture a degraded site and facilitate new species recruitment as part of the succession process. In diverse species communities, we need to understand how land- and sea-scape factors influence dispersal and what site factors enable or limit recruitment. Our restoration experience on land in the Wet Tropics has been world-leading. Over the last five years, four nurseries have produced 420,000 plants of 544 species. Community support and volunteers have been a vital part of this process and have ensured continual government engagement. While we have good data on what is being produced, we don't know enough about species survival, growth and community recovery. Furthermore, given the longevity of individuals in our communities and the potentially rapid rate of change in climate, there is a need to think beyond what grows best now and to consider alternative community trajectories and outcomes.

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THE IMPORTANCE OF FARMERS: HOW ALGAL-FARMING DAMSELFISH INFLUENCE REEF RECOVERY AND CORAL RESTORATION

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Reef fish associations with coral can change when habitats suffer major coral mortality and loss in structural complexity, as they are under added pressure to survive. For benthic communities, Damselfishes from the Pomacentridae family are known indicators of benthic change and therefore coral health as they can cover up to 90% of reef habitat and manipulate their surroundings with algal cultivation. This habitat manipulation can be a huge impact when assessing and managing reef recovery and growth over time. Data was collected on the Great Barrier Reef over 18 months after a major bleaching event to assess the impacts of algal-farming damselfish on coral hosts after a major disturbance. Species abundance and diversity of five large-bodied farmers and live coral cover were recorded on three different sites of Opal reef, a highly visited tourism site of economic value. Temporal changes in the composition and abundance of algal-farming damselfishes have shifted to a primarily dominant species at each site, contributing to a further loss in live coral as species diversity declines. Further, as live coral declined in damselfish territories, algal succession increased, leading to the growth of less-palatable, fleshy macro algae or slime algae. These findings suggest that algal-farming damselfishes exacerbate degradation of coral habitats in the aftermath of severe coral bleaching, and in turn, degradation of benthic habitats leads to reductions in the abundance of algal-farming damselfishes, highlighting their important role in influencing the outcome of reef rehabilitation.

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REEF HAVENS: AN IN-SITU RESEARCH PLATFORM FOR DEVELOPING EFFECTIVE SCIENCE-BASED LOCAL-SCALE INTERVENTIONS FOR THE GBR

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In terrestrial ecosystems, active short-term intervention and management of refuges is considered warranted if it enables valued ecological communities to persist while more complicated longer-term and larger-scale solutions are enacted (Morelli et al. 2016). Unfortunately, on the Great Barrier Reef, we have limited knowledge of science-based tools and methods that could be used to actively manage refuges for persistence and/or better enable adaptation of complex coral communities to climate change, even at small scales. The Reef Havens Research Project is helping address this significant gap in Australia's coral reef science and management capability. This research collaboration between the marine tourism industry, scientists and engineers has established an in-situ research platform at Moore Reef near Cairns that will be used to increase mechanistic understanding of patterns in local-scale coral bleaching and recovery, and evaluate the effectiveness of possible interventions with scientific rigour. The Reef Havens Research Project has an independent scientific Steering Group and all data will be publicly available. The first of the interventions to be tested will investigate whether restoring "normal" water movement during summer doldrum days can reduce coral stress, reduce the

severity of bleaching and/or improve recovery outcomes at the scale of a reef tourism site. Installation of the sensor network has commenced and the research platform is expected to be operational before the next coral bleaching season.

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THE SOCIAL RISK OF BIOCONTROL AND SYNTHETIC BIOLOGY IN AUSTRALIA: EXAMPLES OF SOCIAL SCIENCE IN ACTION

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The development of novel innovations utilising biological and genetic tools can elicit strong attitudinal and emotional responses from proponents and opponents alike. These types of scientific advancements appeal to core human values, influencing perception and interpretation of risk and acceptability. This presentation demonstrates the contribution of social psychological drivers in forming attitudes towards novel technology. We discuss public risk in the context of two distinct examples of biotechnical advancement: 1. Use of Cyprinid herpesvirus 3 (CyHV-3) to biologically control Carp in Australian waterways, and 2. the development of a coherent synthetic biology research agenda in Australia. CSIRO research on social risks associated with the use of carp biocontrol in Australia examines public perception of virus safety, human health, and perceived social impacts derived from the release of an exotic biological agent. Social considerations include ecological implications, water quality, fish kill clean-up, amenity gain/loss and potential fallout from the level of virus effectiveness. The second case discusses CSIRO's investment in a social science program of research across four domains of synthetic biology. Public attitudes and risk perception of synthetic biology (e.g. gene editing, gene drives, genetic engineering) are poorly understood, and there is little evidence to distinguish public sentiment towards synthetic applications in one domain (e.g. health) versus another domain (e.g. environmental conservation). We consider the psychological issues that are relevant in forming attitudes incorporating risk, trust, values, norms and emotion. This contributes to an understanding of social drivers and barriers which are critical to the successful development and deployment of appropriate, acceptable and socially responsible synthetic biology solutions.

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ENGAGEMENT AT ALL SCALES: CONSERVATION ACTIVITIES WITH SMB AND CORPORATE TOURISM CSR PARTNERS

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Small-Medium Business scale tourism enterprises are the main access points for younger tourists in coastal Asia. An increasing number of such enterprises that cater mainly for dive tourism are realising that positive engagement with environmentally sustainable practices provides a clear marketing edge. Corporate tourism enterprises are likewise ubiquitous in tropical islands and coastlines, and tend to market themselves as a way to escape drab urban landscapes. These enterprises tend to cater for older and wealthier customers than SMB operations. However, it is indisputable that customers of all wealth and educational backgrounds respond positively to healthy reef communities, and negatively to degraded environments. Thus, even high-end resort chains are under increasing pressure from stakeholders to adopt sustainable environmental practices, and Corporate Social Responsibility (CSR) are increasingly recognised as conferring market advantage in the competitive island resort industry. Unfortunately, reef rehabilitation and the restoration of ecosystem services are seen as prohibitively expensive and technically difficult, and beyond the scope of usual CSR paradigms for either SMB or corporate operators.

Here, we document two case studies examining how a coalition of dive shops and small hotels engaged with conservation groups and government resource managers to create a roadmap for sustainable development and active impact mitigation, as well as to act cooperatively to enhance their marine environment. We also

examine a similar coalition of multinational corporate resorts who have engaged with government agencies, and NGOs to integrate their CSR programs to augment marine resource use sustainability in the intensive tourism market of Phuket. Our data indicate that forming coalitions of tourism enterprises is the most effective way of engaging government agencies. We have taken the experience of developing the low-cost models of small enterprise and community NGO conservation groups to capture the resourcing potential of large enterprise CSR, enabling the rescue and rehabilitation of reefs adjacent to large resorts, which are effectively under the management of the tourism enterprises. We intend to develop standard models for conservation engagement and cost-effective practices that would encourage large and small tourism enterprises to promulgate the concepts through their networks, creating easily applicable CSR pathways for them.

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BUILDING REEFS VS PLANTING CORALS

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The world's coral reef ecosystems are in dire need of assistance, perhaps even restoration. Today, no significant scientific agreement (SSA) exists to support any the methodologies/ solutions being utilized today. Furthermore, as there are no agreed definitions for either the process itself or the agreed outcomes, all these activities are captured under the term "coral reef restoration". This should be of increasing concern to the worlds marine scientific community.

An outcome should be relatively easy to define, such as "the restoration of the coral reef ecosystem services previously provided" by the original reef. But this does not mean that the reef itself and/or biodiversity has been restored to its original state, merely its overall services. Agreeing a process term to describe the activity itself may prove more challenging. Many words are being used to describe what people are doing today, including fragmenting, gardening, out-planting, rehabilitating etc. which all gets captured under the term – coral restoration.

Mars, Inc. has had an active coral reef research program since 2011. In this timeframe, we have adapted and developed an improved structural reef building methodology (coral spiders). We call it MARRS, which now stands for "Mars Assisted Reef Regeneration System." Mars has now laid coral spiders covering over 2.5 hectares of reef off three different costal islands in Indonesia. Our approach helps assist the reef the regenerate the overall reef ecosystem services amazingly fast, with new coral coverage exceeding 50% after two years. A typical lunar cycle "build' results in approximately 450 square meters of new reef structure consisting of 500 plus spiders containing more than 7500 coral fragments.

The key to the MARRS approach is less about planting coral, but instead about providing a new structural ecosystem with which the fish that sustain the coral reef feed, thus enabling the coral fragments to thrive.

In my talk I will present a quick overview of the MARRS methodology, scientifically validated results, and as well audio-visual evidence to support the view that the worlds marine scientific community needs to evolve its thinking from merely developing and planting new improved corals to building/regenerating new reef ecosystems.

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THE ROLE OF UNDERWATER SOUND IN THE RESTORATION OF CORAL REEFS

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Underwater-radiated noise from anthropogenic sources, such as commercial ships, may have both short and long-term negative consequences on marine life, including inhibiting coral reef colonisation, habitat loss, reducing fitness of resident species and overall diversity. In other sensitive and at-risk marine regions monitoring

programs are currently being conducted to achieve goals ranging from detailed characterisation of individual vessels of all sizes, quantification of ambient noise from vessel traffic as part of soundscape studies, passive acoustic monitoring of biological sounds associated with healthy coral reefs, and monitoring for presence of small vessels that may be fishing in protected areas. Some of these studies also involve investigating the effects of underwater noise on fauna behaviour, and habitat health. Once such baseline information has been gathered, it is possible to expand these studies to assess vessel noise mitigation measures on the overall soundscape, which can then be linked to the outcomes of fauna focused research. Soundscape information is an essential but often overlooked factor for successful implementation of restoration measures in the marine environment. This presentation will concentrate on underwater noise monitoring and mitigation assessment exemplified by some leading practice case studies, to inspire consideration of these methods in regard to restoration of the Great Barrier Reef.

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COLLABORATING TO CREATE AN INNOVATIVE SUITE OF TOOLS: THE REEF RESTORATION AND ADAPTATION PROGRAM

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This year, Australia embarked on a bold project: to create an innovative suite tools that can be rolled-out at the scale needed to help preserve and restore the Great Barrier Reef. They must be targeted, affordable, risk-assessed and socially and ethically acceptable. The breadth and sophistication of the tools under consideration may surprise you. They include: engineering solutions to adjust the coral environment to cool water and shade reefs; enhancing coral species' natural heat resistance; creating coral probiotics to support and accelerate regrowth after a negative event; reef re-seeding; and predator, algae and disease management. The largest, most comprehensive program of its type in the world, leading experts from more than a dozen agencies and universities are collaborating under the program's $6M scoping phase, funded by the Australian Government. They are assessing all existing research and technology and developing refined forecasts of how the Reef will respond under different climate scenarios. They are also extensively consultating with industry, community, and the broader Australian public, to gauge sentiment, appetite for intervention and priorities for action if, when, and where it is decided action is needed. The outcome will be a plan that identifies and prioritises research and development projects which could begin from as early as 2019. This plan will help inform spending of the recently announced Australian Government funding for reef restoration and adaptation research. While addressing climate change remains the most important action to help preserve coral reefs worldwide, that alone now will not likely be enough to preserve the Great Barrier Reef. Even with strong greenhouse gas mitigation, temperatures will continue to rise and stay elevated for a long period. Mass coral bleaching and storm damage are forecast to increase. In addition to strong greenhouse gas mitigation and continued management of local pressures, maintaining coral reefs into the future will require bold and active support.

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ENGINEERING CHALLENGES TO SCALING RESTORATION AND ADAPTATION TECHNIQUES

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The Restoration and Adaptation Program is currently exploring the feasibility of developing and deploying methods to protect key ecological functions and economic and social values of the Great Barrier Reef. These methods all have one thing in common, their deployment means an action undertaken or product deployed onto the reef. And in a system of thousands of reefs, thousands of square kilometres of coral and billions of corals this presents daunting challenge.

So just how solvable is the "scale" challenge, is it so ridiculous that we should stop now before we even start? I believe not, it's certainly a challenge but not impossible. Being smart will be the first requirement, and it is

here where the massive nature of the reef works in our favour. Leveraging connectivity, natural variability, heritability and other reef mechanisms to guide where and how we deploy will reduce the quantities required. Aussies love a bargain, and 2 for the price of 1 guides the next strategy, piggybacking methods into the same deployment action, combinations and sequencing of methods to build synergies will all further reduce the required deployment scale. BUT, it's still an audacious scaling challenge. This presentation explores the types of interventions being considered under the Reef Restoration and Adaptation program and the likely engineering challenges to scaling these techniques to the levels required.

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MASS PRODUCTION OF CORALS FOR AT-SCALE REEF RESTORATION IN THE GREAT BARRIER REEF

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The commercial culture of corals have been maintained in aquariums for hundreds of years, although long-term husbandry and life cycle closure is a comparatively recent occurrence. The 1970s and 1980s witnessed the beginning of "reef" aquariums, where living substrates and biological processes were combined in closed systems. But still the culture systems currently used to spawn corals are generally fairly unsophisticated. Under the Reef Restoration and Adaptation Program, a team has been established to assess the feasibility of utilising aquaculture methods to deploy new corals into the system to either restore degraded reefs or as part of a strategy to increase the rate of temperature adaptation across the reef. Corals the "product" are supported by a two-step protocol. The first step entails rearing coral ''seedlings", in specially designed nurseries, to a certain size, before applying the second step, out-planting or deployment of settlement devices. This study looked at mass coral production using the well defined product and lean manufacturing, with wholesale switch to autonomous systems where practical. The study's objective was to annually deliver 30 million juveniles to the reef. The study incorporated economic considerations to build large-scale coral nurseries.So far, restoration has been carried out only on scales of tens of square meters to several hectares. Large-scale nurseries and transplantation could potentially change this constraint and enable interventions to occur at whole of reef levels. In this research, mass production of coral, for at-scale reef restoration in the Great Barrier Reef, Australia was investigated.

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GREAT BARRIER REEF LEGACY'S COLLABORATIVE EXPEDITIONS: A CATALYST FOR THE FUTURE SURVIVAL OF CORAL REEFS

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GBR Legacy's vision is a future where the health and diversity of coral reefs is assured. Our mission is to be a global leader in marine expeditions delivering innovative and collaborative science, education and public engagement vital to the future survival of coral reefs. In 2017 Legacy funded and led the Search for the Super Corals expedition to provide an overall reef health assessment and to search for coral survivors in the northern GBR after the 2016 and 2017 mass bleaching events.

For 21 days GBRL provided FREE access to 10 teams of collaborating researchers from private and government research institutions. This was the largest privately funded research expedition the Great Barrier Reef had seen with results communicated direct from the reef to the public through live television and radio interviews and daily interactive updates on social media channels with a combined reach of more than 5 million followers.

Findings include a new coral species (the first one in 30 years) & the first definitive 'Super Coral' species, *Acropora tenuis* found at all reef sites regardless of bleaching. The most diverse branching coral site on the Great Barrier Reef was observed - a natural biobank that requires genetic preservation and research. Twelve

live Super Coral colonies were collected by AIMS and 9 spawning colonies are under evaluation at the AIMS National Sea Simulator. Ninety nine live coral fragments were analyzed at the University Technology Sydney. Media included 24 videos sent to an international audience, two Live ABC TV crosses, one live cross to Channel News Asia, 22 TV interviews, 32 radio interviews, 40+ national and international TV/online pieces, and a free public symposium to 150 participants streamed live to over 1500 viewers by Facebook.

Legacy's next expedition in 2018 Search for Solutions will examine why specific sites we found did better than others and what can be done to ensure their long term survival as well as fund, trial and test intervention and restoration strategies. This presentation presents Legacy's mission, achievements and opportunities for researchers to work with Legacy's expeditions to fund, deliver and promote their cutting edge reef intervention and restoration.

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DELIVERY OF IN-WATER COTS CONTROL OPERATIONS: A VIEWPOINT FROM SEVERAL DECADES OF EFFORT BY THE ASSOCIATION OF MARINE PARK TOURISM OPERATORS (AMPTO)

Steve Moon

Association of Marine Park Tourism Operators (AMPTO)

The Association of Marine Park Tourism Operators (AMPTO) has worked to help defend important marine tourism reef sites from being eaten by crown-of-thorns starfish (COTS) for decades on an as-needed basis. Over that time and through several step-changes in urgency, resource availability and scope, AMPTO has amassed considerable expertise in the safe, efficient and effective delivery of COTS control effort on the Great Barrier Reef. Federal Government support for the latest program of COTS control started in 2012, and since then there have been ongoing renewals of federal and state funding in subsequent years, with AMPTO as the major on-water delivery partner. Currently we operate two vessels under the management of GBRMPA, with scientific input from the NESP TWQ Integrated Pest Management research program. This presentation outlines some of the key learnings of safely and efficiently delivering in-water COTS control and scientific support, in an integrated program that also provides opportunities to skill-up local youth, including Indigenous youth, in ways that make them subsequently in demand as marine tourism employees.

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VALIDATING A LARGE-SCALE REEF RESTORATION PROJECT, POST 2016 CORAL BLEACHING IN THE MALDIVES

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Coral reefs are declining on a global scale. Their vulnerability to current atmospheric conditions and anthropogenic influences have left the future status of our coral reefs questionable. Reef restoration work is one such tool which managers have been implementing. However, its infancy and small-scale approach have left managers questioning its implication to kick-start the recovery phase of a highly degraded reef. Recently, large-scale coral restoration projects have been emerging throughout the tropics. The archipelago nation of Maldives is one such area which has used reef restoration projects to engage tourists at resort islands through education and awareness initiatives contributing to the projects both financially and physically.

Herein, we look at this large-scale reef restoration technique implemented by Velaa Private Island Resort, Maldives. Over a two year period, the project has reared over 7,000 coral fragments and has already transplanted over 1,000 coral colonies back onto their home reef (the resorts house reef of which is classified as a mini no-take MPA). We present the findings of our project not only with respect to the success of the corals but also the initiatives created to promote engagement with our guests and colleagues on the island. Our project has shown a 72% survival rate for the corals after one year in the nursery. During this time coral

volume has increased more than 700%. The nursery itself has also attracted coral spats with 3 coral genera being identified. After a minimum of 12 months in the nursery corals are transplanted onto their home reef where they are cemented onto the consolidated substrate to contribute to the growth of the reef. Transplanted corals have a 98% success rate after 3 months on the reef.

This paper illustrates the success of this large-scale reef restoration project as a means to help kick-start the recovery phase of a degraded resort house reef. The study supports the importance of scientific research-based projects with respect to future development of said projects.

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NEW APPROACHES, TRANSDISCIPLINARY WORK AND SYNTHESIS IS NEEDED TO SOLVE GBR PROBLEMS: INTEGRATED PEST MANAGEMENT FOR COTS

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Practical solutions for many of the complex problems faced by the GBR – and reefs around the world – cannot be developed by people working alone within any one specialised field. New approaches, truly transdisciplinary work and synthetic thinking are required if we are to move beyond the limits of our current capability to manage the Great Barrier Reef's complex linked ecosystems. Historically, control efforts for crown-of-thorns starfish (COTS) have been patchy in space and time and research into COTS has been fragmented and driven by ecological questions rather than direct relevance to COTS control. Since 2014 a profound shift in thinking has occurred in the form of the NESP TWQ Integrated Pest Management research program and its close linkages with in-water COTS control. The increased effectiveness of COTS control on the GBR has been enabled by taking lessons learned from completely different disciplines and ecosystems and putting them together in a structured, strategic manner. Many other complex GBR problems would also benefit from such an approach.

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ECONOMIC VALUE AND IMPORTANCE OF GEOGRAPHIC SCALE IN COMMUNICATIONS AROUND REEF HEALTH

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Temporal and spatial variability are endemic characteristics of the Great Barrier Reef (GBR) on multiple scales. Communicating this simply and clearly to a lay audience is difficult regardless of the actual state of reef health. Tourism provides an opportunity to share a better understanding of reef variability and complexity, as well as reef science and health through inspirational personal experiences

At a whole of GBR scale, commentary based around statistics can be misleading as the lay person has little understanding of the inherent granularity that is a characteristic of the GBR. At smaller intra-reef scales, while comparative statistics are useful for science to understand change across space and time, there is poor public understanding of the norm in the context that these statistics represent eg: % live coral cover in shallow water corals such as the reef crest.

Visiting the reef with a tourism operator is likely to expose the visitor to a very small section of reef. This experience is pivotal in the way a visitor enjoys and learns about the reef, forms a personal opinion, shares that experience and potentially engages with the GBR in future.

Reef Restoration has a role to play in lifting the economic value of the GBR by;

1. Delivering on the promise of best practice science via pragmatic solutions and innovation
2. Conserving and preserving key high value sites at small scales to ensure great visitor experiences

Tourism and applied science on the reef can, and should, be key partners in creating global advocates for the reef and to encourage good planetary custodianship by ;

1. Enhancing the economic value of the GBR (direct revenue and intangibles such as brand value)

2. Inspiring global action rather than apathy
3. Showcasing our GBR as world's best practice science and management of reefs
4. Providing personal, transformative experiences on the reef through knowledgeable, passionate reef tourism operators.

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A RESILIENCE-BASED MANAGEMENT SYSTEM FOR THE GREAT BARRIER REEF

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The average state of the Great Barrier Reef (GBR) is declining through a combination of acute impacts and chronic stressors that serve to reduce the recovery rates of reefs. A management challenge is to strengthen the resilience of the reef through tactical and strategic actions targeted at near-optimal locations and times. Here, we describe an approach to develop a Resilience-based Management Guidance System. The approach attempts to synthesize the great diversity of scientific knowledge and data in order to compare the outcomes of alternative management strategies. In practice, this involves combining empirical data on reef state, ecosystem models, biological models, eReefs, connectivity and the anticipated impacts of various management tools. The guidance system will be realised as a standalone computer software and be able to project the state of the reef under different scenarios, allow managers to estimate the outcomes of selected management measures, and identify near-optimal combinations of management to achieve stated outcomes. We demonstrate some early progress on the project and outline our concept for further development.

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NEW TOOLS TO PREVENT MASS CORAL BLEACHING: SHADING BY ULTRA-THIN SURFACE FILMS

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Coral bleaching is having an increasing impact on the Great Barrier Reef, affecting biodiversity and threatening the future of the Reef. Bleaching is typically caused by warm water events, exacerbated by high light intensity which both heats the water and directly contributes to stress within the coral. Application of an ultra-thin film containing light-reflecting particles to the water surface has the potential to shade corals and reduce the intensity of bleaching. The films developed in this project are biodegradable and composed of materials already present in the marine environment. The surface film technology can be rapidly applied in specific areas identified as being at high risk of bleaching, and/or of significant ecological importance. The application of the films requires no permanent infrastructure and only needs to be applied when bleaching conditions are predicted. Early trials indicate the films can be stable for days and can attenuate light across the spectrum. The next phases of research would optimise the film composition and investigate the behaviour and effectiveness of the films to reduce light intensity under field conditions. This information will inform modelling to assess the feasibility of films to reduce the severity of bleaching during warm water events.

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TWEETING THE REEF REVOLUTION: AN ANALYSIS OF PUBLIC DEBATES ON THE GREAT BARRIER REEF RESTORATION

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The Great Barrier Reef's back-to-back bleaching events (2016/17) have seen a shift towards more interventions and restoration project to save the Reef. With traditional media still holding gatekeeper roles, the Twittersphere has become an ideal space to debate the merits of Reef restoration research. From scientists to pollies and the public, opinion is divided over the best approach to restore the Reef's health. This paper is part of research for the Reef Restoration and Adaption (RRAP) project that is analysing social media to identify key theme in online public debates around social licence and restoration projects. Drawing on public Twitter and Facebook pages, we are measuring social perceptions of restoration and intervention projects.

Analysis of Twitter posts over a 12-month period since the last bleaching event, identifies public sentiment and discourse around Reef Restoration projects. Drawing on public tweets from social media and environmental communication literature; this study investigates the public perceptions of interventions via the micro-blogging site Twitter. The data provides insights into the public perception and debates surrounding the feasibility and viability of reef restoration and adaptation interventions. Therefore, this research aims to establish if better understanding of the social perceptions of the Great Barrier Reef can help to find ways of improving the Reef in Australia and around the world.

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LEVERAGING THE SCIENCE TO POSITION THE GBR RESTORATION AS THE GLOBAL BENCHMARK - RAISING COLLABORATIVE CAPITAL

Paul Niederer

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A new era is upon us. It is called "Collaborative Investment".

The recent emergence of Crowdfunding, crowdsales and internet funding platforms pointed us in the direction of Collaborative Funding. Now individuals, companies, associations, councils, governments and any purpose driven groups are finding it a way to fund their objectives.

Whether the target is $50,000 or $500 million.

It works through the involvement of project members, leaders, influencers, supporters, fans and targeted groups of contributors and investors drawn together through a strong meaningful purpose.

To date Collaborative Investment has funded, Community Centres, Bridges, Roads, Buildings (Statue of Liberty / Royal Albert Hall), Research projects and Government incentivised projects

It is now time for the Great Barrier Reef to embrace the benefits of this new capital raising system.

After running the first equity crowdfunding platform in the world Paul Niederer has developed a framework for collaborative finding for both public and private projects. During his presentation he will outline these processes and how easily you can use them to leverage existing funding and raise new funds at a scale that will position the GBR at the epicentre of marine collaborative investment.

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ASSESSING BIOLOGICAL DIVERSITY AND RICHNESS IN NATURAL,TRANSPLANTED, ARTIFICIAL AND 'ACCIDENTAL" REEFS IN PUERTO RICO

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The ecosystem services (i.e. artisanal fishing and tourism) that coral reefs provide deteriorate as reef-building species are lost. The continuous worldwide loss of coral reef habitat has prompted researchers

and conservationists to develop restoration strategies to mitigate these multimillion dollar losses. Artificial reef modules and coral transplantation are some of the most common reef restoration strategies employed worldwide and in Puerto Rico. However, many of these restoration projects have failed to assess the efficiency with which restored areas aggregate biological diversity in comparison to natural reef areas and artificial structures that were submerged without the purpose of creating an artificial reef (i.e. docks and shipwrecks). This project will assess and compare fish and benthic species diversity and richness across four different reef types in Puerto Rico: 1) natural reefs, 2) *Acropora* spp outplants, 3) artificial reefs (i.e. Taíno reefs® & Reef Balls®), and 4) "accidental" reefs (i.e. shipwrecks and docks). We will record some of the factors that influence the abundance and richness of species on each reef (e.g. reef age, substrate type, etc.) and will create a biodiversity map designed for artisanal fishermen and tourism companies. Our research will help deviate pressure from natural reefs toward artificial reefs in Puerto Rico by providing fishermen and tourism companies with alternative sites where they can obtain the ecosystem services that they target (i.e. a good catch/dive). This project will also serve as a baseline to inform stakeholders about the relative efficiency of different reef restoration efforts in aggregating biological diversity.

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SETTLEMENT AND POST-SETTLEMENT MOVEMENT OF CROWN-OF-THORNS STARFISH IN THE CENTRAL GREAT BARRIER REEF

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Effective management of outbreaking populations of crown-of-thorns starfish (COTS) is currently constrained by the real-time detectability of elevated densities of reasonably large starfish. Significant advances in the effectiveness and feasibility of population control may however, be achieved by understanding spatial and temporal patterns of settlement and post-settlement movement for crown-of-thorns starfish. This talk will report on long-awaited results from the experimental deployment of "COTS settlement collectors", and compare patterns of settlement to the distribution and abundance of post-settlement starfish that are amenable to current control efforts. Importantly, this research shows that COTS settle in shallow water reef environments in close proximity to coral-rich habitats that will support the growth and survival of juvenile starfish once they transition to feeding on coral prey. Moreover, this research increases opportunities to develop an "early warning system" that will allow timely and effective response to new and renewed outbreaks.

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LEVERAGING THE SCIENCE TO POSITION THE GBR RESTORATION AS THE GLOBAL BENCHMARK - CATALYST INFRASTRUCTURE

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There has been a long tradition of land based strategic infrastructure investment that has sought to provide resilience and prosperity. The GBR has much to benefit from the insights provided by land-based Catalyst Infrastructure. The current trend to strengthen policy and programs around place-based infrastructure and place-based enterprise is in direct response to poor local outcomes from major capital investment driven by government and corporate agencies.

Place based initiatives allow a more authentic response to the local environment, social and economic characteristics. But strengthened localised resilience without a strategic framework can lack the leverage to deliver legacy benefits at the regional scale.

Getting the best outcomes from catalyst infrastructure projects requires a focused and systematic implementation process. How you start a project determines its success. Resilience is multi-dimensional. A well-structured and agile strategic framework can accelerate the development of business cases that are good for the environment, great for people and attractive to investors.

This presentation will discuss some of the latest transferable learnings for developing the Best Ideas for place-based investment that set the foundation for successful private- public investment partnerships. These learnings will be exemplified in a bold place-based vision to make it happen on the GBR called the “Blue Boomerang”.

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THE POWER OF NETWORKS – THE AUSTRALIAN COASTAL RESTORATION NETWORK AND ITS RELEVANCE TO THE GBR

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Networks provide researchers, practitioners, managers, and the community with a means to connect with peers within a specific discipline. Many disciplines have a professional body or organisation, such as the Australian Marine Science Association, that enable members to connect and communicate professionally. However, many fields, such as restoration, are multidisciplinary and, as such, often do not have a single common organisation or network that connects with peers working across multiple disciplines within the same field.

In August 2017, the Australian Coastal Restoration Network (ACRN) was formed following the consensus of attendees at the inaugural Coastal Restoration Symposium, who identified that there was a need to have a platform by which restoration professionals working within the coastal and marine environment can seek experts, share ideas, and collaborate on research for the greater good of science in Australia.

The intention of the ACRN was not to replace or duplicate the smaller, discipline-specific networks (such as the Shellfish Reef Restoration Network), or to compete with the larger national scale associations (such as the Australian Coastal Society), but to provide a link between both scales. The ACRN has been designed as a conduit for information, where professionals can share knowledge and information, seek collaboration or specific expertise for projects, and as a vehicle to enable coordinated coastal restoration in Australia.

This short presentation will introduce the ACRN, the tools and mechanisms it provides for its membership, the benefits of being within the Network, and the potential for coral reef restoration to be included as part of the disciplines coordinated by the Network.

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ASSISTED GENE FLOW: FACILITATING THE SPREAD OF ADAPTIVE VARIATION FOR CORAL REEF RESTORATION

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Coral reefs are among the most diverse ecosystems on earth and provide numerous ecological, economic, and cultural benefits. However, the rate and extent of reef degradation from climate change is accelerating and testing the feasibility of interventions to increase climate resilience and accelerate recovery of corals reefs is now being considered worldwide. One method to potentially increase thermal tolerance is Assisted Gene Flow (AGF); the intentional translocation of warm-adapted or selectively bred individuals to facilitate adaptation to further climate warming. The introgression of temperature tolerance loci into the genomic background of corals from the cool water environment, anticipated to prepare those populations for future temperature increases while maintaining fitness to other existing local environmental conditions. However, there are many gaps in our understanding of the full extent of the potential, impacts and trade-offs associated with AGF. In this perspective, we synthesize relevant information in applying AGF on coral reefs, model single and multiple release sites for AGF and estimate diffusion approximation rates and the spatial extent of genetic fixation. Finally, we examine the evidence for the potential success of AGF and place it in the context of restoration of scleractinian corals on the Great Barrier Reef.

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ASSESSING THE VALUE OF NORTHERN GREAT BARRIER REEF BLEACHING SURVIVORS FOR SELECTIVE BREEDING AND ASSISTED GENE FLOW

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The Great Barrier Reef (GBR) experienced two years of back-to-back mass-coral bleaching in 2016 and 2017 that resulted in extensive coral mortality. Some coral colonies survived the bleaching event, however, and the selective breeding of these survivors may produce offspring that are comparatively tolerant to thermal stress. Yet, whether these bleaching survivors were simply 'lucky' to escape the worst environmental conditions, or whether the genotypes are indeed more thermally tolerant remains to be tested. Here we compared the thermal tolerance of non-bleached adult *Acropora spathulata* colonies from two sites in the far northern GBR with colonies from one site in the central GBR. Replicate coral fragments of each genotype were exposed to either control (28°C) or elevated (32°C) temperature conditions, and bleaching status, photophysiological health, and survival were monitored over 18 days. The northern populations exhibited lower survivorship than the central population at both temperatures, suggesting that latent stress from previous years of mass-bleaching may have impacted coral health. However, one northern population (Tijou reef) was more thermally tolerant than the other northern population (Lagoon reef). These results suggest that the population at Lagoon reef was 'lucky', while the population at Tijou reef may have more thermally tolerant genotypes that warrant further testing in selective breeding trials.

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ENGAGING CITIZENS IN THE FUTURE OF THE GREAT BARRIER REEF

Andy Ridley

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Citizens of the Great Barrier Reef is a collaborative global movement, engaging and inspiring individuals, organisations and industry to drive positive action for the Reef.

Weâ€™re engaging the world in the future of the reef and have already begun our journey, collaborating with businesses and communities along the length of the Reef and showcasing some of the best citizen-driven projects that are bringing the Citizens movement to life.

The perception that the Reef is dead, and the apathy that comes with it, is one of the main challenges the Citizens movement aims to address. Overconsumption is fuelling climate change, the plastic epidemic, and biodiversity loss - key threats to the Reef and issues at the heart of the Citizens movement. But while the challenges are immense, there is hope.

Weâ€™re asking people to go beyond Facebook likes and petitions, to feel empowered to take the next step and commit to making simple but meaningful changes in their daily lives. We're inviting Citizens around the world to get involved and commit to a brighter future for the Reef.

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HABITAT MAPS SUPPORTING THE RESTORATION OF THE GREAT BARRIER REEF

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The GBR (Great Barrier Reef) stretches over 2300 km and including 3000 individual reefs, and is a globally unique and precious national resource for Australia. However, there is no single map that shows geomorphic reef zones (e.g. slope, flat, crest, lagoon), benthic habitat types, (e.g. coral, algae, sand) or coral type (e.g. massive, plate, branching) for its full extent. Managing and restoring coral reefs require this fundamental information, to help estimate the area considered suitable for corals to colonise and specify what areas are already dominated by coral.

This work characterised the geomorphic zonation and benthic composition for all offshore GBR reefs shallower then 20 m, using a combination of object based analysis and ecological modelling, to map physical attributes, eco-geomorphology and benthic communities

The approach used was initially developed for 20 reefs in the Capricorn Bunker region, then updated for 237 reefs in the Cairns region. Our approach combined: benthic field data, satellite imagery, physical attributes, and object based analysis driven eco-geomorphological and neighbourhood rulesets. The physical attributes used included: Landsat 8 OLI satellite imagery (15 m pixels) derived depth, consolidated/unconsolidated substrate type and slope, and with wave exposure parameters modelled wind climate and satellite depth. Dominant coral types were modelled through derivation of a relationship between field data and physical attributes.

The resulting maps of the Cairns and Capricorn region provide inside in the areas suitable to be occupied by coral and the extent of area currently dominated by coral. The mapping and validation methods presented are now being developed for application to the whole of the GBR. This large scale application will include existing field data collection programs (e.g. AIMS) and citizen science groups (e.g. Eye on The Reef) and crowd sourcing (e.g. GeoWiki). The methods and digital maps produced from this initial work represent a significant advancement in our capability to map coral reefs at a relatively fine scales (15 m pixels) over large areas (237 reefs over 400 km), for monitoring in Australia, supporting management and science for the conservation of the GBR with application to other reefs globally.

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AGGREGATION, ALLEE EFFECTS AND MANAGEMENT OF THE CROWN-OF-THORNS STARFISH

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We investigated how population density and aggregation of spawning crown-of-thorns starfish (COTS) influences the species' reproductive success and identified potential exploitable management implications. Through an empirically-tuned, individual-based model we found that high levels of aggregation are beneficial to small low density populations and detrimental to large high density populations because of polyspermy effects. On the Great Barrier Reef, contemporary control strategy prioritises reducing starfish numbers at a number of socioeconomic and ecologically important sites, the efficacy of which depends on surveillance of the species. Based on our results we propose an Allee threshold of 3 starfish.ha-1 (for starfish of a mean diameter 345 mm) below which reproductive capacity is greatly reduced – regardless of aggregation level. Additionally, comparison of results with in situ measures of COTS aggregation suggests the existence of a cost-benefit equilibrium between aggregation and reproductive success, and that relief from mechanisms limiting aggregation (for example, relative predator abundance) may permit increased aggregation resulting in increased fertilisation success and zygote production. These preliminary findings posit aggregation as a key factor in outbreak formation that may be feasibly incorporated into monitoring and control activities in order to prioritise survey locations to detect incipient outbreak conditions and define stop/start rules for control efforts – an important consideration in resource allocation to mitigate subsequent risk of large scale outbreaks. Through this presentation, the motive for the work will be delivered with the primary focus being on the results and synthesised management implications whilst only broadly detailing the modelling approach.

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NOVEL ECOSYSTEMS: MANAGING NOVELTY IN THE MARINE REALM

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The concept of novel ecosystems is a relatively new and has been emerging in the field of terrestrial conservation and restoration over the last 15 years. It is built on the realisation that ecosystems are changing at an increasing rate, through abiotic, and biotic changes (e.g. invasive species) and through (inadvertent) human activities. In terrestrial ecosystems, conservation activities often involve restoring ecosystems back to a specific historical baseline and the concept of novel ecosystems offers a framework to set conservation and restoration priorities in the light of an increasing discrepancy between restoration needs and available means to restore modified ecosystems. Of interest to marine ecologists and managers is whether the concept of novel ecosystems can be adapted to help advance conservation, restoration and management of marine ecosystems. Here, the original concept of novel ecosystems is presented, outlining its strengths and weaknesses. A critical appraisal of the concept is made in relation to key marine ecological concepts and a new decision framework, fit for marine systems, is proposed as a possible way to use the novel ecosystem concept to advance the conservation and restoration of marine ecosystems.

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REEF TO REEF: SHARING KNOWLEDGE AND RESOURCES ACROSS THE GLOBE WITH THE REEF RESILIENCE NETWORK

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The Reef Resilience Network connects marine resource managers with information, experts, resources, and skill-building opportunities to accelerate and leverage solutions for improved conservation and restoration of coral reefs and reef fisheries around the world. The Network is a partnership led by The Nature Conservancy that is comprised of more than 1,350 members and supported by dozens of partners and TNC staff. It also includes over 100 global experts in the field of coral reefs, fisheries, climate change, restoration, and communication, and more who serve as trainers, advisors, and content reviewers. To achieve these goals over the last 15 years, we have focused on 1) synthesizing and sharing the latest science and management strategies through our website modules, journal article summaries, manager case studies, and newsletter; 2) connecting managers and experts to share resources and lessons learned through Network-hosted learning exchanges, trainings, and interactive webinars; and 3) providing training, seed funding, and support to help managers incorporate resilience concepts into their management strategies and regulatory policies, and encourage increased knowledge-sharing within and across regions. We have recently launched our newest website module on coral restoration, focused on sharing best practices for methods including coral gardening in field-based and land-based nurseries, larval propagation, micro-fragmentation, and substrate enhancement with engineered and other approaches. In this presentation, we will share information about RRN resources, the coral restoration module, and our plans for new content and tools coming down the pipeline.

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HOW TO BUILD A BUSINESS CASE FOR AN INTERVENTION ON THE REEF

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Sometimes the best science can stall in the blocks because, whilst the inventors or researchers know exactly how good their concept or solution is, the ‘market’ doesn’t necessarily see it that way, and there will be some convincing to do. To attract government or industry funding to take a research concept into a pilot or field trial, a compelling business case is often required. Those who might invest in a new intervention on the reef for example, will need a written document in order to obtain approval from a Director or a Board. A business case may be presented in various formats; it might be one page, ten pages or 100 pages, but the fundamentals are the same. It will describe the technical elements of a project but equally importantly it must outline the value proposition for the intervention –

for example, what problem does it solve, how is it improving the situation, what quantified value does it provide, why is it unique and why is it the best solution? An effective business case justifies why a project should be undertaken, why a private or public partner should invest in it, and why the project represents a worthy expenditure of funds. A government funding body must be confident that the project has been well planned, will provide the expected return (whether that's a economic, commercial or financial return, or a social or non-market benefit) and is in the best interests of the state or nation. An industry partner will also want to understand the potential for a commercial return on their investment – or some other indication of how a successful project will benefit their business. We will present a case study / example of the process for developing a business case for a GBR intervention.

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INDIGENOUS PERSPECTIVES ON CORAL RESTORATION IN THE GREAT BARRIER REEF

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Maintaining and enhancing cultural and Indigenous knowledge systems in the GBR is critical to the ongoing protection and maintenance of the Great Barrier Reef. This includes understanding and valuing Indigenous knowledge systems as vital to comprehending the foundations of sea country and the ability to manage it effectively. Three themes will be addresses in this presentation. Connection to Country, Impact to Country and Traditional Owner Aspiration. These themes are inextricably linked to the emerging GBR restoration space. The future health of the Great Barrier Reef is under threat from climate change and other stresses, there has never been a more critical time to harness the capacity of Traditional Owners for reef protection, management and restoration. Achieving an improved policy understanding about the status of Traditional Owner management of sea country estates within the Great Barrier Reef is of direct relevance. Followed with critical investment in the Traditional Capacity, to enable their full participation in the restoration sector. Traditional Owner involvement in the management of the Great Barrier Reef is complex, and collaborative partnerships is the avenue for success.

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THE HISTORY OF REEF RESTORERS

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Documenting the history of reef restoration is important because it allows us to understand our past and be more informed to take action in the future. The great men and women in our history were innovators who responded to crisis and went against convention. We have categorised the history of people and organisations involved in reef restoration as Pioneers, Scientists, Managers, Communicators and Businesses.

The Pioneers were the ones who started restoring reefs. It may have occurred thousands of years ago with the indigenous inhabitants of New Zealand and Australia placing rocks into the intertidal; the first man-made oyster reefs.

In the early 1900's there was pioneering research on oyster transplantation in America. The earliest published research on coral transplantation methods was from the 1928-29 Great Barrier Reef Expedition on Low Isles. Research on coral farming methods started around 1974 and two of the early pioneers of transplanting corals and prolific scientists are Dr Austin Bowden-Kerby and Dr Baruch Rinkevich. In the early 2000's Tom Moore, NOAA, Ken Nedimyer CRF and Caitlin Lustic, further developed *Acropora* nursery techniques. The Mote Marine Laboratory pioneered micro fragmentation with significantly increased coral growth rates. Biorock technology was pioneered by Tom Goreau.

The early leader in management of reef restoration was NOAA who developed legislation in 1973 to protect and restore habitats. This led to small and large-scale repair of coral reefs damaged by ship accidents.

Reef restoration communicators are authors of books, manuals, scientific papers as well as photographs, films, TED talks and underwater art. The notable people in this field include Margos (1974), Jaap (2000), Precht (2006) and Edwards (2010) who wrote manuals for practitioners and scientists. There are popular (over 1 million views) TED talks by scientists such as Kristen Marhaven and artist Jason deCaires Taylor.

The business of reef restoration includes aquaculture, insurance, conservation and tourism. The Nature Conservancy, Coral Restoration Foundation and Mars Foundation are international leaders in coral restoration. In 2017 the Reef Restoration Foundation deployed Australia's first coral nursery.

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SEAWEED (*SARGASSUM* SPP.) REMOVAL ON THE GREAT BARRIER REEF

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We describe an innovative pilot research and education program called 'Reef Recovery at Magnetic Island' which involved citizen scientists undertaking removal of macroalgae from the benthic substrate to aid reef restoration. The project coordinated 362 citizen scientists from international educational programs and local volunteers over 21 days between May 2016 and October 2017. Mean macroalgae cover of approximately 50% was reduced to 13.9-21.3% as a result of annual intervention. The results from socio-cultural surveys (n=135) indicated that 78% of citizen science participants were satisfied, 98% pledged to increase their stewardship and 97% increased their capacity for learning. There were extensive communication outputs from the project, which reached over 1.6 million people. The next steps include permanent quadrats, trialling larger scales of intervention and a removal of algae\coral reseeding experiment.

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CAN UNDERWATER ART HELP REEF RESTORATION SCIENCE?

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Underwater art has a long history, with a range of installations inhabiting underwater environments at popular dive locations around the world. Many of the earlier installations were installed as tributes, recognising famous figures or honouring people lost in marine accidents. Recently, an important new underwater art movement has emerged with a strong focus on environmental issues and social engagement.

Among the most famous and effective examples of this art form are works by Jason deCaires Taylor who has deployed sculptures in Caribbean, Mexico, Spain, Bali and the Maldives. Numerous other examples of underwater art currently exist in America, Thailand, Indonesia and Australia.

Underwater art illustrates strong links to reef restoration, an expanding activity undertaken by governments, managers, industry and community groups globally. Underwater art illustrates substantial socio-cultural links while reef restoration aligns strongly with ecological values. A strong driver for the expanding interest in underwater art and reef restoration is the dramatic increase in public concern for the future of marine ecosystems, especially coral reefs. Underwater art attracts large support from government and tourism and global media interest (deCaires Taylor has a media reach of 1 billion people). Like any development activities, underwater art installations have benefits and risks that must be carefully designed and implemented

We undertook a strategic review of underwater art and tourism and introduce two proposed projects on the Great Barrier Reef: the Museum of Underwater Art (Townsville) and Expansion of the Ngaro Sea Trail (Whitsundays).

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SCRATCHING THE SURFACE: HOW IN-WATER OBSERVATIONS CAST LIGHT ON POSSIBILITIES FOR SMALL SCALE INTERVENTIONS

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The freely-available coral stress indicator of Degree Heating Weeks (DHW) developed by NOAA and derived from remotely-sensed sea surface temperatures is widely used to predict and analyse cumulative temperature stress on reefs worldwide. While it is a demonstrably useful indicator of likely stress at large scales, at local scales there is more to the story. This desktop study uses various publicly-available in-water datasets to explore the relationship between sea surface and water column temperature at local scales at reef sites and adjacent lagoon areas during the summers of 2016, 2017 and 2018 on the GBR, comparing actual observations of temperature through the water column between bleaching and non-bleaching years. Local meteorological factors such as low winds (doldrums) correlate with high sea surface and reef flat temperatures, but don't necessarily affect the temperature of the GBR lagoon at depths below ~10 m. This hitherto unexplored complexity of GBR water column temperatures during some mass coral bleaching events may provide insight into interventions aimed at mitigating stress and promoting coral recovery after bleaching. The datasets used in this study were generated by AIMS and IMOS and are freely and publicly available.

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UNDERSTANDING THE PHYSICAL DRIVERS DETERMINING THE SPATIAL VARIABILITY OF CORAL BLEACHING OF THE GREAT BARRIER REEF

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For the first time, back to back mass coral bleaching has occurred on the Great Barrier Reef and Torres Strait in early 2016 and 2017 as part of a continuous global bleaching event that started in late 2014 (NOAA). The combined effect has meant that the majority of the reef has been severely affected however there remain significant areas that have survived along the length of the GBR. This presentation will provide an overview of the key meteorological and oceanographic processes that determined how different areas fared in the recent events and identify the reasons why.

The combination of long term observations through the water column and along the GBR by a range of observing platforms and the application of the operational eReefs models are allowing the 2016 and 2017 bleaching event to be analysed in ways unprecedented since the last major event in 2002.

Whilst winds played a major role in keeping large sections of the southern reef cooler, there are also locations where physical oceanographic processes over a range of spatial scales have resulted in persistently cooler waters even where there was low winds and intense summer time insolation that caused neighbouring reefs to bleach. This indicates their micro-climates may provide long term refugia for corals during future marine heat waves.

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A GLOBAL SYNTHESIS OF CORAL REEF RESTORATION EFFORTS

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Collaborative synthesis research can help distil existing ideas, data, and methods from multiple fields to advance solutions for global-scale environmental issues such as the degradation of important coral reef habitats. Coral reefs

are suffering from existing stressors such as climate change, coastal development, pollution, and overfishing. While the current paradigm of effective conservation advocates habitat protection over restoration, some areas may not have enough intact habitat left to protect. This is where restoration, or assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed, becomes critical. However, decisions on whether, what, how, where, and how much to restore are often impeded by the lack of information about restoration cost and success. Here, we synthesise data from the coral reef restoration literature to March 2018 to evaluate restoration cost, survival of restored corals, project duration, area, and techniques which have been employed on coral reefs around the world. Findings showed the cost of coral reef restoration varied depending on the technique applied. The median reported survival of restored corals was 60%. Restoration projects were mostly short-lived (one year), and conducted over small experimental scales (0.0030 ha). We discuss what is lacking for coral reef restoration to be 1) effective, 2) efficient, and 3) engaging. The current challenge for coral reef restoration is to scale-up restoration efforts to meaningful ecological, social and economic scales and ensure restored ecosystems are resilient to anthropogenic climate change.

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DEVELOPING COST-EFFECTIVE CORAL PROPOGATION TARGETED TO THE GREAT BARRIER REEF: THE OPAL REEF CORAL NURSERY RESEACH FACILITY

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Climate change and local environmental stressors have decimated coral reefs throughout the Great Barrier Reef (GBR), leading to an unprecedented need to implement alternative management interventions including reef restoration. As with many reefs worldwide, populations of *Acropora* sp. were particularly impacted by the 2016-17 mass bleaching. A push to implement reef restoration on the GBR focusing on cultivating *Acropora* sp. is therefore logical as it also leverages immense knowledge already gained from restoring *Acropora* sp. populations in the Caribbean. However, recent unparalleled coral mortality on the GBR has reached far beyond *Acropora* sp. Given the GBR's immense diversity in coral species and reef habitats relative to the Caribbean, it is clear that coral restoration practices must be tailored to local ecologies that consider both the causes of coral loss and rates of natural recovery. We therefore established the GBR's first in situ coral nurseries aimed at addressing key unknowns in how to tailor coral propagation and out-planting at Opal Reef in February 2018. Opal Reef is an important site ecologically as a source reef with immense economic value as a "tourism hot-spot", and the recent feature of high-profile documentaries showcasing the Great Barrier Reef. Our immediate goals are two-fold, specifically; to (1) track growth-survivorship-cost (G-S-C) for farming and out-planting different coral taxa; and (2) determine how G-S-C can be optimised through use of naturally stress resistant variants. We will present implementation and progress of this project at Opal Reef, and importantly how our G-S-C framework has been developed from different taxa/growth morphologies based on reviewing global nursery and out-planting efforts to date. We propose that the G-S-C framework can provide a core tool to enable the growing network of practitioners to evaluate (and continually optimise) nursery and out-planting effectiveness using easily obtained but standardised key metrics. Such tools are critically needed to broadly evaluate performance and scalability as nursery and/or out-planting efforts are increasingly rolled out across diverse reef environments and target different coral taxa across the GBR.

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WHO HAS A STAKE IN REEF RESTORATION? DESIGNING STAKEHOLDER ENGAGEMENT AND PUBLIC PARTICIPATION IN LARGE-SCALE ENVIRONMENTAL INTERVENTIONS

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Intervening to build the resilience of the Great Barrier Reef presents a number of social and institutional

challenges. These include consideration of: (1) how proposed actions (or non-action) are likely to impact the diverse social, cultural and livelihood values held by communities, industries, managers and other interests in the Reef; (2) how to reconcile or accommodate competing assessments of risk among stakeholder groups and management agencies; (3) differing views on the appropriate mix of technical methods and public dialogue; and (4) consequently, conflicting assessments of the acceptability (or otherwise) of planned interventions. These challenges raise important procedural questions about how to best design and support inclusive engagement of communities and stakeholders: who should be included, why, how, and for what ends?

With a view to ongoing implementation of the Reef Restoration and Adaptation Program (RRAP) we present, in this paper, arguments for designing and supporting inclusive and effective engagement of stakeholders and communities. We present some potentially suitable models of stakeholder engagement drawing on international examples of large-scale ecosystem repair, and from cases involving the evaluation and management of complexity, uncertainty and risk. We present the preliminary insights from an analysis of recent interviews undertaken with livelihood, institutional and civil society stakeholders in Reef restoration. These insights include different stakeholders' perspectives on the case for intervention, the suitability of existing engagement arrangements in the Great Barrier Reef, and their preferences for future participation in the RRAP.

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REEF EDUCATION TO SEA COUNTRY CONNECTIONS: INNOVATION OF CO-LEARNING FOR A SUSTAINABLE FUTURE

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Reef Magic Education specialise in place-based learning on the Great Barrier Reef; connecting people, sea country and learning. Projects allow for students, their teachers, pre-service teachers, academics, science undergraduates, marine biologists, researchers and sea country rangers to work together, allowing for participatory action and the sharing of stories. Engaging youth and particularly indigenous youth is the objective of using the Great Barrier Reef as an immersive education experience, showcasing the natural and cultural assets as a key aspect of an innovate tourism strategy, sharing local education, training and career pathways. Reef education is run by marine biologists, providing transport, food and drink with stinger suits, wetsuits and snorkelling gear. All citizen science resources are included. Off shore reef education can be logistically difficult and challenging, however, partnerships between tourism, universities, Traditional Owners and local stakeholders promoting the importance of productive education relationships has allowed for the innovation of co-learning on the Great Barrier Reef.

Concern about the effects of climate change, the loss of Indigenous values and connections to the Great Barrier Reef and the recent mass bleaching events in 2016 and 2017, has presented the question of how we can best contribute to the custodianship of the Great Barrier Reef, promoting inclusive and sustainable communities. The reef education programs highlight the social, cultural, environmental and economic benefits of the reef landscape, encouraging students and teachers to look at the larger entity of the reef as an extension of their community.

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DEVELOPING A SUSTAINABLE BUSINESS MODEL FOR LARGE-SCALE CORAL RESTORATION

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With the state of the world's coral reefs in jeopardy, scientists and ocean experts are scrambling to determine what can be done to counteract this major decline. Coral reef restoration existed on a limited scale previously but has recently gained traction within the scientific and non-profit sectors as the threats to reefs have increased and practitioners have continued to develop new restoration techniques. Despite this increased attention towards restoration, most of the current projects have been limited to small, grant-based ventures

with constraints on the size, scale, and longevity. One of the main issues that reduces the impact of current restoration projects is the amount of funding necessary to make a significant difference to this global problem. Coral Vita is developing a new for-profit business model that can address this funding gap by creating a network of land-based farm systems, each supported by a range of revenue streams. The company is developing a business model to generate sustainable income and ensure the longevity of their restoration projects around the world. As a mission-driven company, Coral Vita is incorporating the latest coral farming techniques developed by marine institutes, including the Mote Marine Lab and the Hawaii Institute of Marine Biology. Their land-based farms can serve as ecotourism experiences, where visitors can come pay to tour the farms, sponsor corals, plant corals, or receive reef restoration dive certifications from major SCUBA agencies, in addition to serving as conservation/education centers for the local communities. The company can also sell the service of reef restoration to interested parties that may include: coastal developers, beachfront resorts, cruise ship operators, governments, international development agencies, fisheries associations, the re-insurance industry, coastal property owners, mitigation banks, and high net worth/corporate sponsors. Without having to rely solely upon donations and grants, Coral Vita will be able to inject much needed private capital into reef restoration. Coral Vita has gained traction with developers and investors in the United States and the Caribbean and hopes to help develop an industry of reef restoration that can sustain local reefs for generations to come.

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LEVERAGING THE SCIENCE TO POSITION THE GBR RESTORATION AS THE GLOBAL BENCHMARK - THE ACADEMIC ROLE

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Academic research into the GBR is already extensive and world-class. Building on this scientific research and education will be a key to timely success of not only the restoration of a resilient reef but also building a resilient smart economy. There is a very strong economic imperative to restore and preserve the GBR. Even so, the $ values placed on the reef are probably low as from a coastal engineering perspective, the GBR living “breakwater” provides the protection for the shoreline against extreme events and its degradation will see our coastal communities, islands and resorts become much more vulnerable. A healthy and resilient living breakwater will grow with sea level rise. There is a view that the knowledge base required to commence implementation of effective solutions to the challenges facing the GBR exists already. To effectively manage the research and implementation processes, this knowledge needs to be freely available in a easily referenced form and kept current as has been done for coastal management knowledge for the Gold Coast.

Whilst most of the research has been carried out by marine biologists, ecologists and oceanographers there is an increasing need with the accelerated program for greater trans- disciplinary involvement with engineers and economists, and at a broader level between the scientific community, business, industry and the community. For success, opportunities must be taken to encourage collaborative research and to train science, engineering and business graduates who can communicate and work together not only integrating knowledge for immediate and tangible implementation of large scale solutions, but also to establish effective research pathways into the future. Examples will be given where marine biologists are working with industry to develop artificial reefs for GBR rehabilitation, and where opportunities exist to integrate structural features such as artificial habitats with temporal and spatial data gathering establishing a framework for baseline and future changing environmental parameters. Also discussed will be a coastal management case study where a long-term inter-disciplinary approach to information gathering and knowledge creation has led to effective large-scale solutions. The science presently available has a huge value and should be leveraged to position the GBR restoration as the global benchmark.

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USING ENVIRONMENTAL DNA TO INFORM CROWN-OF-THORNS SEASTAR MANAGEMENT

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Environmental DNA (eDNA) is genetic material obtained directly from environmental samples (e.g. water,

faeces) without any obvious signs of the biological source material. The Australian Institute of Marine Science (AIMS) has developed eDNA methods for Crown-of-Thorns seastar (COTS), *Acanthaster* cf. *solaris*, with the aim to apply eDNA strategies to COTS management and research objectives. First, we have confirmed that eDNA collected in water samples can be used to detect and quantify COTS larvae in the water column, as well as detect post settlement and adult COTS on reef substrate. To capture spatial and temporal variation in larval presence and abundance, this work is conducted in collaboration with AMPTO and Great Barrier Reef (GBR) pontoon operators. Results provide confidence that eDNA can be used as means of monitoring the progress of existing outbreaks and for detecting new outbreaks, and will contribute to the development of COTS monitoring and surveillance regimes for the GBR. Future work will focus on fine (temporal and spatial) scale larval surveys in combination with details water quality measurements to test important hypothesis about causes of outbreaks and nutrient source regions potentially promoting these. Post-settlement detection, possibly in combination with larval monitoring, will allow early outbreak detection in the present outbreak and the next wave allowing early intervention. Combined, this work will inform monitoring and surveillance of COTS population outbreaks, and provide additional strategies to mitigate such outbreaks.

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COLLABORATION TO IMPROVE EFFICIENCY AND SPUR AGGRESSIVE INNOVATION: THE CORAL RESTORATION CONSORTIUM

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Coral restoration has been occurring in the Caribbean for several decades. At first in response to ship groundings and later to ameliorate the deterioration of coral and reef ecosystem health. In recent years, due to unabated climate change, the decline of coral reef ecosystems has been precipitous. Meanwhile, coral restoration has grown from a somewhat haphazard trial-and-error approach to become more sophisticated, experimental, and scientifically driven.

The Coral Restoration Consortium (CRC) was formed with the realization that even with aggressive action on climate change, greenhouse gases already released into the atmosphere will continue to warm ocean waters to a level inhospitable to corals for decades to come. Thus, direct and informed interventions including re-seeding reefs with resilient corals in select locations, are needed to keep reef ecosystems from completely collapsing in the next few decades. The CRC is a community of practice comprised of scientists, managers, and practitioners from state, non-governmental, academic, and for-profit organization. The mission is to foster collaboration and technology transfer among participants and the broader community, and to facilitate scientific and practical ingenuity to demonstrate that restoration can achieve meaningful results at scales relevant to reefs in their roles of protecting coastlines, supporting fisheries, and serving as economic engines for coastal communities.

The CRC's mission and goals grew out of the November 2016 Workshop to Advance the Science and Practice of Caribbean Coral Restoration. At that workshop four priorities were agreed upon - scaling up restoration, using genetic science to improve coral restoration, developing monitoring guidelines, and demonstrating and communicating the effectiveness of restoration. This talk will highlight the work the CRC has accomplished to date and look forward to what we can accomplish together with our Australian partners.

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SCALING UP CORAL RESTORATION USING MICRO-FRAGMENTATION PLUS SEXUAL REPRODUCTION: TEN YEARS EXPERIENCE IN FLORIDA AND MEXICO

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Since Hurricane Wilma hit Florida and Mexico in 2005, both countries have been developing and implementing coral propagation technologies to restore coral reefs. Starting with large broken fragments, reattachment and rubble stabilization had only minor success. Medium size fragmentation, using field nurseries were successful for

both of the *Acropora* species. Land based nurseries initiated the first success with the massive coral species with small fragments and later developed and refined the first "micro-fragmentation" technologies in large scale, with successful out-plantings to the reefs. Micro-fragmented clones can also be planted together to produce a new fused colony that would have taken decades to grow and can be produced in just a few years. Recent success with settlement of larvae from sexual reproduction has produced both thousands of surviving recruits plus new genotypes for increasing genetic diversity and resilience. New recruits also make new lateral extension growth of both skeleton and tissue, ideal for using micro-fragmentation and allow techniques for scaling up both in numbers and growth rates and new genetic strains. These multi-pronged technologies allow for the large scale-up of production, economies of scale, genetic diversity and fusion of clones into larger reproductive corals within a short period of time. Case studies from Florida and Mexico show similar success of coral reef restoration.

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CAN WE BUILD COMMUNITY RESILIENCE TO CLIMATE CHANGE THROUGH ECOLOGICAL RESTORATION? THE CASE FOR DELIBERATIVE GOVERNANCE

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Resource dependent settlements and communities in reef environments are highly vulnerable to climate change and face an uncertain social, economic and environmental future. In order to avoid some of the worst impacts of climate change, scientists, governments and communities have turned to notions of community resilience as a potential strategy for adapting to and mitigating climate change.

Concepts of resilience have been considered in human welfare contexts for many decades, however the application of resilience concepts to the complex social-ecological problem of climate change is relatively new. Frameworks for measuring and building community resilience to climate change are emerging. They highlight that multiple social, economic and governance attributes are important and necessary to improve human wellbeing for ecological health. Although multiple attributes are relevant, assessments of community resilience undertaken in tropical Queensland and along the Great Barrier Reef (GBR) confirm the importance of governance for community resilience. Governance, which is fundamentally about the processes and actions of decision-making, is commonly highlighted in the literature and in practice as a barrier to the implementation of action toward addressing key environmental problems such as climate change. While governance arrangements can create obstacles for societal adaptation - effectively eroding community resilience - forms of governance also offer hope for the future. Deliberative governance, for example, provides an opportunity to overcome governance barriers and achieve joined-up-outcomes for community and the environment. Deliberative forms of governance can take many forms, though they typically involve skilled mediators, a thoughtful bringing together of interested and affected stakeholders, and strategies for collaboration. Deliberative governance processes are important in setting broad Reef planning and policy objectives such as for reef restoration and adaptation.

Through this presentation I will argue that deliberative governance can build resilience and grow the adaptive capacity of communities and civil society. I will posit that deliberative processes for reef restoration and adaptation have the potential to seed new solution spaces for addressing resilience and climate change.

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ADAPTING TO CLIMATE CHANGE: RISKS AND OPPORTUNITIES FOR THE GREAT BARRIER REEF IN THE 21ST CENTURY

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As with all reefs around the world, the greatest pressures on the Great Barrier Reef stem from global climate change, reinforcing the critical need for strong and urgent mitigation. Given climate-related impacts so far, and the inevitability of future climate change even with strong mitigation, well-resourced and strategic foundational management and regional programmes to support ecosystem, community and industry resilience are essential.

On the Great Barrier Reef, the focus of the last 20 years has primarily been to support resilience by reducing local pressures, particularly from declining water quality, fishing and coastal development. While these existing approaches are providing benefits, it is increasingly apparent that, on their own, they are insufficient in the face of climate-related extreme weather. The emerging focus of the 21st Century is to take a more 'hands-on', interventionist approach, including the adoption of novel strategies and increased research and development, with stronger emphasis on future-looking, resilience-based decision-making. These new strategies present opportunities to improve habitat and species protection, but also challenges across the spheres of biophysical feasibility, governance, funding, and social acceptability. In the end, there can only be hope for the world's coral reefs if we can deliver an integrated programme of global mitigation, traditional Marine Park, catchment and fisheries management, and innovative intervention coupled with resilience-based management.

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GREEN ENGINEERING SEAWALLS IN THE GREAT BARRIER REEF: A TRIAL USING PLANT BOXES TO PROMOTE BIODIVERSITY

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Seawalls made from rock and concrete are engineered to defend coastlines and infrastructure from sea level rise, storm surge and shoreline erosion. However, while they provide a poor substitute for natural intertidal habitat, emerging data addressing this biodiversity deficit has incorporated eco-engineering concepts with promising results. In the Great Barrier Reef seawalls comprise approximately 60% of the total linear extent of urban infrastructure (compared to other marine urban and port engineering infrastructure). This study tested whether adding inexpensive household flower boxes (artificial rock pools) to a seawall in a tropical region would support benthic flora and fauna, and whether simple orientation of boxes improves benthic assemblage colonization. Boxes were positioned at mean tide height (1.1m AHD) along a seawall in tropical Townsville, Australia. Nine boxes were deployed: three positioned vertically on the seawall, while three positioned at 45o facing towards the sea, and three positioned at 45° facing towards the land. Tilting the artificial rock pools at 45° provided a means to test the model that creating overhang walls (simulating rocky shoreline ledge microhabitat) compared to traditional forms that face artificial rock pools upwards. After 12mths, boxes had accumulated (particularly inside on overhang walls compared to outside walls) a greater surface cover of algae and invertebrates. After the second year, box inside walls supported vastly different assemblages compared to outside box walls regardless of orientation, with the highest benthic assemblage found on overhang walls, giving support to the conclusion that artificial rock pools on seawalls support more biodiversity from tilting and creating overhangs. The turbid nature of this coastal region contributed to sediment accumulation at about 25mm/yr, regardless of box orientation, which may pose maintenance problems (and cost) for managers, and if unchecked could negate any advantages offered by these engineered pool features.

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REEF AID: INNOVATIVE RESTORATION TECHNIQUES IN PRIORITY CATCHMENTS TO IMPROVE WATER QUALITY IN THE GREAT BARRIER REEF

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As detailed in the 2017 Scientific Consensus Statement, many of the Great Barrier Reef (GBR) ecosystems continue to be in poor condition caused by an interaction between climate and other stressors. Of all these stressors, poor water quality is understood to be the greatest local threat to the future of the GBR beyond climate change. Greening Australia are working to halt the soil erosion, reduce sediments and improve water quality through innovative restoration techniques extending across the GBR catchments. The focus of Greening Australia's current program is innovative on-ground practical restoration within both wetlands and high priority gully areas. To do this, Greening Australia are leading project partnerships, working with government agencies,

corporate and philanthropic partners and Natural Resource Management bodies. The current Reef Aid projects extend from Cairns to Rockhampton. Two wetland projects are working to restore 700ha of priority wetlands in sites including the Mungalla Wetlands (Herbert River), the West Haughton, Fig Tree Lagoon (Mulgrave River), and the Fitzroy River. These restoration works range from constructed wetlands, installation of bioreactors, solar bores for weed control, and working closely with land managers to sign cooperative agreements and change grazing management practices. The priority gully projects range from targeting hillslope erosion to restoration of large alluvial gully complexes across the Don, Burdekin and Fitzroy River catchments. A range of monitoring techniques have been implemented to determine reduction of sediment and particulate nutrient loads to the GBR and the costs of achieving those reductions based on different interventions. Phase 1 works were competed in 2017, and the initial results showed a great than 97% reduction in suspended sediment concentration between treated and untreated alluvial gullies. The current paper will provide information about existing and future restoration works associated with the Reef Aid.

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TOWARDS AN INTEGRATED PEST MANAGEMENT APPROACH TO CROWN-OF-THORNS STARFISH ON THE GREAT BARRIER REEF

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Crown-of-thorns starfish (COTS) cause widespread loss of hard coral cover on reefs and are considered to be one of the most significant threats facing the Great Barrier Reef. Despite a long history of management and research, there has been only slow improvement in COTS control programs. Other than the development of the single-injection method for culling and the deployment of a dedicated control program, there has been no significant advance in how control activities are implemented or in their effectiveness.

In response to this, we outlined a linked management and research strategy that was firmly focussed on improving the design and performance of the COTS control program. In developing the strategy we applied an integrated pest management approach. We started by asking how COTS outbreaks arise and spread. In light of this, then, we asked what management responses were possible, how they might operate, and from this, what objectives were realistic. The resultant management strategy allowed us to identify key areas where research could best contribute to management by identifying realistic management objectives and providing recommendations to ensure that operations were efficient and effective.

This process identified five clear management domains and associated research needs: 1) Control at sites, individual reefs, and local areas and its optimization; 2) Control at regional scales and its optimization; 3) Identifying appropriate management objectives for existing and new outbreaks; 4) developing new control and monitoring approaches; and 5) addressing ultimate causes. In this talk we describe the management and research strategy, the process through which it is being implemented, the collaborations that have been to key to its implementation, progress to date and future needs.

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CROWN-OF-THORNS STARFISH MANAGEMENT: DOES IT WORK AND WHAT IS IT GOOD FOR?

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Outbreaks of Crown-of-Thorns Starfish (COTS) are one of the key threats facing coral reefs in the Indo-Pacific region. As a consequence COTS outbreaks are typically met with some form of management response. However, despite increases in the number and type of management interventions, along with improvements in control methods over the last 50 years, there are surprisingly few documented examples of successful COTS control. This raises the question of whether the currently available management options are effective and fit for purpose. In this paper we review the management approaches being implemented as part of the

response to the current COTS outbreak on the Great Barrier Reef (GBR). These approaches include one direct intervention method, population control through culling, and two indirect intervention methods, zoning and water quality improvement. For each method we use data from the COTS control program and independent field monitoring programs to ask: i) is the method effective in reducing COTS densities to below ecologically meaningful thresholds, ii) can it maintain COTS densities below those thresholds, and, iii) is a response in coral cover is observed? We then consider the implications of our results for the design of the COTS control program on the GBR both in terms of its field operations and its strategic objectives.

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REBORN FROM THE FRAGMENTS: URBAN CORAL RESTORATION IN HONG KONG

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Some have suggested that the sub-tropics will become critical habitat for coral reef development under future climate change scenarios. Currently home to marginal reefs, the subtropics are characterized by limited light penetration, extreme temperature fluctuation, salinities, or nutrient levels, conditions further exacerbated by urbanization. Nutrients accelerate bio-erosion by grazers, microborers, and macroborers which abrade corals and threaten their structural integrity. In marginal coral communities of Hong Kong, the dominant long-lived are Platygyra exhibiting massive growth forms. However, the low skeletal density of *Platygyra* makes it a natural victim of bio-erosion and collapse. Using the micro-fragmentation-fusion strategy we restored *Platygyra* in the Hoi Ha Wan Marine Park, giving them a second chance to rebuild a new skeleton. This project has illustrated the restoration potential of slow-growing species in urbanized reefs with sub-optimal conditions – with >90% survivorship and re-sheeting rate of 1 cm^2/month.

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POSTERS

Presented at Great Barrier Reef Restoration Symposium

CORAL REEF RESTORATION IN THE NORTH OF THE MEXICAN CARIBBEAN: 15-YEAR TIMELINE

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National Park Costa Occidental Isla Mujeres, Punta Cancun y Punta Nizuc in Mexican Caribbean is one of the most visited marine parks in the world (one million visitors a year). The coral reefs in this protected area are under constant threat due to tourism, water pollution, illegal fishing, groundings and hurricanes. Since 2004 authorities have been working to solve damage caused by all these factors. A 15-year timeline is presented. (2004-2005): Three hurricanes hit the area and activities were conducted to rescuing coral fragments to reduce mortality; trained guides, dive instructors and Marine Park staff collaborated mooring and reattachment the fragments. (2005-2009): Field nurseries became a source of fragments for restoration purposes; 4,500 fragments were cultivated and planted in different reef units according to a restoration plan. (2009-2011): A laboratory to produce coral colonies systematically was built at National Institute of Fisheries and Aquaculture (INAPESCA) in Puerto Morelos. Coral colonies were raised in control systems with enclosed water and artificial light systems. (2012-2016) Outdoor semi controlled open seawater systems and natural light were installed within the facilities. Production of coral colonies in aquarium and field nurseries using clonal, as well as sexual reproduction techniques, allowed the use of coral modular nurseries to produce near than 8,000 coral colonies from 8 species. Four sites have been successfully restored: coral coverage reached 14%, environmental heterogeneity increased, and the number and biomass of fish community doubled. Colonies of *Acropora palmata* out-planted as asexual fragments in 2011 have been spawning massively since August 2016. The absence of hurricanes since 2005 has allowed maintaining coral survival rates above 80% in the restored sites. (2017-2022) Current project, with a grant by the local government, try to develop new active restoration programs to: scaling up coral production (goal of 260,000 colonies) through micro-fragmentation techniques developed at Mote Marine Laboratory, Florida, improve survival and growth rates, identify successful genotypes for reef restoration; hybrid restoration to build coral colonies that reach sexual maturity faster than naturally. Finally, a monitoring program based on six-component to assess changes in the structure and function of coral reef sites undergoing restoration.

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OPTIMISING CORAL RECRUIT OUTPLANTING SUCCESS IN TURBID ENVIRONMENTS

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A common restoration approach is to transplant aquarium-reared coral recruits to nearby reefs, which allows for controlled settlement densities, and coral husbandry through the first few weeks of recruit growth. However, turbid environments such as those occurring in the inshore Great Barrier Reef (GBR) pose a number of specific challenges for these diminutive recruits because of sedimentation, algal competition, and reduced light. Here, we assessed the influence of surface orientation of 4-week old outplanted recruits on post-settlement survivorship and growth using settlement structures deployed at two sites of differing turbidity. The highest survival was on vertical and downward-facing surfaces, whereas the greatest growth of recruits was recorded on vertical and upward-facing surfaces. All things considered, the vertical surfaces were optimal for field transplants. Further, we assess if gregarious settlement enhanced survivorship and growth of the recruits exposed to these inshore stressors.

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USE OF MODULAR REEF STRUCTURES FOR STABILIZATION OF SUBSTRATE AND MULTI-SPECIES TRANSPLANTATION

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Case study of a restoration project in Nusa Penida, Bali in which we try to restore an area of reef flat and reef crest. Over several years an area of rubble substrate was eroding neighbouring areas of reef and expanding across the reef flat and down the reef slope. We attempt to reverse this process by stabilizing the substrate using 2 designs of modular reef structures. Each structure was designed for a specific coral growth form of coral. Two species of branching *Acropora* were transplanted upon structures in the reef flat and *Galaxea* sp for the encrusting and massive structures upon the reef slope. We experimented with transplanting fragments onto different structures using the following treatments: a single parent; multiple parents from a single species; and multiple species.

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SETBACKS AND MITIGATION TECHNIQUES FOR THE LARGEST CORAL NURSERIES IN THE MALDIVES

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The largest nursery based restoration project in the Maldives was established in 2016. It utilizes the first floating nurseries in the country to cultivate thousands of coral fragments to restore the degraded reef surrounding a resort island. As with many restoration efforts, setbacks encountered with preliminary methods have the potential to devalue results or dismantle projects. Consequently, project growth and success relies on adaptation and technique innovation. Here, we address the most significant setbacks encountered throughout the first two years of this project as well as the actions taken to mitigate them.

The three principle setbacks have been:

1. Deep anchoring (~30m) combined with strong currents resulting in nursery entanglement and potential collapse
2. Fragment mortality from overgrowth of biofouling organisms
3. Fragment mortality from necrotic coral disease

Aims of these mitigation techniques were to reduce nursery fragment mortality; reduce the number of diver hours spent cleaning; and reduce the overall number of nursery maintenance dives. The following techniques are in the trial phase, to be fully implemented based on success:

1. Amended nursery frame design to minimize movement (Figure 1)
2. Temporary relocation of nursery ropes to the reef to allow for fish to consume biofouling organisms (Figure 2)
3. Hanging fragment design to promote easy removal of diseased fragments (Figure 3)

Thus far these adapted techniques have halved the amount of diver hours spent cleaning and increased nursery stability. Of the three, the most successful was rope relocation (2) as it reduced diver work hours and produced more thoroughly cleaned ropes. While still being trialed, it's hypothesized that the amended nursery frame (1) and hanging fragment method (3) will improve survival rate by reducing rope movement and entanglement as well as providing an efficient method of removing diseased fragments.

Even facing these challenges, this project has cultivated over 7,000 coral fragments with 1,000 already transplanted back to the reef. However, while manageable, the setbacks encountered by this project have reduced its overall success. We promote these mitigation techniques in the hope that other restoration efforts may gain knowledge and avoid similar setbacks in order to expand their success.

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GROWING AGAINST THE ODDS: THE CHALLENGES OF GROWING CORAL IN A REMOTE ISLAND NATION

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Despite their remoteness, the reef ecosystems of the Maldives are not exempt from the pressures of a changing climate and a dramatically increasing global population. This island nation relies on healthy coral reefs for both ecological and economic stability, however human activities are profoundly impacting their degradation. Island development, compounded with more regular and persistent bleaching events, is placing reefs under immense stress. To address this, several resort islands are attempting to mitigate reef decline by implementing active coral restoration techniques.

Velaa Private Island, a resort in northern Maldives, established the country's largest scale nursery restoration project in 2016. Like many Maldivian islands, Velaa is fringed with a shallow lagoon and degraded reef that descend into open ocean. The islands remoteness and its exposure to the elements can present challenges for restoration, making project instigation and execution demanding. Trials such as deep nursery anchoring (~30m) combined with strong currents, rough seas, changing monsoons, poor visibility and limited man power are dealt with on a regular basis. These conditions can be physically and mentally strenuous and have the potential to dismantle projects entirely. However, with perseverance, the outcomes of these efforts have proven successful. Here we aim to demonstrate a real-life view of restoration in these circumstances by sharing several setbacks and challenges alongside the achievements in order to inspire and encourage restoration work worldwide.

To date, over 1,000 coral colonies have been transplanted back onto the reef with an overall survival rate of 98.6%, and 4,000 colonies are still growing in the nurseries. With aims to double the number of transplanted colonies in the coming months, improve nursey design, and expand public outreach and awareness, the project continues to overcome obstacles. We anticipate that the long-term outcomes of this mitigation will not only restore reef structural complexity and fish communities but also enhance localised chances of withstanding future bleaching events. This short film will demonstrate the value of restoration efforts even in taxing environments; a message that provides hope for the coral reefs of the Maldives and the world, and for the people whose livelihoods depend on them.

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NOTES

Photo Right: Suzanne Long, RRRC

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