T10: BENEFIT STREAMS

Can restoration and adaptation interventions help sustain economic benefit streams from coral reefs on the Great Barrier Reef under climate change?

A report provided to the Australian Government by the Reef Restoration and Adaptation Program

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September 2019

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This report should be cited as

Stoeckl N, Anthony KRN (2019) Reef Restoration and Adaptation Program – Benefit Streams. A report provided to the Australian Government by the Reef Restoration and Adaptation Program (160 pp).

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Acknowledgement

This work was undertaken for the Reef Restoration and Adaptation Program, a collaboration of leading experts, to create a suite of innovative measures to help preserve and restore the Great Barrier Reef. Funded by the Australian Government, partners include: the Australian Institute of Marine Science, CSIRO, the Great Barrier Reef Marine Park Authority, the Great Barrier Reef Foundation, The University of Queensland, Queensland University of Technology and James Cook University, augmented by expertise from associated universities (University of Sydney, Southern Cross University, Melbourne University, Griffith University, University of Western Australia), engineering firms (Aurecon, WorleyParsons, Subcon) and international organisations (Mote Marine, NOAA, SECORE, The Nature Conservancy).

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1 PREAMBLE

The Great Barrier Reef

Visible from outer space, the Great Barrier Reef is the world's largest living structure and one of the seven natural wonders of the world, with more than 600 coral species and 1600 types of fish. The Reef is of deep cultural value and an important part of Australia's national identity. It underpins industries such as tourism and fishing, contributing more than $6B a year to the economy and supporting an estimated 64,000 jobs.

Why does the Reef need help?

Despite being one of the best-managed coral reef ecosystems in the world, there is broad scientific consensus that the long-term survival of the Great Barrier Reef is under threat from climate change. This includes increasing sea temperatures leading to coral bleaching, ocean acidification and increasingly frequent and severe weather events. In addition to strong global action to reduce carbon emissions and continued management of local pressures, bold action is needed. Important decisions need to be made about priorities and acceptable risk. Resulting actions must be understood and co-designed by Traditional Owners, Reef stakeholders and the broader community.

What is the Reef Restoration and Adaptation Program?

The Reef Restoration and Adaptation Program (RRAP) is a collaboration of Australia's leading experts aiming to create a suite of innovative and targeted measures to help preserve and restore the Great Barrier Reef. These interventions must have strong potential for positive impact, be socially and culturally acceptable, ecologically sound, ethical and financially responsible. They would be implemented if, when and where it is decided action is needed and only after rigorous assessment and testing.

RRAP is the largest, most comprehensive program of its type in the world; a collaboration of leading experts in reef ecology, water and land management, engineering, innovation and social sciences, drawing on the full breadth of Australian expertise and that from around the world. It aims to strike a balance between minimising risk and maximising opportunity to save Reef species and values.

RRAP is working with Traditional Owners and groups with a stake in the Reef as well as the general public to discuss why these actions are needed and to better understand how these groups see the risks and benefits of proposed interventions. This will help inform planning and prioritisation to ensure the proposed actions meet community expectations.

Coral bleaching is a global issue. The resulting reef restoration technology could be shared for use in other coral reefs worldwide, helping to build Australia's international reputation for innovation.

The $6M RRAP Concept Feasibility Study identified and prioritised research and development to begin from 2019. The Australian Government allocated a further $100M for reef restoration and adaptation science as part of the $443.3M Reef Trust Partnership, through the Great Barrier Reef Foundation, announced in the 2018 Budget. This funding, over five years, will build on the work of the concept feasibility study. RRAP is being progressed by a partnership that includes the Australian Institute of Marine Science, CSIRO, the Great Barrier Reef Foundation, James Cook University, The University of Queensland, Queensland University of Technology, the Great Barrier Reef Marine Park Authority as well as researchers and experts from other organisations.

2 EXECUTIVE SUMMARY

This report describes how socio-economic data were compiled using the Common International Classification of Ecosystem Services (CICES) framework, combined with estimates of coral condition, to generate estimates of the benefit of various reef restoration interventions in different climate scenarios (per annum until 2075), for use in the cost-benefit analysis. This assessment focuses on:

- A small geographic part of the entire Great Barrier Reef World Heritage Area—specifically, the 24,000 km^2 of coral reefs within the much larger 324,000 km^2 world heritage area—likely to be affected by reef intervention activities.
- The benefits that accrue to Australian residents and tourists who visit the Reef.
- Eight of ten, identifiable benefits (examples of ecosystem services) associated with this Reef area.
- 20 of the 44 intervention/climate scenarios evaluated by the ecological modellers—in all cases assuming just one intervention for the entire 60 years, without allowing for more adaptive implementation strategies (where, for example, one intervention could be pursued for several years, with another brought online later).

The research described here does not pertain to the costs (tangible or otherwise) of undertaking intervention activities.

Important caveats

We have included a benefit stream termed *Indigenous Cultural Values.* This is only a ***placeholder.*** We have conferred with several Indigenous scholars, who have given 'in principal' support to the idea of including these very rough estimates within our broader assessment. But our estimates are inadequate—and used here only to highlight the importance of ensuring they are not overlooked. There is agreement on the need for more detailed work to properly assess these values, and that the work is led by Indigenous scholars to ensure the investigation is undertaken in a culturally appropriate manner and to allow for truly innovative thought. Numerous non-Indigenous scholars have tried (and failed) to describe Indigenous cultural values, using knowledge developed from non-Indigenous (Western science) perspectives; it is time to allow for new perspectives (which may properly blend Indigenous and Western knowledge) that may allow for significant scientific breakthroughs.

The (annual) benefit estimates provided were calculated by combining information relating to:

- The monetary value of current benefits (annual measures)
- Predictions of coral condition—based on a simple Reef condition index (RCI)
- Predictions about the likely sensitivity of benefits to changes in Reef condition index.

Data deficiencies abound, so the estimates of current and projected benefits in this report are—like all estimates—far from perfect. We do not have the resources to collect data for or build a model that could appropriately estimate benefits. We have instead developed a systematic evaluative framework. We do not have a perfect system for collating values, so we have selected that which we assess as 'best', given the circumstances. We do not have perfect information about current values, so we have used 'best' estimates. We do not have perfect methods for predicting the response of benefits to changes in Reef condition index, so we have developed simplistic functions to do so.

As such, our estimates do not describe the total 'value of the Reef', or of all ecosystems within the Great Barrier Reef World Heritage Area. Neither do our estimates adequately measure all direct and indirect impacts of reef intervention activities on all ecosystems, or account for interactions between and within related ecosystems and human systems. If it were possible to include all benefits associated with all ecosystems then benefit estimates would be larger, perhaps substantially. We suspect a complex systems model, able to account for interactions between and within systems, would also be likely to generate benefit estimates much larger than those presented here.

Those points aside, we are unaware of any other data/research that is less imperfect for these purposes. We have done our best to make assumptions transparent, and to design our 'model' (more accurately described as a system for collating benefits including equations to project benefits into the future) so it can be updated and improved as knowledge is improved. Absolute estimates relating to a specific value at any point in time should be treated with caution; however, the comparative values are likely to be relatively robust, and provide particularly useful insights.

Methodological overview

Assessing benefits is a non-trivial task: the challenges we face are not just attributable to lack of resources, need for more time, or better data. To quote from one of our reviewers: "*As we increase our understanding of the complexities of socio-ecological systems, the limitations of both the theoretical constructs and methodological tools at our reach are becoming more apparent.* This relates to epistemological limitations beyond [our] capacity ... to address".

This study identified a framework for aggregating value-estimates to assess multiple market and non-market ***impacts*** on broad classes of benefit streams relevant to the Reef (the Common International Classification of Ecosystem Services (Haines-Young & Potschin, 2012)). It used this framework to guide the compilation of information for use in the overall assessment. For each benefit listed in the CICES, we asked: *Is it relevant to the Reef? Is it likely to be impacted by changes in coral condition (i.e. by reef interventions)*? We selected benefits for which the answer to both was yes. Grouped into four broad categories, these were:

- Material benefits (Termed provisioning benefits in the Millennium Ecosystem Assessment/CICES)
  - Commercial fishing
  - Coral harvesting
  - Medicinal option values (Rreflecting some biodiversity/gene pool values)

- Regulating services
  - Storm surge protection

- Non-material (cultural) benefits
  - Tourism
  - Recreational fishing
  - Learning/inspiration
  - Non-use values
  - Indigenous cultural values

o Relational and other values associated with complex social goods.

Research that provided information on the monetary value of Reef-dependent benefit streams, and the likely impacts of climate and/or other changes/interventions on those benefit streams were identified.

We populated the framework with relevant empirical estimates to:

- Identify information gaps and estimate current values (where possible)
- Develop simple formulae that use current value estimates and information about likely responses of benefits to changes in reef condition, to generate estimates of the potential benefit of different interventions.

This study devised a system for converting outputs from CSIRO's coral and crown-of-thorns starfish simulation model (CoCoNet) to indicators of coral condition.

We selected a subset of scenarios (reef interventions under different climatic conditions) and used the associated Reef condition indexes to predict benefits for each scenario until 2075.

Although Reef condition indexes can be calculated at reef-scale, many benefit streams are inherently a-spatial and do not map to specific locations; other benefit streams are only relevant at larger spatial scale (e.g. tourism regions). We do not, therefore, attempt to report benefit estimates at reef-scale, instead amalgamating all into a single estimate (per annum). Figure 1 provides a visual representation of the work undertaken, identifying the general methods used to estimate the economic benefits of specific interventions.

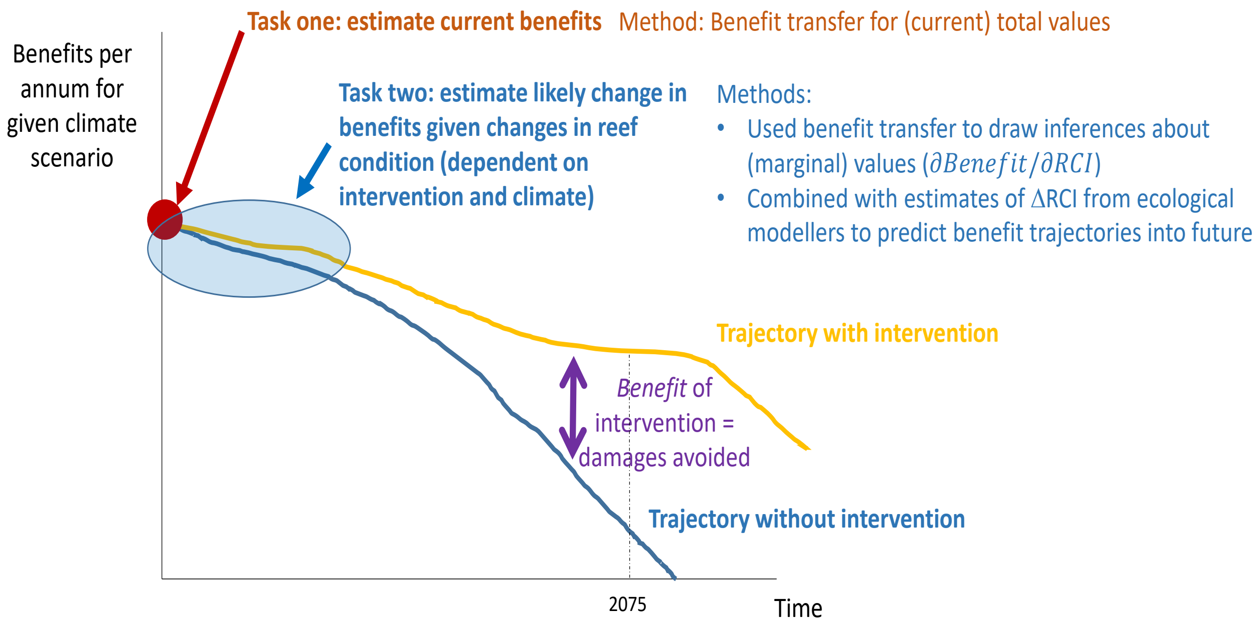

Figure 1: Stylised representation of benefit streams over time with and without interventions, and the steps taken to generate estimates. The gap between trajectories provides an estimate of the benefit of an intervention, formally: the damages avoided.

Results

Our projections and estimates, summarised in the table below, were sensitive to the assumptions (and data) underpinning them. We used relatively conservative assumptions when estimating current benefits, and when estimating the fall in benefits that could be associated with a fall in Reef health (the percentage fall in benefits were always less than the percentage fall in Reef condition index). As such, when generating benefit estimates, we erred on the side of caution, aiming to ensure estimates understated, rather than overstated, true values (by, for example, using low prices and omitting values if their inclusion gave even the slightest chance of double counting). Similarly, when estimating benefits, we assumed there was just one intervention strategy undertaken for the entire 60 years. This did not allow for more adaptive implementation strategies (where, for example, on intervention could be pursued for several years, with another brought online later), which could yield much greater overall benefits of RRAP.

Our estimates thus represent a minimum, or 'benchmark' for use in the cost benefit analysis (**T9—Cost Benefit Analysis**). We underscore the importance of using sensitivity analysis to explore the extent to which data deficiencies (uncertainties, ambiguities, unknowns and unknowables) influence final estimates, noting that was also done in the cost-benefit assessment. If, when compared with the costs of the interventions, the overall net present value was positive in a range of different situations, there should be no doubt for decision-makers that the interventions would be welfare-enhancing. If, on the contrary, net present value was close to zero or negative, no conclusive argument could be made, and a more in-depth investigation, involving collection of primary data, may be needed to improve the accuracy of estimates.

Table 1: Summary of estimates: current values and predicted benefits of RRAP – mean (and range), by benefit stream.

Benefit stream	Current value in $M p.a. (range)	Mechanisms through which RRAP could impact	Predicted undiscounted* damages avoided via RRAP, mean $M p.a. added to 2075 (range)		Considerations
			RCP 8.5 (14 scenarios)	RCP 2.6 (6 scenarios)	
1. Commercial fishing	5.6 (2–8)	Maintenance of habitat and complexity	66 (8–111)	67 (50-78)	Some adaptive capacity (location)
2. Recreational fishing	10.6 (5–15)	Maintenance of habitat and complexity	11 (0–16)	6 (5-6)	Moderate adaptive capacity (location, target species)
3. Coral harvesting	0.25 (0.02–0.60)	Maintenance of habitat and species	3 (1–6)	6 (5-7)	Some adaptive capacity (location and species)
4. Medical options for the future	174 (20–1000)	Support of biodiversity	2209 (254–3608)	2557 (1833–3028)	Biodiversity most important
5. Coastal protection	26 (10–50)	Support of reef structure	439 (67–791)	612 (416-725)	Choice of coral species would be critical
6. Reef tourism	1543 (1200–1800)	Biophysical state and 'image'	6214 (999–10 517)	4877 (3240–5705)	Adaptive capacity within regions; image crucial; worldwide competition
7. Non-use (bequest, existence, identity)	1015 (490–1200)	Holistic, including 'image'	3382 (647–5192)	2409 (1782–2835)	Rarely place specific; perceptions crucial
8. 'Placeholder' Indigenous cultural values	More than 629 (179 to more than 2000)	Unknown, but likely holistic	5332 (1045–8887)	4450 (3340–5157)	Highly place specific. No capacity for substitution
All benefits (added)	**3404 (700–8000)**		**17 657 (3021–29 128)**	**14 985 (10 672–17 522)**	

* undiscounted damages, noting that insights from the literature suggest the longer the relevant time horizon, the lower the rate should be. T9—Cost Benefit Analysis includes a sensitivity of estimates, using different discount rates.

3 INTRODUCTION, BACKGROUND AND OBJECTIVES

This report describes how socio-economic data were compiled using the Common International Classification of Ecosystem Services (CICES) framework and combined with estimates of Reef Health (formally, the Reef condition index (RCI)) to generate estimates of the benefit of various reef restoration interventions in different climate scenarios (per annum until 2075), for use in **T9—Cost Benefit Analysis**. This assessment focuses on:

- A small geographic part of the entire Great Barrier Reef World Heritage Area—specifically, the 24,000 km^2 of coral reefs within the much larger 324,000 km^2 world heritage area—likely to be affected by reef intervention activities.
- The benefits that accrue to Australian residents and tourists who visit the Reef.
- Eight of ten, identifiable benefits (examples of ecosystem services) associated with this Reef area.
- 20 of the 44 intervention/climate scenarios evaluated by the ecological modellers—in all cases assuming just one intervention for the entire 60 years, without allowing for more adaptive implementation strategies (where, for example, one intervention could be pursued for several years, with another brought online later).

The research described here does not pertain to the costs (tangible or otherwise) of undertaking intervention activities.

3.1 Terminology

Different people attach different meanings to the word ‘value’. Social psychologists, for example, are unlikely to associate the word with money. Instead they are more likely to associate the word ‘values’ with individual and social norms. Some people think of the word ‘value’ in purely monetary terms (e.g. as the price or cost of a good, or its worth if sold) and many people assume that economists also equate price with value. This is not true. Economists think of value more broadly, acknowledging that something is of value, if it increases the welfare/wellbeing (or, more formally, the utility) of an individual. Many (but not all) economists assume that welfare cannot be properly measured (formally, in cardinal terms), so they often measure the contribution that goods and services make to welfare indirectly – using *income compensations,* and hence money as a metric. For an economist, the word value is thus inextricably linked to welfare/wellbeing – money is just a proxy measure, used in some circumstances. In this report, we use the word ‘value’ as economists most frequently do – noting that something is of value if it is important (and contributes to welfare/utility).

We define:

- A ‘benefit’ as something which makes a positive contribution to welfare (utility)
- A ‘cost’ as something that detracts from welfare (utility): and,

we are primarily interested in the contributions the Reef makes to human wellbeing and refer to those contributions as BENEFITS. The phrase *benefit stream* is used to refer to a stream (flow) of benefits incurred over time.

3.2 Background

3.2.1 Core objective

Our core objective is to generate quantitative estimates of the potential benefits of various RRAP interventions, for use in **T9—Cost Benefit Analysis**. This analysis requires costs and benefits to be measured using a common metric (money), so we estimate the monetary value of core benefits.

Using money to measure outcomes of RRAP interventions and reef-related benefits is a non-trivial task because of the scale, diversity and complexity of the Reef and surrounding environs. With a total length of Total length of ≈ 2300km, the Great Barrier Reef World Heritage Area covers an area of ≈ 348,000 km^2 – although the reef extends north beyond the World Heritage Area boundaries, into Torres Strait. The Great Barrier Reef World Heritage Area is larger than the UK, Switzerland and Holland combined. The area is composed of 14 coastal and marine ecosystems (GBRMPA, 2012), is biophysically diverse and generates a diversity of benefits for diverse groups of people (Table 2). Our core area of interest is on the Reefs (shown in Figure 2), which themselves, over an area of more than 24,000km^2.

Figure 2: The Great Barrier Reef World Heritage Area.

Complex spatial and temporal relations between and within the biophysical and human sub-systems associated with the Great Barrier Reef World Heritage Area, mean that changes in one part of the linked social-ecological system may invoke changes in other parts of the system at different places at different times. Our understanding of these relationships and how they might change under different climate scenarios is limited (Bohensky et al., 2011; Evans et al., 2011).

Table 2: Physical descriptors and indicators of biodiversity in the Great Barrier Reef World Heritage Area. Data compiled from GBRMPA (2014) and De Valck and Rolfe (2018).

Physical descriptors	Indicators of biodiversity	Groups of people 'benefiting'
Islands (comprising ≈ 1% of GBRWHA) ≈ 2600 km^2 Mangroves ≈ 24 099 km^2 Coral reefs ≈ 34 864 km^2 Seagrass 61% seagrass, shoals or muddy seabed (< 200m deep) 15% continental slope (200-1000m deep) 16% deep oceanic waters (>1000 m deep)	> 1500 species of fish ≈ 400 species of coral ≈ 4000 species of mollusc, ≈ 240 species of birds, + great diversity of sponges, anemones, marine worms, crustaceans, and other species.	≈ 70 Aboriginal and Torres Strait Islander Traditional Owner groups with connections to the Reef ≈ 1 million people who live in the 424,000km^2 catchment ≈ 2.3 million people who visit the reef each year ≈3 million people who visit islands in the Great Barrier Reef World Heritage Area each year (some residents of the catchment) Other national and international people who may never visit the region, but nevertheless derive benefits from it • Tangibly (e.g. by eating fish caught in the Great Barrier Reef World Heritage Area, by earning money from tourists traveling through their cities to get to the Reef, by enjoying pictures of the reef) &/or, • Intangibly (e.g. by simply 'knowing it is there').

Current non-market valuation methods, while markedly more sophisticated than they were 150 years ago, struggle to monetise such a diverse array of benefits at such a large geographic and social scale. We do not understand the complex inter-relationships between and within the human and biophysical sub-systems. We lack information about the economic 'value' (expressed in monetary terms) of numerous benefits; we lack information about the way in which those benefits are likely to change in the future (under different climate scenarios) and we lack information about the way in which interventions described above could alter projected benefit trajectories.

We also lack the resources to build a model that can adequately predict impacts (a complex coupled systems model is likely required), so we instead, devise a systematic framework for thinking about the whole of system (economic) benefits of reef restoration/adaption work. We compile insights from the literature to (wherever possible) populate the framework with data that allows us to estimate current benefits and draw inferences about the likely impact on those benefits of reef interventions. This generates information that is empirically useful (even in the presence of significant knowledge gaps). Moreover, the framework developed to generate empirical insights can be updated and refined with new knowledge and information as and when it becomes available. The research thus improves our overall understanding of various economic benefits of the Reef and of the benefit of different numerous reef-related interventions, while providing a system for thinking about the benefits of intervention that can be adapted and improved with time.

3.2.2 Measuring benefits as damages avoided

The framework we devise is adapted from one that was developed by the Centre of Excellence in

Biosecurity Risk and Analysis (CEBRA) for generating whole-of-system estimates of the benefit of Australia's biosecurity system. The system evolved from a series of related investigations, associated with CEBRA project 1067A, and is reported on in Spring, Dodd, and Kompas (2017), Dodd et al. (2017) and N. Stoeckl, Kompas, and Dodd (in review). The CEBRA system is capable of generating a whole-of system estimate of the economic benefit of biosecurity measures capable of mitigating multiple impacts of multiple threats on multiple assets. It was designed to consider both the market and non-market economic consequences of biosecurity threats and the benefits of measures undertaken to reduce those threats. It also allows one to generate benefit estimates in the presence of considerable information deficiencies (unknowns, uncertainties, and ambiguities).

We use that same conceptual approach here, adapting it so that it can be used to consider the market and non-market consequences of climate change on the reef and of measures/interventions undertaken to sustain or improve reef condition. We focus on problems attending the estimation of economic benefits—abstracting from the problems of assessing (a) the probability of *climate change impacts* and (b) the efficacy of reef intervention efforts. We do this by first sourcing data that allows us to assess the current value of reef-related benefits, and secondly sourcing information that allows us to draw inferences about the way in which those benefits might respond to changes in reef condition. The ecological modelling team generates predictions of coral condition under different climate-change scenarios with different intervention strategies. We combine information on current benefits, reef condition, and the link between benefits and reef condition to estimate benefit streams (trajectories) given a set of Reef condition indexes. By comparing trajectories associated with different Reef condition indexes that are associated with different interventions, we are able to estimate the benefit of that intervention—formally, the damages avoided or possibly additional benefits where interventions improve reef condition relative to current state. By comparing trajectories associated with different Reef condition indexes that are associated with different interventions, we are able to estimate the benefit of that intervention—formally, the damages avoided, or possibly additional benefits where interventions improve reef condition relative to current state.

When generating benefit estimates, we have erred on the side of caution – aiming to ensure that our estimates under, rather than over, state true values (by, for example, using low prices and omitting values if their inclusion gives even the slightest chance of double-counting). As such, our estimates likely represent a minimum, or 'benchmark' for use in **T9—Cost Benefit Analysis**. If, when compared with the costs of the interventions, the overall net present value is positive, there should be no doubt for decision-makers that the interventions are welfare enhancing. If, on the contrary, net present value is close to zero or negative, no conclusive argument can be made and a more in-depth investigation, involving the collection of primary data, may need to be carried out to improve the accuracy of estimates.

3.2.3 Geographic focus

We focus on the 24 099 km^2 of coral reefs that sit within the much larger Great Barrier Reef World Heritage Area.

> ***Estimates of the value of current benefit streams would be larger (perhaps substantially) if all other ecosystems within the Great Barrier Reef World Heritage Area were included in this assessment. Our estimates of the likely loss of benefits with climate change would also be larger.***
>
> ***It is likely a complex systems model, that could account for interactions between and within systems, would generate benefit estimates much larger than the benefit-***

estimates in this report.

When imposing this geographical restriction, we assumed that the benefits associated with non-reef ecosystems, such as mangroves and islands, would not be directly impacted by reef restoration work (such as out-planting of warm-adapted corals – referred to in sections of this report as 'enhanced corals'). If that is a valid assumption then our geographic restriction, while impacting 'total' benefit estimates or estimates of the impact of climate change, will not affect estimates of the benefit of reef interventions.

If, however, RRAP intervention generates benefits for non-reef ecosystems, then our estimates of the benefits of RRAP will understate true values.

3.2.4 Social focus

We identify the benefits the Reef generates for people. Beneficiaries considered include:

- Residents: People who live within the Reef catchment—including the Torres Strait.
- Traditional Owners: People with traditional rights and links to the land or sea-country in the Great Barrier Reef area. They may not be residents of the reef catchment.
- Reef tourists: People who visit the Reef (a subset of those who visit the catchment, since many visitors come to the area, but do not travel to the Reef).
- Reef fishers (commercial, recreational, or traditional): People who fish within the boundaries of the Great Barrier Reef World Heritage Area or in Torres Strait.
- Other Australian stakeholders: People who do not fall into any of the above categories, but nevertheless derive benefits from the Reef. We divide these into other Queenslanders and other Australians, since research indicates statistically distinguishable values for these groups (Rolfe & Windle, 2012).

We do not include benefits flowing to people who live outside Australia. The information we are providing is for use in a cost-benefit analysis which seeks to assess the (Australian) business case for RRAP. Although benefits accrue to people throughout the world, the costs of restoration and adaptation interventions fall upon the Australian people. We restrict our benefit estimates to Australian residents only – although it is theoretically more correct to include ALL benefits (to whoever they accrue) in cost-benefit analysis studies. Data deficiencies prevent us from doing otherwise.

If world beneficiaries were considered in our assessment, estimates of both the current value of benefit streams, and the impact of climate change and/or reef restoration activities on those values, would likely be much larger.

3.2.5 Benefits considered

By focusing on a small set of benefits, we run the risk that omitted benefits are assigned an implicit value of zero, potentially prioritising interventions that generate the most easily measured benefits, rather than the most benefits *per se* (Figure 3).

Figure 3: Prioritising expenditure on different RRAP measures with unknown costs and benefits. In this hypothetical example, there are both known and unknown (unmeasurable) costs and benefits associated with two restoration/adaption measures (A & B). Measure A generates highest known net benefits and would thus be given highest priority. If one were able to accurately assess all costs and benefits, measure B would, instead be prioritised.

Historically, a significant amount of research effort has considered the market-related tourism and commercial fishing values of the Reef (section 4.3), with much recent work also considering what economists term non-use values (bequest, existence and iconic) – a subset of what is elsewhere commonly referred to as non-material benefits. But there is a relative scarcity of information that quantifies (in monetary terms) the benefits of many other crucially important goods and services (benefits) associated with the Reef. Significant information gaps relate to some types of provisioning services, regulating services, relational values, and the benefits associated with complex social goods – a vitally important subset of which includes Indigenous cultural values, dealt with separately. Scarcer still, is information about the way in which current benefits are likely to change over time under different climate scenarios and about the way in which reef restoration and adaptation projects might alter projected benefit trajectories.

Not only does our current state of knowledge about the monetary value of benefits associated with the Reef have significant information gaps (N. Stoeckl et al., 2011) but the related body of knowledge comprises numerous individually constructed research projects, papers and reports that provide unrelated information 'snap-shots'. There are, for example, individual studies that tell us how particular corals might be affected by rising sea temperatures; or about the way in which tourists might respond to reef degradation in a specific part of the Reef, but few studies provide big-picture overviews or simultaneously assess multiple benefit streams. A recent study by Deloitte Access (O'Mahoney et al. 2017) sought to estimate some of the tourism, recreational and non-use values of the reef, De Valck and Rolfe (2018) considered changes to water quality on tourism, recreation and commercial fishing values and Stoeckl et al. (2014) assessed a wide range of benefits associated with the Reef. Large, cohesive bodies of work that consider multiple Reef benefits or threats to multiple Reef -benefits assets (be they biophysical or socio-economic) are, most often, conceptual or qualitative in nature. Oxford Economics (2009) sought to estimate the economic costs of coral bleaching for the Reef, but we are unaware of any research that has generated quantitative estimates of the potential economic impact of the multiple manifestations of climate change in the presence and absence of reef restoration/adaption projects, on the numerous values of the Reef.

Relevant information deficits can be loosely grouped as follows:

1. Missing information—there are countless unknowns (particularly about the costs and benefits of non-market impacts)
2. Limited knowledge and resources—we do not know how to measure some types of benefits (Stoeckl et al. 2018). Even if we had the knowledge and tools to adequately assess the potential costs and benefits of each individual climate-related threat and restoration/adaption measure, it would be prohibitively expensive to assess them all (Bowen, Chesson, Mazur, & Buetre, 2012).
3. Missing framework—we do not have a perfect system for compiling and/or aggregated independently-generated information. Complex inter-relationships between and within various parts of the biophysical and human systems mean the value of the whole will not generally equal the sum of its parts (section 4.2). Care must be taken when adding information collected from unrelated studies.

To minimise chances of prioritising activities that generate most measurable (rather than simply 'most') benefits, we have deliberately chosen to start by collating research within an internationally recognised framework for categorising environmental benefit streams (section 4.2.1). That there is a need to be systematic when selecting benefits for inclusion in broad-scale ecosystem assessments is highlighted by Boithias et al. (2016), who seek to identify the primary, and most significant sources of uncertainty in large-scale ecosystem assessments. They conclude that it is the number of ecosystem services considered and the associated number of benefits within each service that contribute most uncertainty in valuation exercises.

We consider ten different benefit streams (section 4.2.1). Data deficiencies mean that it is only possible to generate monetary estimates of the 'value' of eight benefit streams – some with more precision than others. **If we were able to measure and include all benefits, estimates of current values, and of the likely impact of climate change and/or restoration activities on all benefits would be larger.** We are, at this stage, unable to fill all gaps, but our approach identifies areas in need of future research.

3.3 Report structure

The remainder of this report is structured as follows:

Section four, Methods, is divided into sub-sections.

In section 4.1, we describe various techniques and issues relevant to the general problem (of generating monetary estimates of the benefits associated with a large ecosystem). We begin with a very brief history of the development of literature on non-market (environmental) valuation. We then describe existing non-market valuation methods, providing examples of their use in reef/climate change/restoration and adaption relevant literature (Appendix B). We identify core constraints facing those interested in valuing a full suite of benefits – noting that large scale assessments do not generally have the budget to assess all benefits so must draw insights from studies undertaken elsewhere. We briefly discuss the use of benefit transfer – a technique for transferring empirical estimates that have been generated in one region/context to another, which we use in this assessment. We describe various frameworks for compiling transferred estimates, selecting an internationally accepted one: the Common International Classification of Ecosystem Services (CICES, Haines-Young & Potschin, 2012).

In section 4.2, we discuss logistic/operational issues relevant to geographic and social/environmental scale that must be considered before undertaking this large-scale assessment. We use the CIES to guide selection of benefits for inclusion in our assessment. We note that benefits accrue to numerous different types of people (businesses, consumers, individuals with no financial or physical connection to the reef), located in different parts of the world, highlighting the crucially important spatial dimensions of the problem. The data required to assess those benefit streams is, however, either not collected at all, or collected by different agencies, often at different times, and at different geographic scales. This complicates the estimation problem. We are not in a position to correct the temporal and spatial mismatches in data sets so instead work with whatever data are available, at the smallest (reliable) geographic scale, for the most recent year in which data are available for most benefits (2016).

Section 4.3 is divided into ten sub-sections; one for each benefit. In each sub-section, we discuss literature relevant to it, where possible using insights to generate (1) estimates of the current monetary value of each; and (2) equations that describe the way in which benefits are likely to respond to changes in Reef condition indexes.

Section 4.4 identifies the relevant scenarios selected for assessment.

Section 5 presents estimates, and a subset of projected benefits (raw data were delivered to Aurecon, who undertook the cost-benefit analysis, in excel spreadsheets for use in their larger, cost-benefit analysis). This section also includes a short synthesis/summary.

4 METHODS

4.1 Review of general valuation literature

4.1.1 Historical context

Although the economic consequences of change are often described in monetary terms, economists have long held that price is not synonymous with value – to wit the fact that numerous non-priced goods are necessary preconditions for life (e.g. water) and that numerous other non-priced goods serve to enhance life's quality (e.g. aesthetically pleasing vistas). Those measuring the economic consequences of change thus, invariably, need to look beyond market price.

Some of the first economists to give serious consideration to the 'valuation' issue were Mills and Marshall (late 1800s), who cemented the concept of *utilitarianism* within mainstream neoclassical economics. Although the concept of 'utility' has various contextual meanings, for most economists, utility represents the individual satisfaction gained through the consumption of a good or service. For an economist, measuring the consequence of change (which could be a change in the condition of the Reef) thus involves quantifying the impact of change on an individual's utility.

In the 1930s some of the most influential economists of the time—namely, Irving Fisher and Vilfredo Pareto—successfully argued that utility could not be measured in a way that facilitated meaningful interpersonal comparisons (Kristoffersen, 2010). This somewhat complicated the task of attempting to assess the economic consequences of change, since it meant that the 'consequence' of interest (the effect a change has people's welfare/utility) could not be measured directly. The problem did not prevent progress for long. Hicks (1939) demonstrated that one could measure impacts using income-equivalent compensations (Figure 4)[1].

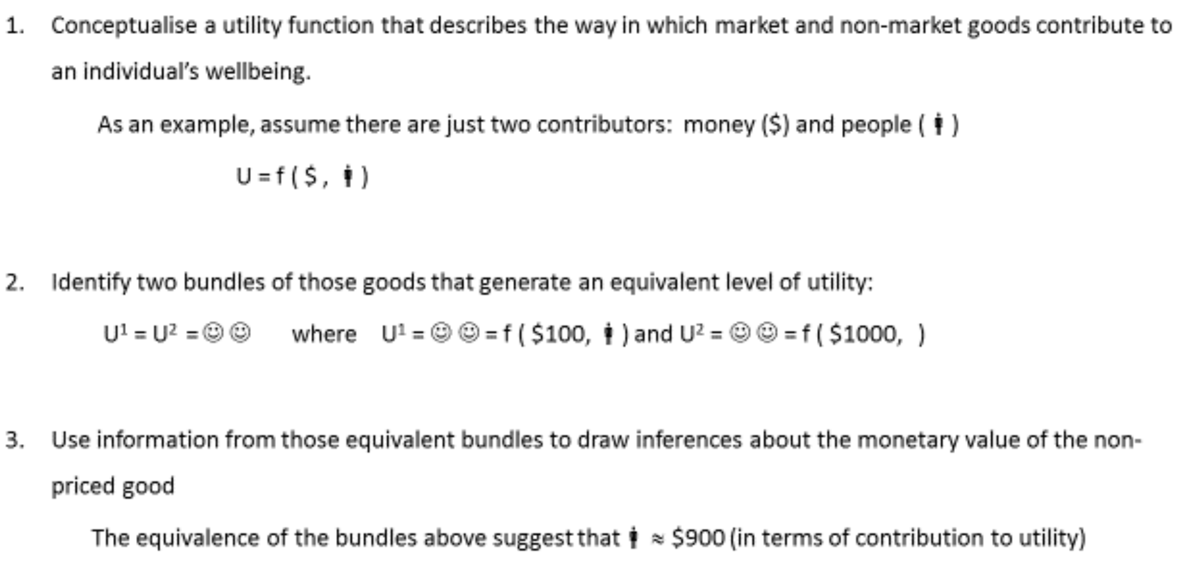

Figure 4: Measuring the value of a good (in terms of its contribution to utility) when utility cannot be measured.

Although economists have long considered value to be inextricably linked to utility, it was, arguably, the Millennium Ecosystem Assessment (MEA, 2005), which brought such issues to the fore. Specifically, the MEA drew attention to the contribution that ecosystems make to human wellbeing by

[1] This works because the value of a good is inextricably associated with its contribution to utility: one can thus assess the value of a non-priced good (of the consequence of changes to a non-priced good) by comparing its contributions to utility with the contribution of, say income.

providing what is termed *ecosystem services.* The terms 'wellbeing' or 'human wellbeing' are used in various disciplines – each attaching subtly different meanings. Common to all, however, is the sense that wellbeing is a holistic concept with both subjective and objective dimensions relating to people's overall quality of life and factors affecting it (Diener, Suh, Lucas, & Smith, 1999; Stutzer & Frey, 2010). *Wellbeing* can thus be thought of as being conceptually equivalent to the economist's notion of utility, and individual welfare.

In recent decades an increasing vocal group of behavioural economists have argued that wellbeing (utility) is directly measurable (Brereton, Clinch, & Ferreira, 2008). If it is also possible to make intra- and inter personal welfare comparisons (Kristoffersen, 2010), then it is theoretically possible to estimate a utility function directly. This suggests that it is no longer necessary to rely solely on income-equivalent compensations to draw inferences about the value of non-market goods: as briefly discussed below.

4.1.2 Current methods

Over the last 150+ years, economists have developed numerous non-market valuation tools (Bateman et al., 2002; Getzner, Spash, & Stagl, 2004). These techniques are briefly summarised in Appendix B, which groups valuation methods into four: the first three, based on the traditional neoclassical premise that welfare (utility) is only measurable in ordinal terms; the fourth assuming utility can be measured cardinally[2].

Not all of these methods can be validly applied in all settings (just as a hammer is well suited to the task of nailing but is rarely the tool of choice if cleaning windows). Techniques that use market prices (e.g. changes in the value of output, replacement cost approach) are not able to provide information about the value of goods and services that are not traded in the market. Consequently, market-price approaches cannot be applied to estimate things like existence and bequest values; they also struggle to provide information about the value of goods that are only loosely connected to the market. Revealed preference approaches circumvent some of the problems associated with market-based approaches in that they do not require goods to be exchanged in the market. But they do require, at minimum, a link/connection between the environmental good or service of interest and the market (e.g., house prices and views of the ocean). If this connection cannot be established, one cannot apply these techniques. With careful survey design and data analysis, stated preference approaches are theoretically capable of estimating the monetary value (as an income compensation) of any good or service – even if no direct, or indirect connection between it and other markets can be established.

That said, imperfect information and uncertainty can make it difficult to use stated preference approaches in all settings (Fernandez, Stoeckl, & Welters, 2019). This is because of several crucially important assumptions that underlie them, including that respondents are able to:

1. Assess their welfare (*utility)* in the status quo.
2. Assess their welfare (utility) in hypothetical circumstances.

[2] Cost Benefit Analysis and assessments of the Social Return on Investment (SROI) are sometimes referred to as non-market valuation methods. Strictly speaking, they are not. Rather, they are structured ways of aggregating monetised data about benefits and costs – weighting them against each other according to specific rules (e.g., including discount rates). A rigorous cost-benefit analysis or SROI analysis should include monetised estimates of all benefits and all costs associated with the project/program being evaluated. Since many benefits and costs are not directly associated with the market, both cost-benefit analysis and SROI require researchers to undertake non-market valuation exercises (using techniques like those listed in the table below) to generate estimates of relevant costs and benefits, for use in the wider analysis. Cost-benefit analysis and SROI studies thus often entail numerous non-market valuation activities, with 'value' estimates aggregated into a single value (e.g., the net benefit, or the 'return' on investment).

3. Compare (1) with (2), converting the difference into a monetary equivalent, to determine how much they would (or would not) be willing to pay, to ensure the hypothetical situation occurred (instead of the status quo).

There is a well-established literature that provides guidance on the best way to construct questionnaires and analyse data to achieve the most accurate value estimates (Bateman et al., 2002). But – as for all empirical techniques – the guidelines cannot guarantee that final estimates will be unbiased representations of true values – particularly when information is uncertain, and when evidence suggests that people do not always behave in a manner that maximises expected utility (Kahneman & Tversky, 2013; Simon, 1955).

Importantly, this problem attends all neoclassical non-market valuation methods: if people lack perfect information about the true costs and benefits of outcomes, their market behaviours (be they based on real or hypothetical markets) will not reflect true costs and benefits, so will not allow analysts to use markets (real or hypothetical) to draw inferences about the true value (in terms of income compensations) of related goods and services. Just as imperfect information constrains the operation of market goods (Akerlof, 1978), so too does it constrain the ability of non-market valuation methods (which rely on observed market prices, prices from related markets, or prices elicited in hypothetical markets) to reflect true values. That this is a problem when using observed markets to assess the value of regulatory services or hypothetical markets to assess non-use values is well-established (Norton, Costanza, & Bishop, 1998); the empirical implications of this problem could also be substantial for valuation methods that rely on observed data from related markets (Farr & Stoeckl, 2018).

Although also not problem-free, the life satisfaction approach (sometimes called the subjective well-being approach) circumvents some of those problems by only asking respondents about their subjective well-being (assumed to be a proxy for utility) (Dolan & Metcalf, 2008; Fujiwara & Campbell, 2011), and then regressing that measure of wellbeing against factors thought to affect it. The life satisfaction approach does not require respondents to be able to ‘look into the future’ and/or assess their well-being in different scenarios[3], so avoids problems of imperfect information, and does not require one to assume utility maximising behaviour. But it does require one to assume that the wellbeing (welfare) implications of past changes, adequately approximate the welfare implications of similar future changes. As for other non-market valuation methods, there are also numerous empirical hurdles for applied life satisfaction researchers to overcome if wishing to generate unbiased estimates of true values – not the least of which relates to the problem of identifying the components, and relationships between parts of the utility function, which are unlikely to be (additively) separable (Carbone & Smith, 2013; N. Stoeckl, Farr, Larson, et al., 2014).

4.1.3 Constraints and knowledge gaps pertinent to valuation

The valuation tools developed by economists over the past 100 years are differentially suited to assessing particular types of goods and services (N. Stoeckl et al., 2018), with two key issues particularly relevant to the task at hand.

First, current valuation methods are good at highlighting instrumental and intrinsic benefits that accrue to individuals: but tools that are able to estimate relational values – those that “pertain to all manner of relationships between people and nature, including relationships that are between people but involve

3 Additional benefits include the fact that these approaches do not impose a significant cognitive burden on respondents (a problem common in contingent valuation and choice modelling studies), do not force trade-offs, and do not require one to assume the existence of an underlying ‘market equilibrium’.

nature (e.g. a relationship of impact via pollution, which is mediated by a watershed)" (Chan et al., 2016) – are relatively less developed. Related to that point, methods for estimating values that accrue at a collective (social) level, rather than to individuals (N. Stoeckl et al., 2018) are also somewhat less developed – and are less accepted within government institutions than, for example, processes such as cost-benefit analysis.

Schulz and Martin-Ortega (2018) argue that existing methods of considering human-environment systems have the capacity to measure relational values and (Martin-Ortega, Glenk, & Byg, 2017) use a choice modelling experiment to assess the impact (on human values) of peatland restoration (see also, (Glenk & Martin-Ortega, 2018)). The choice models used by these researchers push methodological boundaries by exploring issues of socio-ecological scale and avoiding problems that prevail if attempting to value individual services/benefits and add. As such, they are vastly improving methods for assessing the value of goods and services that generate a complex array of benefits (including, relational values). But data collected in the choice experiments is done so at an individual level, an implicit assumption being that social values can be inferred from the sum of individual values. The value an individual place on a good or service when asked to consider only their own personal preferences may be quite different from the value they place on that good or service if asked to consider the views of (or for) a group. Neoclassical non-market valuation methods (including, but not limited to choice models) are particularly adept at measuring value from the perspective of an individual (panel a, Figure 5); deliberative processes are thought to be better suited to the task of assessing social/collective values (panel b, Figure 5) (Hansjürgens, Schröter-Schlaack, Berghöfer, and Lienhoop (2017), (Himes and Muraca (2018) – and better able to meet the goals of 'fairness' and 'sustainability' than individualist methods – (Costanza et al., 2017).

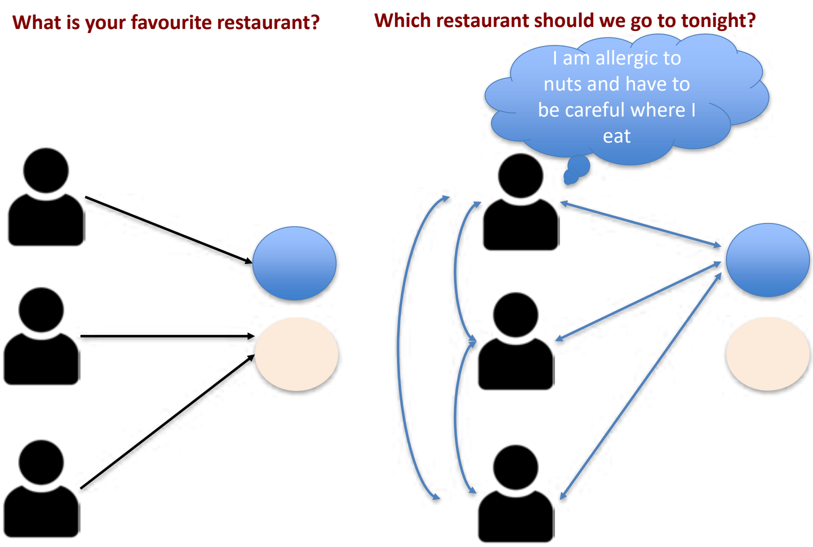

Figure 5: Adding individual choices (left) versus negotiating social choices (right). Most neoclassical non-market valuation methods ask people to express their own preferences and aggregate responses to declare a 'winner' (panel a); this is quite different from asking people to make a choice for the collective good of many (panel b). If people care about each other's preferences, a process which simply aggregates personal preferences will identify different 'winners' than one which allows for negotiated outcomes.

Deliberative approaches attempt to elicit social values by explicitly encouraging discussion amongst individuals (Kenter et al., 2015). The deliberations thus provide a mechanism to reveal relational values that explicitly account for connections between people and assets (Chan, Gould, & Pascual, 2018; Himes & Muraca, 2018). Many deliberative approaches (termed deliberative valuations, by Hansjürgens et al. (2017)) elicit preferences as income compensations – e.g. as willingness to pay. But while monetisation usefully informs social decision-making and allows one to incorporate values within cost-benefit analysis, it is taboo to trade-off some values in monetary terms (Kallis, Gómez-Baggethun, and Zografos (2013), Daw et al. (2015)), commoditising ecosystem services can lead to a long-term problems for biodiversity conservation (Gómez-Baggethun & Ruiz-Pérez, 2011) and over-reliance on monetised values can contribute to the crowding out of complex social goods (Stoeckl et al. 2018). Deliberative approaches which elicit preferences in other ways (termed deliberative institutions, by Hansjürgens et al. (2017), thus offer themselves as an attractive alternative in some settings. That said, methods which seek to identify social preferences by first asking individuals to rank preferences (without using money as a metric), and second aggregating individual preferences to generate a social ordering, are vulnerable to criticism by neoclassical economists on (Arrow's) theoretical grounds (Kenter et al., 2015). The lingering shadow of Arrow's Impossiblity thus makes it difficult for approaches that do not measure values using money as a metric to gain traction as rigorous alternatives to the norm – although current research suggests that this Arrow's impossibility may not hold when there is (a) altruism (i.e. at least some individuals care about each other), and when there is opportunity to share information about each other's preferences, as is the case for deliberative processes (Grainger & Stoeckl, in review). Evidently, the core challenge when moving from individual to group assessments, is to allow for information exchange, suggesting that almost all existing neoclassical non-market valuation methods, could – in theory – be readily adapted to better assess social values (choice of restaurant for a group of friends, rather than for an individual) if transformed from a one-step to a two-step evaluative process, sharing information between steps one and two.

Second, despite the fact that "single-species [threat] oriented management philosophy has been increasingly replaced by an ecosystem approach" (Schlueter et al. (2012)), whole-of-system studies that simultaneously consider numerous impacts, to numerous stakeholders, of numerous changes (be they climate-related threats, recovery/adaption measures or something else) are, for the most part, qualitative/conceptual. Most empirical studies are small in scale, in that they focus on a single change associated with a single event (e.g. one cyclone, one bleaching event), and only estimate costs and benefits for a subset of people/actors/industries (e.g. on tourists, on commercial fishers, or on the tourism industry). This is largely because available analytical methods for estimating economic 'value' have been developed using microeconomic tools that have a partial equilibrium focus (section 4.1.1): they have been explicitly designed to assess the monetary value of (changes in) goods and services that have been very narrowly and precisely defined (e.g. the value of improving water quality from that which has x percent nitrogen, to that which has y percent nitrogen; the value of an extra apple) and are not generally suited to whole-of system valuation (the collective value, to all residents, businesses, communities and tourists of a deteriorating or improving reef)[4]. Those who are interested in assessing the monetary value of multiple non-market impacts of any change (be it related to climate change, reef restoration or something else) thus invariably need to undertake multiple non-market valuation exercises, and aggregate the individual estimates obtained.

It is costly to undertake non-market valuation exercises, so whole-of system empirical valuations almost always involve benefit transfer, discussed below.

[4] That a single tool is not capable of simultaneously assessing the value of all (changes in) all goods and services, is not a criticism of the tool. A hammer is an extremely useful tool but is not capable of fixing all things; most tradespeople thus rely on using a variety of tools.

4.1.4 Benefit transfer

Benefit transfer is, sometimes referred to as a type of valuation method. Strictly speaking, it is not. Instead, benefit transfer describes the practice of *transferring* valuation estimates that have been generated in one context, to another context (Rosenberger & Loomis, in press). The reliability of estimates reported in a benefit transfer study thus depends, *inter alia,* on the reliability of the non-market valuation studies generating the initial valuation estimates, and also upon the approach taken when transferring estimates – of which there are many (Johnston, Rolfe, Rosenberger, & Brouwer, 2015). Not all of the methods summarised in Appendix B produce estimates that are readily transferrable across sites (Farber et al., 2006).

Resources permitting, it is generally best to estimate values directly (Akter & Grafton, 2010): if benefit transfer is the only option, then one should avoid transferring across regions/situations with markedly different contexts (social, economic, political, biophysical or other). As is the case for most tools/methods there are numerous different ways of implementing the general benefit-transfer principal, including the use of:

1. Unit-value transfers—using a single value (or a simple function, e.g. mean of individual values). For example, if agriculture generates $\$\alpha$ per hectare in surplus in region A, then it is assumed to also generate $\$\alpha$ per hectare of surplus in region B.

   and,
2. Transfer functions

   A. Value transfer function – using the parameters of a value function estimated from a single study, in conjunction with locally relevant data, to 'contextualise' values before transfer – e.g. if the willingness to pay for reef preservation, per visitor in region A = $\$\alpha + \beta$ Income-of-residents$_A$, then the \$ willingness to pay for reef preservation in region B can be estimated at $\$\alpha + \beta$ Income-of-residents$_B$.
   B. Meta-value transfer function – using the parameters of value function estimated from multiple studies, in conjunction with locally relevant data to 'contextualise' values before transfer.

There is much controversy about the best transfer approach and about the best variables to use within transfer functions (Baker & Ruting, 2014). It may be possible to reduce transfer errors by ensuring that transfer functions include socio-economic (Johnston, Besedin, & Stapler, 2017), geospatial (Fitzpatrick, Parmeter, & Agar, 2017) and 'perception' variables (Farr, Stoeckl, Esparon, Larson, & Jarvis, 2016), all of which have been found to influence value estimates. The more different are contexts and/or the less able one is to control for contextual differences, the more important will it be to include sensitivity analysis as part of the transfer exercise (Akter & Grafton, 2010) - using +/- 100 percent when context differs markedly (perhaps even more when there are insufficient data to appropriately parameterise value-transfer functions).

Arguably, one of the most well-known (early) large scale benefits transfer studies was undertaken by (Costanza et al., 1997), when assessing the total value of the world's ecosystems (see also: (Kubiszewski, Costanza, Dorji, Thoennes, & Tshering, 2013; S. Liu, Costanza, Troy, D'Aagostino, & Mates, 2010). Significant compilations of estimates from valuation studies (e.g. Van der Ploeg and De Groot (2010); see also Lantz and Slaney (2005)), have facilitated the growing use of benefit transfer (Richardson, Loomis, Kroeger, & Casey, 2015) – there is even an interactive computer program/model[5] which has transfer functions for recreation, property premiums, and willingness to pay for threatened and endangered species recovery where users can enter values for independent variables, to generate estimates of economic value per household or recreation day (reported in Bagstad, Semmens, Waage, and Winthrop (2013)).

Two examples of benefit transfer studies in the Reef include that of: Asafu-Adjaye, Brown, and Straton (2005) and Oxford Economics 2009. Asafu-Adjaye et al. (2005) did not collect any primary data, so their contribution to knowledge was not so much an addition of new knowledge, but a new assemblage of existing knowledge. The Oxford Economics 2009 study also relied almost exclusively on data collected by other researchers, using unit-value benefit-transfer techniques wherever possible (although they did provide some innovation in that they used data collected by Prideaux and Coghlan (2009)[j] within a TC framework to generate an estimate of the recreation use value of tourism in the Reef catchment). Additionally, they attempted to determine the extent to which the full range of values would change if there were to be a 'complete, catastrophic, and immediate' bleaching event across the entire Reef.

4.1.5 Difficulties assessing benefits in complex systems

Estimating the potential economic benefit of even a single reef recovery/adaptation measure is a non-trivial problem requiring one to first have a solid understanding of biophysical relationships. This understanding allows one to estimate the likely biophysical impacts of measures. Only then, can one use non-market valuation to assess the economic consequences of those changes (DeFries et al., 2005). But recovery and adaption measures do not occur in a vacuum – both their biophysical and socio-economic 'impacts' will depend, interactively and dynamically, on (a) what other biophysical and socio-economic changes are occurring; and (b) how people respond to the full suite of biophysical and socio-economic changes (and the consequences of those responses, which themselves invoke responses). Impact mechanisms are thus numerous, varied, and dynamically inter-related. Some biophysical changes will directly affect the economy, humans and infrastructures – as when, for example, an extreme event which damages the reef also destroys physical and social infrastructures altering adaption options. Other changes will be indirect, operating through the environment or through other parts of the complex system (as when, for example, reef degradation impacts fisheries which affects trade and thus commodity prices, generating feed-back effects elsewhere). If wishing to gain a complete understanding of the economic value of the RRAP it is thus important to consider a wide range of direct and indirect impacts on numerous assets and activities, in addition to socio-economic adaptations. Carleton and Hsiang (2016) highlight the complexities of these types of problems with a simple example, relating to rainfall: the extent to which people 'get wet' (the socio-economic outcome) will depend upon both the amount of rain experienced, and their adaptions (e.g. using an umbrella).

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[5] *The Benefit Transfer and Use Estimating Model Toolkit.*

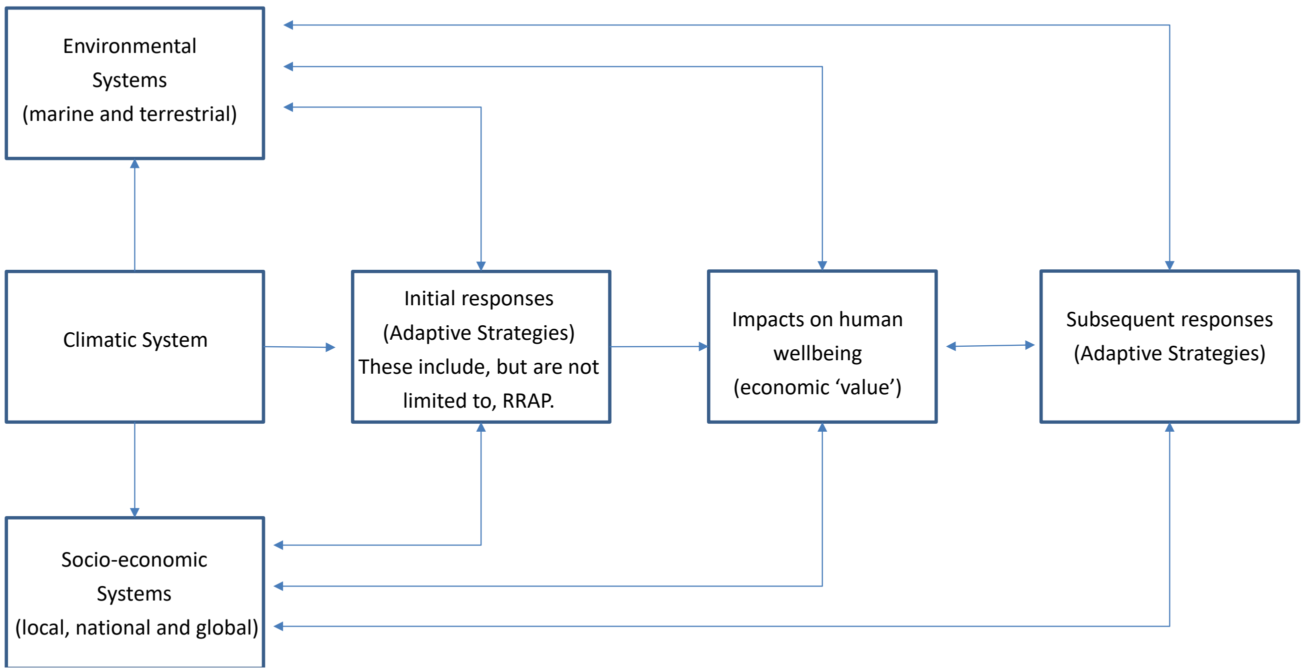

Figure 6: Reef interventions and climate change in context (source: adapted from Stoeckl et al. 2018b).

The empirical challenge of assessing the benefits of RRAP is further complicated by the fact that some consequences will be 'felt' in the marketplace (e.g. altering the prices and/or quantities of goods traded) and some will not. As such, it will be necessary to use at least some non-market valuation methods to adequately assess all impacts. Likewise, some impacts will occur immediately and as a direct consequence of initial changes (e.g. in coral cover), but other impacts will play out, dynamically, over time and in response to other changes occurring in the system. Economists often differentiate between what they term *short-run* and *long-run elasticities* (of demand and supply), using a range of sophisticated modelling techniques to estimate inter-related temporal impacts of 'change'. Differences between short-run and long run responses to change in are expected and commonly observed (e.g. tourism and political unrest in Croatia[6], Poverty and food prices in Asia[7], and gasoline use and prices in California[8]). Spatial factors are known to interact with the temporal, as when a biophysical pest spreads across a region over time (Holmes, Liebhold, Kovacs, & Von Holle, 2010). Moreover, the temporal persistence of shocks (like those related to climate change) on economic variables (such as GDP) is well-documented, if only rarely modelled empirically. When explicitly accounting for persistence, estimates of the economic cost (on GDP) of climate change are three to four times larger than when assuming one-off impacts, with instantaneous and complete adaption (Estrada, Tol, & Gay-García, 2015).

In short, it is a non-trivial exercise to estimate 'whole of system' benefits for RAAP because we are dealing with a complex dynamic system that comprises interlinked human and natural (sub) systems. Natural (biophysical/environmental) systems are themselves multi-faceted systems, composed of non-linear, inter-dependent components (Koch et al. 2009). So too are human systems: the utility an individual gains from a benefit stream, for example, will depend at least in part, on the size of that gain relative to the gain awarded to others (Brosnan & De Waal, 2003). As such, there are links ***within*** and ***between*** components of the natural and human (sub) systems. To name but two examples: the benefits that an individual gains from an environmental good/service depends crucially on social

[6] Mervar and Payne (2007).
[7] (Ivanic & Martin, 2014).
[8] See also (Auffhammer, 2018).

context (as per Chan et al. (2016)'s relational values); and people often need to purchase market goods if they wish to access and thus benefit from nature and its services (as when, a person needs a car and fuel to travel to a beach or forest for recreation, (Carbone & Smith, 2013)). This makes it difficult to separate environmental goods/services from market goods/services (Fu et al., 2011) when attempting to assess 'value'. A reef recovery project undertaken under harsh climatic conditions with communities that are prone to *maladaption* (Barnett & O'neill, 2011) may thus have a much smaller chance of success, than one undertaken in more favourable conditions.

Complex systems models allow one to consider different parts of a system, explicitly accounting for connections and feedbacks. When first developed by Forrester in the early 1960s (Kelly et al., 2013), these models often used simple rules and a computationally tractable number of subcomponents. The connections between subcomponents were often written as difference equations explicitly quantifying links between stocks and flows (e.g. each day, 10 percent of the water contained within an aquifer (the stock), is extracted for agricultural use (the flow)). Over time, complex systems models have evolved with many researchers now developing them as a series of sub-models, some even altering their name to refer to them as 'coupled components' models ((Blair & Buytaert, 2016); (Kelly et al., 2013)). One of the strengths of complex systems models is that they allow one to simplify complex problems by firstly thinking about the larger system, and then considering how aggregated subcomponents of the system interact. These models thus involve an element of top-down design (Blair & Buytaert, 2016); requiring model developers to firstly create a big-picture overview of how various components of the system are connected, and to later, parameterise those connections. The process of developing a 'big picture overview' has itself evolved into philosophical modelling approach (sometimes termed mediated, participatory or group model building), where intended outcomes of model development are not solely focused on generating quantitative predictions of and visualisations of integrated systems, but rather on bringing diverse groups of stakeholders together, to better understand the way in which their actions/activities affect one another (see, for example, (Boumans & Costanza, 2007) and (van den Belt, Schiele, & Forgie, 2013)) for applied examples relevant to integrated water resource planning). As such, these models are, in principal at least, able to capture social values – not just the aggregation of individual values (discussed in section 4.1.3).

Whilst the development of some complex systems models has emphasised the participatory/mediating side of the modelling process, other complex systems models have instead focused on the task of generating (verifiable) quantitative predictions, from linked, quantitative models. These highly quantitative complex systems models often combine insights from ecology, chaos, psychology, econometrics, growth theory, business cycles theories, structural change and game theory into systems models that can deal with complex interconnections between various sub-systems across multiple scales (J. Liu et al., 2015), and can allow for 'bounded rationality' and endogeneity, can model transition paths and also complete regime shifts ((Polhill, Filatova, Schlüter, & Voinov, 2016); (Filatova, Polhill, & van Ewijk, 2016)). Depending upon the model (and the sub-models that are contained within), complex systems models are usually able to provide detailed information at multiple scales (micro, mezzo and macro), and about interactions between sub-systems (normally, but not necessarily, at the meso or macro scale). These models generate information that is useful to decision-makers working at a relatively aggregate (large) scale, who wish to explore the (potential) collective outcome on multiple (sub) systems of the complex interactions between multiple, connected, sub-systems (e.g. a regional economy, embedded within the natural environment, with changes occurring to the macroeconomy and to the climate). That said, the size and complexity of some complex systems models, means that they can take decades (and many resources) to develop from scratch (often first building the sub-components, and then coupling them).

There is a dearth of socioeconomic data available to facilitate the analysis and understanding of the way in which changes to reef health might affect the broader system – particularly data that would allow one to adequately capture spatial and temporal dynamics. Indeed, we are unaware of the existence of a coherent large-scale dataset that adequately includes enough information relevant to the Reef to develop a complex systems model. The Australian Institute of Marine Science's long-term monitoring program collects data from the same reefs, at regular intervals, using the same data collection methods each time. This facilitates the analysis of data, to assess changes over time and space. But that data is not linked to socio-economic data. There are no similar long-term monitoring programs in place for social and economic data along the Reef Coast[9]. The National Environmental Research Program funded the development of SELTMP (social and economic long-term monitoring program)[10], but the data collected for that project during 2013 were not collected for a *longitudinal* study: people completed questionnaires anonymously, with no longer term plans for follow. The same questions were asked during 2013 were asked again several years later – but it is not be possible to retrospectively link responses from one time period to another, significantly constraining the analysis that can be done. Comparing 2013 'results' with 2017 'results' is akin to comparing data on reef health that had been measured at different points in time, but on different reefs – one would not be able to determine what change is attributable to differences across time, and what is attributable to difference across space (sample). This is not a criticism of SELTMP – it was not funded for *longitudinal work.*

We lack the resources to develop and populate a complex systems model that would be able to adequately capture the multiplicity of spatio-dynamic relationships that exist between the human and biophysical sub-systems which are relevant to the reef and to RRAP. We note that, resources permitting, it would be possible to learn more by conducting in-depth cross-system studies in a few sub-regions of the Reef, but the sheer scale of the Reef World Heritage area means that one would likely need to do this at several sites (selected to capture the significant social, economic and biophysical differences within the 348,000 km^2 area that comprises the Great Barrier Reef World Heritage Area, and to assess spatio-temporal interactions across and between sites). Lacking the resources to do that either, we instead consider other ways of generating useful information about the likely benefits of interventions. We suggest using a systematic framework for compiling 'benefit' information that already exists. Below, we discuss two common frameworks, selecting that which we feel is most suited to the task at hand.

4.1.6 Frameworks for thinking about benefits

Total Economic Value

Economists who undertake valuation exercises often categorise benefits using the Total Economic Value framework (Pascal et al., 2010). Evolving gradually from (about) the 1940s, the Total Economic Value framework categorises benefits according to the way in which people benefit (i.e. derive utility) from environmental goods and services: *directly, indirectly,* or without using the environment at all. This categorisation helps identify appropriate valuation methods – with different methods most validly used for different types of goods and services.

The Total Economic Value framework identifies three broad categories of values. First, is the category most frequently assessed using money as a metric, namely those that generate a *direct use value* – specifically, where individuals benefit from (i.e. derive utility from) a good or service by using it (e.g.

[9] For many years, the University of Melbourne has managed the collection of social and economic data relevant to employment, in a longitudinal survey (HILDA: https://melbourneinstitute.unimelb.edu.au/hilda). Some data are collected along the GBR coast, but not enough at fine enough geographic scale, to usefully inform analysis.
[10] http://www.nerptropical.edu.au/project/seltmp

when individuals use the environment for agriculture or recreation). These goods and services are the readily valued, since value is related to usage, which is directly observable (e.g. amount of agriculture produced/consumed, amount of recreation provided/undertaken). Second, are *Indirect use values:* those that generate utility indirectly – as when, for example, forests filter water for subsequent human use (drinking, agriculture, or other); or when islands provide off-shore nesting havens for birds, enjoyed by birdwatchers many thousands of kilometers away. It can be challenging to estimate values for indirect use values because one needs to establish a quantifiable link between the environmental good / service of interest and the human benefit/utility. Third, the total economic value highlights that people derive a range of '*non-use* values' from the environment through, for example, existence values (e.g., knowing the environment is there) and bequest values (e.g. leaving the environment intact for future generations) (Krutilla, 1967); and option values (e.g. maintaining the environment for potential future use) (Weisbrod, 1964). Another category of benefits (*option values)* is also sometimes included in the total economic value – although there is some debate about whether these values are a separate category or can be thought of as types of both use and non-use values.

Figure 7 provides reef-specific examples of these different types of 'values', a key point being that the language used to categorise benefit streams can obscure meaning to those unfamiliar with the framework. Species, habitats and biodiversity are, for example, considered – but not as single named categories. Instead, they are mentioned variously throughout the framework (mostly as option or non-use values), highlighting that they generate a range of related benefit streams, each contributing to 'utility' (welfare) in subtly different ways.

The option value issue illustrates the important point that not all benefits can be neatly categorised, so the total economic value framework is perhaps best thought of as a highlighting the continuum of diverse ways in which humans derive utility from the environment. As one moves along the continuum from direct, to indirect, to non-use values, the link between benefits and markets becomes increasingly tenuous and the valuation task becomes increasingly complex, requiring one to use different valuation methods. The framework thus helps guide the selection of appropriate valuation methods if seeking to estimate the value of a specific good or service. Crucially, the total economic value was not devised to be used as a framework for collating values that could subsequently be 'added'. The values cannot be assumed to enter the utility function in an additively separable manner (Carbone & Smith, 2013), so adding values using this framework risks double counting (N. Stoeckl, Farr, Larson, et al., 2014). This is not a critique of the total economic value framework: it was not developed with the intention of being used to guide large-scale 'whole of system' valuation exercises.

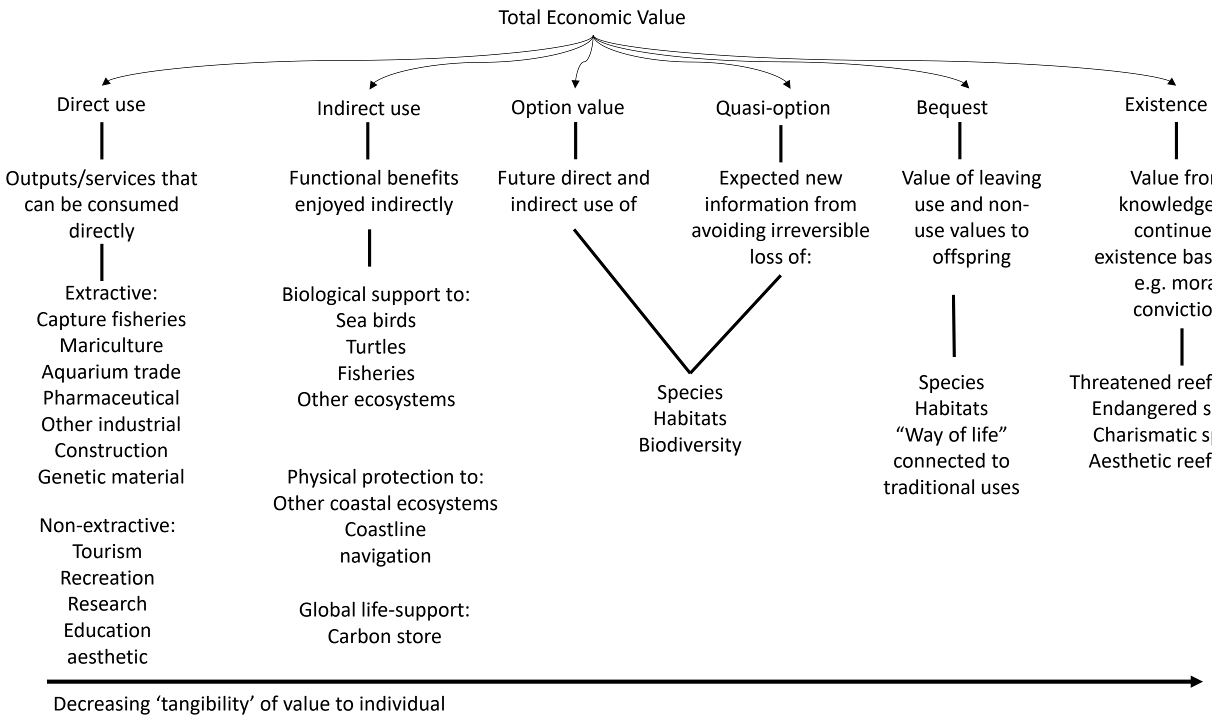

Figure 7: Different economic values associated with coral reefs – illustrated in the Total Economic Value framework (Adapted from: Hoagland et al. (1995))

To use the total economic value framework without ‘adaption’ as a structure for large-scale whole-of—system valuation would be to run the risk of double counting environmental impacts or values. The Common International Classification of Ecosystem Services System (CICES), discussed below, can – if used with care, and if appropriately contextualised - avoid double-counting (assuming also, only final goods are ‘valued’). We therefore suggest using it to identify, and wherever possible ‘value’ benefits associated with the Reef and RRAP.

The Common International Classification of Ecosystem Services

Ecosystem services are defined as “the benefits that people obtain from ecosystems” (MEA, 2005). Derived from the original Millennium Ecosystem Assessment classification system, the Common International Classification of Ecosystem services (CICES (Haines-Young & Potschin, 2012)) is a framework for thinking about numerous ecosystem services in a systematic manner. The CICES categorises ecosystem services hierarchically: ‘sections’ are at the highest level, each with (nested) ‘divisions’, ‘groups’ and ‘classes’ (Table 3). The framework includes all of the different types of direct-use, indirect-use, option and non-use values identified in the total economic value, but refers to them using different terminology, and groups them in different clusters. The hierarchical structure of the framework means that with care, one can use it to guide the compilation of information about the value of ecotourism services, to generate a final composite estimate of the value of all ecosystem services from a particular area or region without double counting (see, for example, Costanza et al. (1997)).

Table 3: CICES ecosystem service classification (based on Haines-Young & Potschin, 2012).

Section	Division	Group
Provisioning Services All nutritional, material and energetic outputs from living systems.	Nutrition	Biomass Water
	Materials	Biomass, Fibre Water
	Energy	Biomass-based energy sources Mechanical energy
Regulation & Maintenance Services All the ways in which living organisms can mediate or moderate the ambient environment that affects human performance.	Mediation of waste, toxics & other nuisances	Mediation by biota Mediation by ecosystems
	Mediation of flows	Mass flows Liquid flows Gaseous / air flows
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection Pest and disease control Soil formation and composition Water conditions Atmospheric composition and climate regulation
Cultural Services All the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people.	Physical and intellectual interactions with ecosystems & land-/seascapes	Physical and experiential interactions such as tourism and recreation Intellectual and representative interactions
	Spiritual, symbolic & other interactions with ecosystems & land-/seascapes	Spiritual and/or emblematic Other cultural outputs

Building upon the previous two frameworks, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services re-considered some of the categories used in the Millennium Ecosystem Assessment (MEA), and some of the ideas they discussed above, adding more insights from research seeking to operationalise them in different contexts (Díaz et al., 2018). Their (new) generalised framework identifies 18 categories to be considered when assessing nature's contribution to people, grouped into three partially overlapping, groups: regulating, material and non-material. These categories very loosely correspond to the regulating, provisioning, and cultural services of the MEA – but with explicit recognition of the importance of cultural context. The partially overlapping nature of the grouping, highlights the importance of contextualising before using. In particular, it is noted that a categorisation system applicable for, say, western people living in an urban environment, may be very different from that which might be applicable to Indigenous people living traditional lifestyles 'on county'. To simply collate values for each of the 18 categories and add, is to thus risk either double counting, or altogether missing important values.

In summary: to use the total economic value framework without 'adaption' as a structure for large-scale whole-of—system valuation would be to run the risk of double counting environmental impacts or values. The CICES framework (evolving from MEA and adapted to include insights from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) can – if used with care, and if appropriately contextualised - avoid double-counting (assuming also, only final goods are 'valued'). We therefore suggest using it to identify, and wherever possible 'value' benefits associated with the Reef and RRAP, carefully considering each category of good to ensure a comprehensive and appropriately contexualised assessment.

4.2 Operational / logistical matters

4.2.1 Selecting benefits for assessment

Broad categories of ecosystem services identified in CICES and related literatures are listed in column one of Table 4, with associated benefits listed in column two. Research that provides evidence of the relevance of specific benefits to the Reef is cited in column three. In the remaining columns we focus thought on benefits streams relevant to the task at hand. First, we ask if it is likely to be impacted by climate change. Second[11], we ask if it is likely to be impacted by reef interventions. Only benefits that are relevant to the Reef and likely to be impacted by climate change and reef interventions selected for inclusion in our assessment (the potential magnitude of which is discussed in Section 4). The final comment indicates whether the sub-service is included in our assessment (yes/no).

Our final list includes ten benefits (the underlining shows key words used to identify each). Species, habitats and biodiversity are included in the list, but do not appear as single named categories. Instead, they underpin and thus contribute indirectly to various different benefit streams (e.g. biodiversity conservation is 'valuable' because it leaves open the option that we may later discover medicinal 'cures' in coral ecosystems; similarly, biodiversity is 'valuable', by and of itself – it has pure *existence* value – a type of non-material benefit). It is the collective value of all benefit streams together (including those we are unable to measure), which comprise the outstanding universal value for which the Reef is inscribed.

Table 4: Identifying relevant asset categories for assessment.

Ecosystem service/ broad type of benefit	Sub-service/benefit[12]	Non-exhaustive examples of research demonstrating relevance to reef	Climate change impacts on these values?	Could RRAP potentially impact?	Include?
Provisioning services / Material benefits	Energy (from, for example, biofuel crops, animal waste, wood, peat)	N/A			No
	Food and feed (from wild and domestic plants and animals)	Commercial fishing seeGBRMPA (2014), Deloitte Access Economics (2013). NB: Recreational and Traditional fishing are considered as a cultural service, below	Almost certainly (if fish habitat impacted)	If RRAP improves habitat	Yes
	Materials (e.g. for construction, clothing, ornaments),	Corals for art/decoration (Harriott (2001), Harriott (2003), Wood, Malsch, and Miller (2012); Jones (2011))	Yes	Yes	Yes
	Companionship (e.g. pets)	Aquarium Fish - (Roelofs & Silcock, 2008)	Not much – most aquarium fish appear to be grown in tanks (aquaculture)	Not if raised in aquariums	No
	Labour (e.g. when horses are used for ploughing fields)	N/A			
	Medicinal, biochemical and genetic resources + (values likely to include OPTION VALUES)	The medicines that could be found in the reef are vast. Reef and related ecosystems may be as 'rich' as tropical forests (Bruckner, 2002)	Yes (if decline in biodiversity – coral or other)	Almost certainly	Yes

[11] And following the lead of De Valck and Rolfe (2018) in their assessment of impacts relating to water quality improvement in the Reef.
[12] Adapted from supplementary materials, Díaz et al. (2018)

Ecosystem service/ broad type of benefit	Sub-service/benefit[12]	Non-exhaustive examples of research demonstrating relevance to reef	Climate change impacts on these values?	Could RRAP potentially impact?	Include?
Regulating benefits (loosely associated with Regulating and Maintenance Services)	Habitat creation and maintenance	Potential for double counting other values if include these 'intermediate' goods, so safer to omit unless funding to undertake primary research that ensures no double counting			No
	Pollination and dispersal of seeds and other propagules	Potential for double counting other values if include these 'intermediate' goods, so safer to omit unless funding to undertake primary research that ensures no double counting			No
	Regulation of air quality	N/A			No
	Regulation of climate	Blue carbon important for mangroves, saltmarshes and seagrass beds (Lovelock et al., 2014), but perhaps not relevant if corals do not sequester carbon			No
	Regulation of ocean acidification	Corals affected by acidification, not the other way around. Some evidence that seagrass may help with acidification (Unsworth, Collier, Henderson, and McKenzie (2012), Mongin, Baird, Hadley, and Lenton (2016)); mangroves may hinder (Camp et al., 2016).			No
	Regulation of freshwater quantity,	N/A			No
	Regulation of fresh and coastal water quality	N/A			No
	Formation, protection and decontamination of soils and sediments	Considered as part of the sub-category below so not also counted here			No
	Regulation of hazards and extreme events	Reef, mangroves and wetlands offer storm protection to coastal communities (Fabricius et al. (2008), Young and Hardy (1993)). Shoreline overall – descriptive overview (Wells & Ravilious, 2006)	Coral mortality shown to increase wave energy in the Seychelles (Sheppard, Dixon, Gourlay, Sheppard, & Payet, 2005). Acidification, warming and/or extreme events impact coral (Albright et al. (2016), Eyre et al. (2018)[13];	Probably but potentially very small given distance between GBR and shoreline	Yes
	Regulation of detrimental organisms and biological processes	Sponges shown to remove bacterial carbon and released ammonium (NE pacific - Kahn, Yahel, Chu, Tunnicliffe, and Leys (2015)) but this is almost certainly an intermediate good, so need to omit to avoid double counting unless funded to undertake primary research specifically designed to ensure no double counting			No
Non-material benefits (loosely linked to cultural services)	Physical and psychological experiences	Tourism – numerous references: (Hundloe (1990), Knapman and Stoeckl (1995), Carr and Mendelsohn (2003), Kragt, Roebeling, and Ruijs (2009), N. Stoeckl, Farr, Jarvis, et al. (2014)).	Yes – but geographical and temporal substitution may mitigate impacts	Most likely if impact reef, fish and IMAGE.	Yes
		Recreation (including, but not limited to, recreational fishing): Prayaga, Rolfe, and Stoeckl (2010); Farr and Stoeckl (2018)	Yes, but recreational fishing not overly responsive to catch, and much occurs inshore.	Perhaps	Yes
		Amenity values and aesthetics – demonstrated impact on house prices (Gopalakrishnan, Smith, Slott, and Murray (2011); Milon, Gressel, and Mulkey (1984); Hamilton (2007)). Reef dependent amenity values likely captured in tourism and recreation and supporting Identities so omitted to avoid double counting.			No
	Learning and Inspiration	Cognitive / scientific research important. Inspiration and creativity essential for innovation, and linked to environment(Florida, 2005, 2014)	Yes – much evidence to highlight artistic and other inspirational values of reef	Yes	Yes
	Supporting identities	Non-use values including Iconic status (O'Mahoney et al., 2017)[14], Bequest and 'existence' values, also some 'option' values. (Rolfe &	If iconic status impacted, or bequest/existence	Almost certainly Probably	Yes

[13] https://www.smh.com.au/environment/climate-change/world-s-coral-reefs-face-new-peril-from-beneath-within-decades-20180223-p4z1ev.html
[14] From Deloitte Access

Ecosystem service/ broad type of benefit	Sub-service/benefit[12]	Non-exhaustive examples of research demonstrating relevance to reef	Climate change impacts on these values?	Could RRAP potentially impact?	Include?
		Windle, 2012)'s work suggests that people who have plans to visit the GBR in the future have higher protection values, so these are in excess of the option values linked to medicine / biodiversity	perceived to be affected		
Indigenous cultural values	Added to ensure appropriate contextualisation	Many Indigenous cultural values cannot be compartmentalised – they are integrated with and inseparable from other values, and are often incurred at a social rather than individual scale (N. Stoeckl et al., 2018); there are more than 70 TO groups with sea-country in and around the GBR, with significant values and aspirations (Smith (1987), Delisle, Kiatkoski Kim, Stoeckl, Watkin Lui, and Marsh (2017), Watkin Lui, Stoeckl, Delisle, Kiatkoski Kim, and Marsh (2016))	Yes – If any part of sea-country is affected.	Almost certainly	Methods very limited in ability to appropriatel y value, so highly uncertain value estimates:
Other complex social goods and relational values		Relational values and the benefit-streams created by complex social goods are, as for Indigenous people, many values inherently inseparable, and crucially dependent on context (Chan et al. (2016), Díaz et al. (2018), N. Stoeckl et al. (2018))	Almost certainly	Almost certainly	No known valuation method – qualitative discussion only

4.2.2 Determining how to measure benefits

There are numerous different ways of 'valuing' benefits like those above. This is true even if focusing on just one specific type of good or service. Using tourism as an example, note that two different types of economic studies are frequently undertaken (with numerous Reef applications):

A. Studies looking at the regional economic benefit/ 'impact' of (marine associated) tourism.
B. Studies that focus on the 'value' of recreation that accrues to tourists (simplistically, the total amount that tourists would be willing to pay, minus the amount that must pay).

Although both of these types studies are referred to as if they measure the 'value' of tourism, neither measures 'value' in the purest economic sense of the word – i.e. as the benefit to both consumers and producers and thus a measure of the contribution that tourism makes to individual and social welfare / wellbeing (section 4.1.1). Specifically:

Expenditure/impact studies fail to consider either the costs (to businesses, and society more broadly) of hosting tourists, or the benefits (to tourists) over and above the amount they have to pay. If only considering expenditure and resultant economic impacts, one cannot determine if the tourism activity is having a positive or negative impact on the welfare of society as a whole – since the 'costs' of generating that tourism income could outweigh the benefits[15]. Rather than providing information about the contribution that tourism makes to social welfare/wellbeing (the 'true' economic 'value' of tourism), these studies provide information about the contribution of tourism to the macro-economy.

[15]Some tourism-related costs, such as costs paid by tourism businesses when providing goods and services, are captured in the market, other costs, including, but not limited to social and environmental impacts of tourism, may fall outside the market but should nevertheless be considered if wishing to assess the net benefit, to society of the industry (e.g. tourism expenditure can serve to raise local prices, thereby 'crowding out' other forms of expenditure (Dwyer, Forsyth, & Spurr, 2004). Tourism may also cause environmental degradation, conflict, cultural challenges, disruptions to daily life, and disillusionment (see also: Brown Jr and Mendelsohn (1984)

Recreational values are often assessed using either Travel Cost or Stated Preference (e.g. contingent valuation, choice modelling) techniques. Travel cost studies that focus exclusively on consumer surplus (panel b, Figure 8), underestimate the value of tourism to society as a whole (unless producer surplus is zero). Stated preference studies, may either overestimate values (if generating estimates of total benefit, which will equal expenditure plus consumer surplus), or underestimate them (if estimating consumer surplus as willingness to pay over and above the amount actually paid) – depending upon the scenarios presented to respondents.

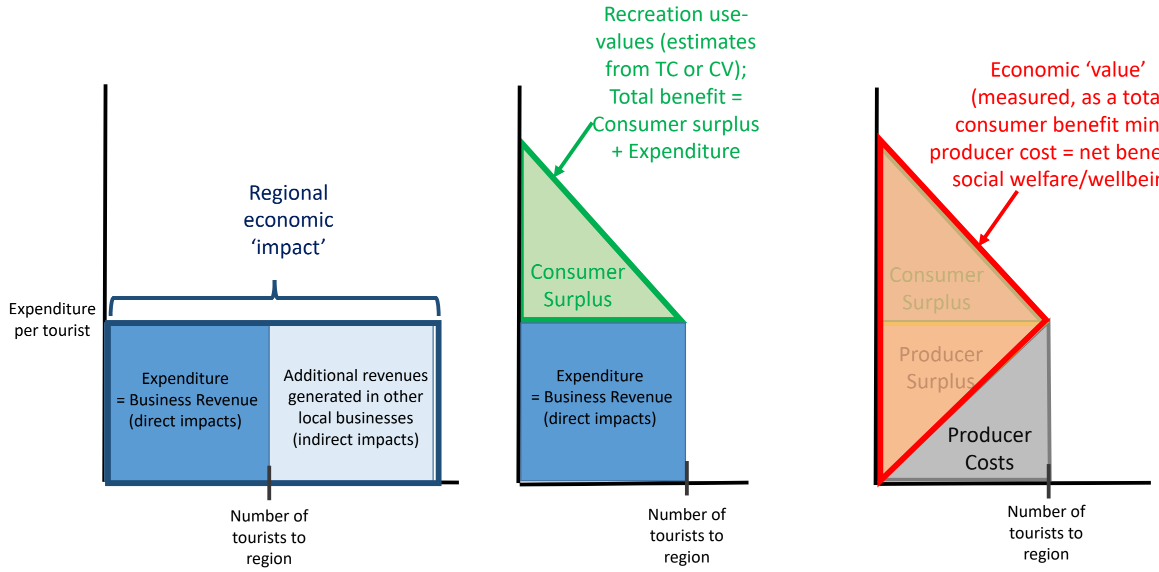

Figure 8: Expenditure, impact, surplus and economic 'value'. The left panel shows measures of expenditure (equal to business revenue) and 'impact'; the middle panel shows expenditure/revenue and consumer surplus; the right panel shows measures of economic value – which can be calculated by either adding estimates of consumer and producer surplus, or by subtracting estimates of producer costs from estimates of consumer's willingness to pay (Source: Crossman, Stoeckl, Sangha, and Costanza (2018)).

This illustrates the crucial importance of understanding first the intent of a study (e.g. for cost-benefit analysis or for impact assessment) and second, the nature of value estimates produced, before selecting numbers to use as part of a benefit transfer study. Since our estimates are intended for use in a cost-benefit analysis, the appropriate measure is net-benefit, which can be approximated by adding estimates of consumer and producer surplus[16]. De Valck and Rolfe (2018) provide these types of estimates, in the Great Barrier Reef, for tourism, recreation and commercial fishing, and we adapt their approach, aiming to do similarly for all benefit streams.

4.2.3 Spatial and temporal issues

Benefit measures include both producer and consumer surplus (section 4.2.2), so the spatial dimensions of 'value' link back to the location of both producers/businesses (if they exist) and consumers. These spatial dimensions are not the same for all types of benefits (Costanza, 2008). For those interested in linking benefit estimates to geographic areas, there are three inter-related issues to consider.

First, is the issue of identifying the regions in which benefit streams accrue. Benefit-streams are flows with different types of benefits flowing from and to different regions. The values associated with

[16] Strictly speaking, on should use estimates of equivalent or compensating variation instead of consumer surplus, but as shown by Willig (1976). Consumer surplus is, in most cases, a good approximation.

sedentary marine resources such as oysters, for example, are ‘produced’ at the location in which the oysters are farmed, so can be directly associated with an identifiable location on a map. But the producer surpluses (roughly, ‘profits’) associated with oyster farmers may be transferred to almost anywhere in the world (if farmers are part of a multinational business), and the consumers who benefit from the oysters may also be located anywhere. Moreover, there are opportunities for ***spatial substitution:*** for example, some fishers are given licences to fish in a large area, when faced with falling catch on one reef, they may respond by choosing to fish on another reef (effort shifting). The task of mapping benefit-streams is thus more complicated than simply mapping the biophysical location in which benefits are generated – one needs information about the people who benefit (Drakou, Pendleton, Effron, Ingram, & Teneva, 2017), and also about opportunities for *spatial substitution*.

Second, is the problem that data relating to benefit streams are generally available at different geographic scales. Several groups of people are likely to benefit from coral reefs, including Traditional Owners, residents of the Reef catchment, tourists visiting the reef, recreational and commercial fishers, and people living elsewhere in Queensland and Australia. Data relevant to the assessment of the benefit streams from Table 4, are available at different spatial scales – a subset of which are shown, for illustrative purposes, in Figure 9.

- The Australian Bureau of Statistics collects data at quite fine geographic scale – notionally making it possible to scale information to different geographic areas – as is done, for example, in the Deloitte Access Economics reports on the economic contribution of the Reef, which provides data relevant to the Reef ‘catchment (all river catchments draining into the Reef Lagoon). But the Australian Bureau of Statistics is rightfully careful about data confidentiality, which can affect the scale at which data are available in rural and remote regions. In remote areas, data are generally only accessible at larger, geographic scale. Figure 9 shows the boundaries of Natural Resource Management regions and Indigenous Local Areas for which it is generally possible to obtain reasonably good quality census data. These river catchment boundaries, crucially relevant to Natural Resource Management groups and biophysical scientists, do not generally align with the geographic boundaries associated with political or administrative territories (e.g. local government areas).

- Australian Bureau of Statistics boundaries do not generally align with those relevant to the 70+ Traditional Owners with land & sea country in and around the Reef (See: https://aiatsis.gov.au/explore/articles/aiatsis-map-indigenous-australia).

- The Queensland Department of Agriculture and Fisheries makes available, information relating to commercial fish catch for relatively small grid-spaces along the Reef (through QFish); this tells us where fish are caught, but not where the fishermen (who accrue producer surplus) or consumers (who accrue consumer surplus) live. Commercial fishing data for Torres Strait are not so readily available.

- The Department of Agriculture and Fisheries also provide data about recreational catch, harvest and effort for five regions along the Reef coast. These regions do not exactly coincide with the grid-cells used for commercial fisheries. Although the waters in and around Torres Strait and on the Eastern side of Cape York Peninsula are identified as separate regions in the recreational fishing reports, data were not separately available for those two areas from the most recent survey. The department explicitly states that they are able to provide data for ‘customised’ regions, but will, like the Australian Bureau of Statistics, be constrained on the level of detail which can be provided for remote/regional areas for fear of breaching confidentiality.

- The Great Barrier Reef Marine Park Authority collects data on reef visitation for regions with boundaries that do not coincide with either the commercial fishing or the recreational fishing zones used by the Department of Agriculture and Fisheries.

Third, different agencies are responsible for collecting data relevant to different benefit streams, the empirical implication being that relevant data is often collected at different points in time and different temporal intervals. The Australian Bureau of Statistics collects census data once every five years – the most recent having been conducted in 2016 (with data released over about a two-year period after collection). The Department of Agriculture and Fisheries provides commercial fishing data on an annual basis – most recent data relating to the calendar year ending December 2017. Reef-visitor data are available from Great Barrier Reef Marine Park Authority on a monthly basis. Much other data is only collected at intermittent points in time – the most recent survey of recreational fishers having been undertaken during the 2013/14 financial year.

Figure 9: The different geographic scales at which data relevant to Reef-related benefit streams are available. Recreational fishing data are available from Queensland's Department of Primary Industries for the regions bounded by the unbroken blue lines; commercial fishing data are available from QFish for the regions bounded by the consistently sized squares that have been shaded light blue. Tourism data are available from the Great Barrier Reef Marine Park Authority for the regions bounded by the unbroken black lines, and the red lines show the marine boundaries used by the Australian Bureau of Statistics in its experimental environmental accounts for the Great Barrier Reef.

Misalignment of geographic and temporal boundaries makes it challenging to collate data relating to different benefit streams. Even if looking at just one type of benefit stream, there can be inconsistences in the scale at which data are collected: commercial fisheries data are recorded at relatively small scale within the marine park areas, but only at large scale in Torres Strait; the Great

Barrier Reef Marine Park Authority collects data on the number of visitors going to particular reef and reports that information for management areas which do not exactly coincide with the terrestrial boundaries used by Tourism Research Australia when reporting on visitors to the Reef catchment; there are also differences in the way data relating to recreational fishers are reported.

In short, some benefit streams are inherently a-spatial and do not map to specific locations (e.g. a desire to 'know the Reef is healthy' and/or a desire to "leave the Reef in good health for future generations"). Moreover, human adaptations transcend geographic areas – when one fishing ground is denuded, for example, fishers may move to another region to fish (permits allowing). Although data relevant to some current benefit streams are available for particular geographic locations (e.g. commercial fish harvest) and although it is possible to measure biophysical changes at fine geographic scale, it is not sensible to assume that a measurable biophysical change at location X translates exactly to a measurable economic change at that same location[17].

All estimates generated for **T9—Cost Benefit Analysis**, were aggregated across the entire reef area (one estimate, for all the Reef). Before combining information from disparate sources to generate an aggregate estimate of all (eight) benefits, we converted values to a single year and currency ($AUD, 2015) and to a single geographic scale (whole-of-Reef). Future research could usefully explore spatial issues in more detail – but it would be a non-trivial exercise to do so, well.

4.3 Reef condition index – a simple measure of coral condition linked to benefit measures

The large–scale ecological model used to simulate coral projections in space and time (described in **T6—Modelling Methods and Findings**) generated estimates of coral condition under a range of different climate/intervention scenarios. While coral cover is the output metric most frequently used in assessments of coral condition (e.g. De'ath et al. 2012; Richards 2013), we extended this here to include a minimalistic representation of coral composition, specifically the relative cover of fast-growing, branching corals. The rationale for this conversion is two-fold. First, representing coral condition using coral cover only will not capture a transition from high to low coral diversity. Because a diversity of coral species and functional groups provide a habitat and resource basis for reef biodiversity, minimal representation of composition is critical to reflect the biodiversity dimension. While we do not formally account for structural complexity in the Reef Condition Index used with the large-scale model, tracking the relative abundance of branching and fast-growing corals in the model provides a proxy for habitat structure, which has direct implications for some ecosystem services. For example, disturbances that lead to severe loss of three-dimensional reef structure can lead to dramatic decline in major groups of reef fishes: 40-65 percent for predatory fishes (e.g. coral trout and emperors), up to 65 percent in wrasses and 90 percent for butterfly fishes (Emslie et al. 2014). Conversely, preserving complex fish habitat by sustaining three-dimensional coral cover can help sustain scope for a diverse reef fish community. Second, many other ecosystem services on coral reefs can be linked to coral condition. For example tourism value is in part linked to coral condition aesthetically (Vercelloni et al. 2018) and fisheries value is linked to the quality and quantity of habitats for young and adult fish and their prey (Rogers et al. 2014). Further, the capacity of a coral reef to offer coastal protection under climate change scales with its capacity to maintain and grow structure in pace with sea level rise and physical damage (e.g. Woesik et al. 2015).

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[17] Spatial analysis of value is arguably more useful in a terrestrial environment, where, for example, rules governing land tenure and land use, limit the ability of humans to adapt to change by simply moving activities to another area.

Formally, the simplified reef condition index (RCI) used here is the product of (1) a subindex for coral cover and (2) a subindex for composition (fast versus slow-growing corals). The subindices (which ranged from 0 to 1) for coral cover and composition were scaled such that their contribution to the Reef condition index was 1 when coral cover or composition (relative abundance of branching corals) exceeded 50 percent. The rationale for using this threshold is that most ecosystem services will be most sensitive to changes in coral cover and composition below 50 percent. See **T6—Modelling Methods and Findings** for further details.

Reef condition index output from the large-scale models were then aggregated to QFish grid-scale (see below), to facilitate the development of models (more accurately, simple equations) linking indicators of coral condition, to benefits.

Reef condition indexes were calculated for each individual reef across the Reef domain (2096 reefs modelled in the CoCoNet, the CSIRO ecosystem model used for Reef-wide analysis) and then partitioned into 157 'grids' corresponding to the grid-zones used to report commercial fishing data, the smallest scale for which economic data are available (Figure 9). A single reef-area-weighted Reef condition index was then estimated for each 'grid':

$$RCI_t^r \ for\ grid\ r\ at\ time\ t = \sum_{1}^{z} \frac{RCI_t^z x\ Area\ of\ reef\ z, in\ grid\ r}{Total\ area\ of\ reefs\ in\ grid\ r}$$

These area-weighted Reef condition indexes were used, in conjunction with information on benefits (section 4.4) to generate predictions, over time, of benefits in various climate/intervention scenarios (section 5.2).

4.4 Developing equations linking benefits to the Reef condition index

4.4.1 Commercial fishing

In the Great Barrier Reef, it is the commercial fishing industry which contributes most to the 'food' sub-category of provisioning services (material benefits). Unless precluded by law, recreational fishers often keep at least some of their catch for home consumption. These fish could thus be considered a type of provisioning service (material benefit). There is, however, evidence that the Reef's recreational fishers are not primarily motivated by the need/desire for food – rather it is the recreational experience that drives them (Prayaga et al., 2010). When undertaking broad-scale ecosystem assessments, and in accordance with the CICES guidelines, recreational fishing is thus generally included in the 'cultural services' category – a practice we follow here. Similarly, many of the Indigenous people who live in regions adjacent to the Reef, supplement their diets with food harvested from the environment. There are substantial cultural values associated with customary harvesting activities (Delisle et al. (2017), Watkin Lui et al. (2016), Jackson, Finn, and Scheepers (2014)). We include those values in our assessment of Indigenous cultural services.

We focus exclusively on wild-caught commercial fisheries – assuming that the aquaculture industry will be unaffected by RRAP – and use publicly available data to identify, and estimate 'values' for reef-vulnerable fisheries: We define ***reef vulnerable fisheries*** as those that capture fish which are likely to be impacted by reef health (coral cover, composition, or structure), and which may thus benefit from RRAP.

Estimating current benefits

There are numerous studies of the commercial fishing industry in the Reef, which provide evidence of its contribution to local communities, and to the catchment, Queensland and wider Australian Economies. Many studies report on fishing revenues (value of output) and/or on the economic 'contribution' that the commercial fishing industry makes to the broader economy (Deloitte Access Economics (2013), and the more recent Deloitte Access study of O'Mahoney et al. (2017)). These publications do not provide data on the 'true' economic value of fisheries for use in cost-benefit analysis (where value is measured in terms of producer and consumer surpluses – as in panel (c) of Figure 10) so are not directly relevant here. That said, De Valck and Rolfe (2018) demonstrate a relatively simple way of converting revenue estimates (equivalent to value of harvest) to estimates of producer surplus using profit rates (8 percent from Bath et al, 2016), a technique used here.

Our first task, was thus to estimate revenues for the subset of fisheries most likely to be impacted by RRAP.

The Department of Agriculture and Fisheries provides data on the tonnes of fish caught, for more than 50 different species groups, within each of the QFish grid-zones depicted in Figure 9[18]. There are 157 'grids' that lie either entirely or partially within the boundaries of the marine park (Figure 10). Data for the Torres Strait are not available at this 'grid scale', and are thus reported on separately, below.

Figure 10: QFish grids overlapping boundaries of Marine Park Boundary and Torres Strait.

For the grids that intersect with the marine park, QFish reports that during 2016, a total of 7156 tonnes of fish were harvested – the catch comprising 120 separate species. Just 26 species account for more than 80 percent of the total catch, by tonnage, but some species are more valuable than others. The Australian Bureau of Agricultural and Resource Economics and Sciences in the Federal Department of Agriculture and Water Resources publishes data on the value of exports of 26 species,

[18] http://qfish.fisheries.qld.gov.au/

and the tonnes exported, for the 2015/16 financial year[19]. For each of these 26 species groups, we divided estimates of the value of exports, by total tonnes exported, to generate estimates of the 'average' price (per tonne) of the species group[20]. We then multiplied those average prices by QFish's tonnage data to estimate the value of the catch for each (Table 5). During 2016, total catch for the species about which we were able to estimate 'prices' added to almost $96M. This estimate seems plausible when compared with the Deloitte Access Economics estimates of total expenditure for Queensland's commercial fishing industry (including Aquaculture) which was $118M – Deloitte Access(O'Mahoney et al., 2017).

Just 3 species groups contributed to almost 80 percent of our entire estimated value of catch (Table 5). These were: prawn – multiple species including tigers, kings, endeavours and banana (contributing to 33 percent of total value); coral trout (33 percent); bugs (12 percent). Only one of these (coral trout) is likely to be impacted by RRAP (Emslie, Cheal, and Johns 2014) – although emperors and snappers are also reef-dependent. The final column of Table 5, provides an estimate of the producer surplus, highlighting the reef-dependent species groups. For these groups, the producer surplus associated with this fishery is ≈ $2.8M, for the year ending December, 2016.

Table 5: Tonnes and estimated values of species groups harvested by commercial fishers in the Great Barrier Reef Marine Park, 2016

Species group	Estimated 'price' (from ABARES – using average of species if multiple in a group)	Tonnes Harvested	Estimated value (price x tonnes) ($AUD)	Value as a % of total value	Estimated PS of reef-dependent fisheries (8% of 'value') ($AUD)
Prawn total	11026.25	2920	32,196,650	33.77	2,575,732
Coral trout total	32692.57	966	31,581,018	33.12	2,526,481
Bugs total	23192.1	476	11,039,440	11.58	883,155
Crab total	9404.019	656	6,169,037	6.47	493,523
Lobster total	23192.1	183	4,244,154	4.45	339,532
Mackerel total	6274.999	454	2,848,849	2.99	227,908
Red-throat emperor + emperor	6737.936	297	2,001,167	2.10	160,093
Barramundi	9171.584	195	1,788,459	1.88	143,077
Tropical snapper and sea perch total + snapper	7120.021	234	1,666,085	1.75	133,287
shark total	2999.989	212	635,998	0.67	50,880

Table 6 shows the tonnes of different species harvested in Torres Strait during the 2014/15 financial year and our associated estimates of the value of that harvest. Our estimates highlight that in Torres Strait, reef dependent species (coral trout) contribute to about five percent of the value of the commercial harvest in this area (approx. $1M per annum of revenues from a total of about $23M), generating an additional $80,000 of producer surplus, over and above that earned in the marine park area.

[19] http://www.agriculture.gov.au/abares/research-topics/fisheries/fisheries-data#australian-fisheries-and-aquaculture-statistics-2016

[20]Akin to the price indices used in models of household expenditure, that work with aggregated groups of commodities (Deaton & Muellbauer, 1980).

Table 6: Commercial Fisheries of the Torres Strait Protected Zone. Tonnes harvested in the 2014/15 financial year (tonnage data source: (PZJA, 2015), prices estimated from ABARES[21]).

Species	Tonnes harvested	Average export 'price' (per tonne)	Estimated total value of harvest ($AUD)	Estimated PS of reef-dependent fisheries (8% of 'value') ($AUD)
Tropical rock lobster fishery				
Australia	**401**	**23192**	**9,299,992**	743,999
Papua New Guinea	**255**	**23192**	**5,913,960**	473,117
Prawns				
Brown tiger prawns	314.5	15299	4,811,536	
Blue endeavour prawns	75.8	7190	545,002	
King prawns	2.6	12800	33,280	
Other prawns	0.5	8186	4,093	
Finfish				
Spanish mackerel	105.4	7000	737,800	
Coral trout	**30.9**	**32693**	**1,010,214**	80,817
Bugs	18	23192	417,456	
Other species	2.1	N/A	N/A	

Despite calls for research on consumer surplus in fisheries (Sumaila, Cheung, Lam, Pauly, & Herrick, 2011), we are unaware of any research that has been undertaken on the consumer surplus associated with coral trout (but note that Sam Peredes, from CSIRO, is undertaking related studies as part of her PhD). We were unable to find information about the proportion of coral trout caught that comprise the 'live fish trade', but note that anecdotal evidence suggests it is an important market. Sadovy et al. (2003) looked at biological, social and economic aspects of the live reef fish food trade, most usefully providing a conceptual diagram of the 'value chain' which underscores the complexity of the market, and the related difficulties of empirically estimating the 'value add' for each related component. They also make some interesting observations about the prices paid for live (rather than dead) fish – by wholesalers, retailers, and consumers, but do provide any empirical estimates that shed light on the value of associated surpluses. In the absence of other, better quality information, we assume here, that consumer surpluses are approximately equal to producer surpluses ($2.8M for the marine park and Torres Strait combined). Our estimate of the total economic 'value' of reef-dependent fisheries in the Reef region during 2016, is thus $5.6M. Although the errors associated with our estimates of producer surplus are likely to be relatively small (given that they compare plausibly with estimates from other researchers), the uncertainties associated with our consumer surplus estimates are substantial. We thus tentatively suggest that one could use $5.6M as the base (per annum) estimate +/- $3M.

For the modelling work, initial, 2016, benefits for (reef dependent) fish were derived by estimating consumer and producer surplus for each QFish grid (see section 4.4.1), focusing on the (approximately) 11 percent of fish caught in the Great Barrier Reef World Heritage Area that are reef dependent.

For t = 0, PS_0^z and CS_0^z were formally calculated as:

$$PS_0^z = \rho \sum_{i=1}^{n} P_{i0} Q_{i0}^z \qquad CS_0^z = \gamma \sum_{i=1}^{n} P_{i0} Q_{i0}^z$$

Where:

PS_0^z is PS at time 0 (in this case, 2016), in Qfish grid-zone z

[21] http://www.agriculture.gov.au/abares/research-topics/fisheries/fisheries-data#australian-fisheries-and-aquaculture-statistics-2016

$CS0^z$ is CS at time 0 (in this case, 2016), in Qfish grid-zone z

P_{i0} is the average price per tonne of reef-dependent fish *i* (column 1, Table 5) during year 0

Q_{i0}^z is the number of tonnes of reef dependent fish *i* [22], caught in grid-zone z, during year 0.

ρ and γ are the proportion of the total value of the catch attributable to PS and CS respectively (in the first instance, 8 percent, after De Valck and Rolfe (2018)).

Projecting future benefits

There is a dearth of information about the likely way in which the producer and consumer surpluses generated by reef dependent commercial fisheries might change in response to changes in reef health. Empirical estimates require in the first instance, information about the way in which reef health impacts the fish, and there is at least useful information available on that: Emslie, Cheal, and Johns (2014) predicts that coral trout could effectively disappear in areas where there was a 'major decline' in reef health (measured in terms of complexity); in areas where there is a 'moderate' decline in reef health abundances would fall by less (perhaps a reduction of just 5 percent).

But that is only the first piece of information required to empirically estimate changes in values. Next, one needs empirical estimates of the short-run impacts of changed fish stock on fishers, wholesalers, retailers and consumers (along Sadovy et al. (2003)'s value chain). We are unaware of the existence of such estimates, but note that even if they were available, they would only provide estimates of the short-term (e.g. one- to two-year) impacts on value. One needs still more information to predict changes in benefit streams beyond that point in time. Coral trout are exported to a world market, so dynamic feedbacks will occur through the wider global economy. If the changes that occur in the Reef are significant enough to influence world prices, then these price-changes could have unexpected feed-backs on Australia fishers (Quiggin (2010), Lin, Deng, and Jin (2013) Sumaila et al. (2011)).

At the risk of over-simplifying a complex process, the following series of events is possible

A reduction in the health of corals ⇒ a reduction in the health and availability of coral trout

This will cause a reduction in the profitability of coral trout fishers (increase in costs, if they need to expend more effort to catch same amount, or a decrease in revenues if they catch less)

This will be associated with a reduction in the supply of coral trout.

In the 'short run' (with a year or so), this will generate an increase in the price of coral trout

If the percent ↑ price > percent ↓ fish caught, then fisher's revenues (and surplus) will increase

If the percent percent ↑ price < percent ↓ fish caught, then fisher's revenues (and surplus) will decrease.

The question of whether fishers' surpluses will rise or fall during the first few years following a decline in catch, can thus only be answered empirically, with current, spatially relevant data about changes in

[22] Derived from http://qfish.fisheries.qld.gov.au/, raw data in Appendix C.

price and quantity for impacted fishers. The issue gets even more complicated if looking into the 'long run' (after the first year or two). If, fisher surpluses rise during the first year or two then one would expect more fishers across the world, to try and enter the market, thus depressing world prices. If instead, surpluses fall, then one would expect some fishers, across the world, to 'go broke' (and leave the market); their exit serving to increase world prices. These subsequent changes in world prices, will then feed-back to again affect local fishers (and consumers).

We do not have a large-scale coupled systems model that incorporates the dynamic and spatial complexities inherent in both the biophysical and human sub-systems (across the world, if dealing with globally traded commodities), so cannot generate precise predictions about final impacts on values. We could not even find an Australian bio-economic model of the Coral Trout Fishery that provides empirical estimates that are specifically relevant to RRAP, but are nevertheless able to glean insights from studies looking at other fisheries in northern Australia – most notably from Fulton (2011)[23]. Taking a 'whole of ecosystem' approach to assessing impacts of climate change she generates predictions about changes to three Australian fisheries, including along the Reef:

> *In all the systems modelled, the large-scale commercial fisheries see a 0.9 percent increase in the relative value of their operations, because they have the socio-economic freedom to respond to new target mixes, distributions, and biomasses.*
>
> *For the Reef, [the] small-scale sector increased by 9–14 percent, but that is only if they were willing to accept small fish, because the trophy fish (large-bodied reef fish) they currently target are no longer a sustainable target (the catch of those groups declining by 22 percent or more)*.
>
> *(Fulton, 2011)*

When unable to target other fish, Fulton (2011)'s models predict that small-scale fishers may experience longer-term declines in revenue of 30-50 percent. That there are differences in the impacts felt by large and small scale fishers is consistent with observations from the broader adaption literature, which consistently reports links between financial resources and adaptive capacity (Darryl and Choy (2013); Mallon, Hamilton, Black, and Beem (2013); Bennett, Dearden, Murray, and Kadfak (2014)). This is particularly relevant for Aboriginal and Torres Strait Islanders associated with reef dependent fisheries.

One expects declines in Reef health to be associated with short-term reductions in both producer and consumer surplus associated with the coral trout fishery. Changes could be as substantial as the biophysical impacts described by Emslie et al. (2014), but human adaptions (e.g. fishers and/or consumers targeting other species) may help mitigate at least some impacts. In the absence of better information, we estimated responses by looking at the relationship between 2016 Reef condition index data and 2016 data on the value-of-fish caught within each zone. We ran a series of regressions, to (crudely) estimate the relationship between the two, using linear, semi log, and double log equations. We tried using both the 'raw' Reef condition index scores and the RCI-sz scores (weighted by reef size). The best relationship is described in the equation below, so we have used 0.8 as a coefficient linking ln(RCI) (weighted by reef area) to ln(value of catch) - simplistically, this

[23] Norman-Lopez, Pascoe, and Hobday (2011) incorporate biophysical and economic information (e.g., changes in stock, costs, and revenues with market-based price feedbacks) and predict that climate-induced changes to the marine environment is likely to increase revenues in the northern prawn fishery

suggests that the likely percentage fall in surplus attributable to a decline in reef health was ≈ 0.8 * percent in weighted Reef condition index.

Ln(Value of catch) = 14.16693 + 0.7964846 Ln (Area weighted RCI)
(27.91) (3.91)

T-ratios in brackets; $F(1, 67) = 15.31$ ($p=0.0002$); $R^2 = 0.1860$

While we could, in theory, use the regression estimates, above, to estimate the 'impacts' of change (here termed *damages)* at QFish grid scale, this will not accurately reflect other short-term behavioural responses of fishers who will optimally, spend most time at reefs with most fish. We thus focus on 'regions' when making predictions about response to change. By doing this, we are implicitly assuming that fishers are able to adjust fishing effort within a region: as such, a fall in the Reef condition index (and catch) in grid-zone *i*, can be at least partially made up for, by shifting effort to a different grid zone. Rather than responding to changes in the Reef condition index for a specific grid, what affects producer surplus (PS) and CS is, therefore, the changes in Reef condition index across larger 'fishing' region. There are no commonly used 'fishing regions' in the Great Barrier Reef World Heritage Area. When distinguishing regions, we use ones which approximately coincide with the tourism regions used by the Great Barrier Reef Marine Park Authority when providing data on tourist visitors to the reef. We have four regions, the Far North (between latitudes 10.55 and 14.5; Cairns (between latitudes 14.5 and 17.85); Central (between 17.85 and 20.65) and Southern (between 20.65 and 24.5). This facilitates comparison with other data.

For t=0, we thus estimated producer surplus and consumer surplus (CS) for the four main regions:

$$PS_0^r = \sum_{z=1}^{Z} PS_0^z \qquad CS_0^z = \sum_{z=1}^{Z} CS_0^z$$

Where:

PS_0^r is PS at time 0 (in this case, 2016), in region r (with z QFish grid-zones).

CS_0^r is CS at time 0 (in this case, 2016), in region r (with z QFish grid-zones).

$PS_0 + CS_0^r$ = current (starting) value of commercial fisheries, from Table 1.

For t=1 to T, CS and PS were calculated as:

$$PS_t^r = PS_{t-1}^r - D(PS)_t^r$$

$$CS_t^r = CS_{t-1}^r - D(CS)_t^r$$

$D(PS)^r_t$ and $D(CS)^r_t$ describe the loss of PS and CS (the 'damage') that occurs within region r, during time t, as a consequence of changes in reef condition, and were calculated as:

$$D(PS)_t^r = \beta^{producer} \, \Delta RCI_t^r \, PS_{t-1}^r$$

$$D(CS)_t^r = \beta^{consumer} \, \Delta RCI_t^r \, CS_{t-1}^r$$

Where:

β is the predicted percentage change in catch (and thus change in CS and producer surplus) following a percentage change in the RCI, (assumed to be 0.8 for producers and consumers, estimated by regressing Ln($P_{i0}Q^{z}_{i0}$) against Ln(RCI^{z}_{0})).

$$\Delta RCI^{r}_{t} = \frac{(RCI^{r}_{t} - RCI^{r}_{t-1})}{RCI^{r}_{t}}, \text{ with } RCI^{r}_{t} = \sum_{z=1}^{Z} RCI^{z}_{t}$$

Whole-of reef responses were assumed to be equal to the simple sum of all regional responses in the Great Barrier Reef World Heritage Area.

The monetary value of this benefit stream is small relative to other benefit streams (tourism, non-use, Indigenous and option values), so we did not explore the sensitivity of final estimates to changes in assumptions about the size of β – but note it is possible to do so.

4.4.2 Coral harvesting

Since 2006, commercial coral harvesters have been permitted to harvest live coral from tidal waters that are under Queensland jurisdiction, within the marine park (subject to zoning, and only with specific licences). There are strict management rules in place[24] including:

- Export of live coral is prohibited
- A total allowable harvest of 200t
- Limited licences (currently, 59) – each with an individual quota
- Compulsory reporting of harvest
- Gear/fishing restrictions
    - Limits exist on the number of boats and collectors operating under a licence at any one time
        - Up to three people may collect under the licence at the same time
        - Only one boat may be used under the licence at a time
    - Coral may only be taken by hand (or with hand-held non-mechanical instruments such as hammer); licensees may free-dive or use scuba or hookah.

Materials targeted include:

- Live corals, such as Euphyllidae, Zoanthida, Corallimorpharia and Fungidae families
- Sea anemones
- Ornamental (non-living) corals, such as Acroporidae and Pocilloporidae families
- Live rock (dead coral skeletons with algae and other organisms living on them)
- Coral rubble (coarsely broken up coral fragments)
- Coral sand (finely ground-up particles of coral skeleton, which fishers can only take as incidental catch and must not target in marine park waters).

Estimating current benefits

Despite a total allowable catch/harvest, of 200 tonnes, QFish reports that in 2016 only 12.14 tonnes of coral were harvested from areas within the marine park (Table 7). Information on the value of the harvest was more difficult to obtain, so we have instead, generated a minimum and maximum estimate, calculated by multiplying tonnes harvested by (a) the minimum price paid for low grade coral

[24] https://publications.qld.gov.au/dataset/queensland-coral-fishery-policy-2016

(generally, the rubble); and (b) a higher rate paid (generally for ornamental corals)[25]. We estimate that for all corals, the total value of harvest, is likely to be between $100,000 and $4M per annum – with corresponding producer surpluses of $8000 and $320,000 assuming the same profit rates for coral fisheries as for other commercial fisheries. This describes current conditions. We are unable to comment on why only 6 percent of the total allowable harvest was collected by licensees, but if all 200 tonnes were harvested, and if similar prices and profits were obtainable, then the live-coral trade could generate between $133,333 and $5.3M in producer surplus each annum - the upper estimate exceeding the surpluses associated with the coral trout fishery.

In the absence of any information on consumer surpluses for the live coral trade we use the same assumption imposed upon the reef-dependent fishery, namely that consumer surpluses are approximately equal to producer surpluses. Our estimate of the total economic 'value' of the live coral trade in the marine park during 2016, thus falls between $16,000 and $640,000, with the mid-point being $328,000, and our 'best estimate' (using different prices for different types of corals) being ≈ $250,000. Our estimates are very approximate. We thus tentatively suggest that one could use $250,000 as the base (per annum), with the full range of estimates going from $16,000 to $640,000.

Table 7: Tonnes of coral harvested and estimates of value (2016).

Type of coral	Tonnes	Minimum value (@ $8 kg)	Maximum value (@ $330 kg)	Suggested price per tonne ($)	"Best" estimate of consumer + producer surplus (P x Tonnes x 0.16)
Stony coral	1.95	15 600	643 500	8 000	$2 496
Catalaphyllia jardinei (Elegance coral)	0.49	3920	161 700	169 000	$13 250
Clavulariidae (a type of soft coral)	0.04	320	13 200	169 000	$1 082
Corallimorph (related to stony/reef building corals)	0.05	400	16 500	8 000	$64
Euphyllia glabrascens (Torch coral)	0.35	2800	115 500	169 000	$9 464
Faviidae (Brain coral)	1	8000	330 000	169 000	$27 040
Fungiidae (Mushroom coral)	0.38	3040	125 400	169 000	$10 275
Goniopora/alvepora	0.39	3120	128 700	169 000	$10 546
Montipora	5.95	47 600	1 963 500	169 000	$160 888
Nephtheidae (carnation, tree or colt soft corals)	0.05	400	16 500	169 000	$1352
Other coral	1.14	9120	376 200	8 000	$1459
Pectiniidae (Chalice corals)	0.11	880	36 300	169 000	$2974
Soft coral	0.17	1360	56 100	169 000	$4597
Xeniidae (a soft coral)	0.05	400	16 500	169 000	$1352
Zoanthidae	0.02	160	6 600	169 000	$541
Total	12.14	$97 120	$4 006 200		$247 380

We used QFish data to estimate 2016 values for coral reef harvesting for each zone by adding estimates of consumer surplus and producer surplus (calculated, as above, from data on harvest within each zone).

For t = 0, PS_0^z and CS_0^z were calculated as:

[25] See, for example: http://marinefishdirect.com.au/product/category?path=75. The higher prices for ornamental live corals at least partially reflect the significant transport costs (since they must be transported in water, rather than dry) - Harriott (2001)

$$PS_0^z = \rho \sum_{i=1}^{n} P_{i0} Q_{i0}^z \qquad CS_0^z = \gamma \sum_{i=1}^{n} P_{i0} Q_{i0}^z$$

Where:

PS_0^z is producer surplus at time 0 (in this case, 2016), in QFish grid-zone z

$CS0^z$ is consumer surplus at time 0 (in this case, 2016), in QFish grid-zone z

P_{i0} is our suggested price per tonne of coral type *i* that is harvested (see Table 7) during 2016

Q_{i0}^z is the number of tonnes of coral-type *i* that is harvested in grid-zone z, during year 0 (Appendix D)

ρ and γ are the proportion of the total value of the catch attributable to producer surplus and consumer surplus respectively (8 percent, after De Valck and Rolfe (2018)).

Projecting future benefits

We could find no data specific to the likely impact of changes on reef health on coral harvesting, so used the same approach (and parameters) used for commercial fishing benefits.

For t=0, we also estimated producer surplus and consumer surplus at regional scale:

$$PS_0^r = \sum_{z=1}^{Z} PS_0^z \qquad CS_0^z = \sum_{z=1}^{Z} CS_0^z$$

Where:

PS_0^r is producer surplus at time 0 (in this case, 2016), in region r (with z QFish grid-zones)

CS_0^r is consumer surplus at time 0 (in this case, 2016), in region r (with z QFish grid-zones)

For t=1 to T, consumer and producer surplus were calculated as:

$$PS_t^r = PS_{t-1}^r - D(PS)_t^r$$

Where:

$$CS_t^r = CS_{t-1}^r - D(CS)_t^r$$

$$D(PS)_t^r = \beta^{producer} \, \Delta RCI_t^r \, PS_{t-1}^r$$

$$D(CS)_t^r = \beta^{consumer} \, \Delta RCI_t^r \, CS_{t-1}^r$$

β is the predicted (percent) change in coral harvest (and thus change in consumer surplus and producer surplus) following a percentage change in the RCI, (assumed to be 0.8 for producers and consumers as per commercial fishing)

ΔRCI_t^r is the change in the RCI for the region, calculated as for the commercial fishery.

The monetary value of coral harvesting is also small relative to other benefit streams (Tourism, Non-use, Indigenous and Option values) so we have not explored the sensitivity of final estimates to changes in assumptions about the size of β – but note it is possible to do so.

4.4.3 Medicinal option values (reflecting biodiversity and gene pool values)

Different disciplines place different meaning on the term "option value". In the environmental and welfare economics literature the term option value refers to the fact that people may be willing to pay to protect an environmental asset, in case its value, possibly now thought to be zero, becomes apparent later. Option values are expressed in a willingness to pay to keep options open. They are almost akin to an insurance value. The literature shows that option values are likely to be high if (amongst other things) there is much uncertainty about the future need for the asset and/or if there is an element of irreversibility to decisions or high replacement cost, if an asset is damaged (Weisbrod, 1964). That the Reef is irreplaceable underscores the significance of options values, and the importance of ensuring we include them in this assessment.

Option values can relate to almost any benefit stream – e.g. recreation (I haven't been to the Reef, I don't plan to go, but I'd like to keep that option open); food (I don't eat fish from the Reef, but would like to keep that option open) non-use values (someday we may realise how precious this is) – and researchers have found that those who participate in willingness-to-pay studies consider option values. Rolfe and Windle (2012), for example, used choice modelling to assess non-use values associated with the Reef. Looking at various sub-sets of data, they were able to conclude that at least some (recreational) option values were included in expressions of WTP – specifically, respondents who lived outside Queensland and who had plans to visit the reef in the future, had higher WTP to protect the reef than those without such intentions. So, one must be very careful if including option values as a separate line item in large scale assessments, since they may already be included in values associated with other benefits. We thus focus on only one type of option value, which we can be 100 percent sure is not considered elsewhere in our assessment: that which relates to 'medicine'. By excluding other option values, our estimates will understate true values.

In 2016, the global pharmaceutical industry had revenues in excess of 1,100 billion USD[26] and the top-selling item (Humira) is considered a biopharmaceutical (medicine derived from biological sources). About 7000 medical compounds (≈25 percent of prescription drugs) are derived from plants[27] and the biopharmaceutical industry is growing rapidly: the collective value of all biopharmaceuticals is estimated to be worth more than 340 billion USD by the year 2023[28].

Just as rainforests support more than 25 percent of terrestrial biodiversity, so do coral reefs support more than 25 percent of marine biodiversity, highlighting the potential importance of coral reefs for the biopharmaceutical industry. There is evidence of the use of aquatic medicines dating back almost 5000 years (Figure 11), and more recently, sea sponges have been used in the development of anti-viral and anti-cancer drugs, including those used to treat HIV and leukaemia[29]. The sea hare, tunicates and bryozoans have also been used to produce compounds that are now in preclinical and clinical trials for the treatment of cancer[30], and marine products are now widely recognised as having the potential to be anti-tumour, anti-microtubule, anti-proliferative, photoprotective, antibiotic and/or anti-infective (Martins, Vieira, Gaspar, & Santos, 2014).

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26 https://www.statista.com/topics/1764/global-pharmaceutical-industry/
27 http://www1.udel.edu/chem/C465/senior/fall00/DrugDiscovery/theValueoftheRainforests.html
28 https://www.mordorintelligence.com/industry-reports/global-biopharmaceuticals-market-industry
29 http://ocean.si.edu/ocean-photos/sea-sponge-hiv-medicine
30 http://jrscience.wcp.muohio.edu/fieldcourses03/PapersCostaRicaArticles/FinalPaper.TheMedicinalVa.html

The tax records generated in China in the year 2953 BCE, during the rule of emperor Fu Hsi, are proof that the empire was levying fish-derived medicine (Jia et al. 2004). Circa 400 BCE Hippocrates noticed the antibiotic effects of certain sponges, which he recommended to dress soldiers' wounds with (Riddle 1987). In 41 CE, Scribonius Largus, personal doctor of Emperor Claudius, recommended the discharges of electric fish (Torpedo nobiliana) to cure migraines and headaches (Kuhfeld 1995). Dioscorides noted in his Materia Medica, around 65 CE, the benefits of applying brown algae for treating inflammation. Some years later, Galen also described medicinal uses of algae, noting that the mucilage surrounding the thallus had remarkable properties to dress wounds (Khalilieh and Boulos 2006). Pliny "the elder" also plunged into marine medicine in 77 CE when he suggested stingray spines to alleviate toothaches (Secundus 1603). The contribution of Chinese scholars to this topic is outstanding. Two salient books on the topic are Shen Nung Pen Ts'ao Ching (神農本草經) or The Divine Farmer's Materia Medica circa 200 CE, and the Chinese Materia Medica published circa 618 CE (Halstead 1992). As far as mentioning the Middle East, Lev-Yadun (2004) offers a comprehensive listing of animal-derived medicines used in Levant from 600 CE into 1700 CE, in which mollusks, fish and corals are included.

Figure 11: Five thousand years of aquatic medicines (Narchi, 2018)

Bruckner (2002) claims that 'the prospect of finding a new drug in the sea, especially in coral reefs, is 300 to 400 times more likely than that of isolating one from a terrestrial ecosystem, but it was not until the late 1980s/early 1990s that countries other than Japan started to seriously invest in marine biotechnology research. The value of the industry soon become apparent (In just three years, 1996-1999, 100 new marine compounds were patented in the US (Bruckner, 2002). In 2011, the global market for marine-derived drugs was estimated at $US4.8B with forecast annual compound growth of 12.5 percent per annum[31]. This suggests the industry could have earned as much as $US9-10B in 2017. The cosmetic industry is now also showing increased interest in marine organisms, using extracts from coastal plants, seaweeds, algae and sea minerals (Martins et al., 2014).

Whilst some have raised concerns about the sustainability of the marine pharmaceutical industry (fearing it may contribute to reef degradation), it seems that the quantities extracted are not, at this stage, sufficiently large to have a negative impact (Hunt & Vincent, 2006). We could find no parallel information for the marine-based cosmetic industry.

Estimating current benefits

There is strong evidence to suggest that coral reefs and the other marine organisms they support are likely to be of value to the biopharmaceutical industry, if not tomorrow, in the near future. Several researchers have generated empirical estimates of coral reef biodiversity values &/or the value of gene pools and genetic resources. These values are related, in that they include options for future medicinal values, but not directly so, since they also include other values (not related to medicines). Some researchers have discussed medicinal option values in qualitative terms (Cesar & van Beukering, 2004) and some have measured other types of option values associated with coral reefs (e.g. for future tourism/recreational benefits). But we could find no empirical estimates of medicinal option values for the Great Barrier Reef, or for any other reef. We did, however, find one study (Jobstvogt, Hanley, Hynes, Kenter, & Witte, 2014) that used choice modelling with a sample of

[31] https://www.bccresearch.com/market-research/pharmaceuticals/marine-derived-pharma-markets-phm101a.html

Scottish residents to estimate the option value of deep-sea organisms as a source for future medicinal products. In the year 2013, this was equivalent to about 35 English pounds per household per year (≈ $74,2016)[32].

In the absence of other information, we use a simple unit-value transfer, to infer that the 'average' household would, like the Scott's, be willing to pay $74 per annum to protect the medicinal option value of coral reefs[33].

If wishing to use this estimate within the broader cost-benefit analysis study, one must first answer two questions:

1. **How many households are relevant in the calculations? This allows us to generate an aggregate estimate, for the relevant 'population' (simplistically multiplying value per household by number of households).**

   Arguably, if one were to find a cure for cancer, then the benefits of that cure, could accrue to people all over the world – not just to Australians, or to residents of the Reef catchment. This suggests that one could (perhaps should) consider global populations when estimating these values. Although we acknowledge the potential global value of coral medicines, we take a more conservative approach when estimating benefits here, focusing on benefits accruing to Australian residents. At the time of the most recent Australian Census (2016), the population of Australia was a little over 24 million, with an average household size of 2.55 – or about 9.4 million households. At $74 per household, this suggests that medicinal option values could be as high as $695 million. If global populations were included, the value of this benefit stream would be orders of magnitude greater.

2. **How do we convert this aggregate estimate of consumer value, into an estimate of net benefit (a subset of consumer value)?**

   Panel C, Figure 8, shows that net benefit can be approximated by adding consumer and producer surplus, or by subtracting production costs (approximated by the area under the supply curve) from total consumer benefits (the 'value' estimated above – and shown as the area under the demand curve). So, to calculate net benefits, we need information on producer costs (which must be subtracted from our aggregate estimate above).

Since researchers first started to focus on marine resources for medicine and cosmetics, they have isolated almost 20,000 structurally unique bioactive products, but by 2014, this research had culminated in the production of just eight approved drugs (although there are numerous others marine chemicals in the pre-clinical development phase) – see Martins et al. (2014). The challenges facing companies developing these resources are numerous and varied. The research and development costs of the biopharmaceutical industry are substantial: for example, developers (AbbVie Inc.) claim that it cost more than $US2.5B to get the drug Humira prescription ready (Forbes 100).

In 2015/2016, AbbVie Inc. reported total costs (including taxes paid) that were about 75 percent of revenues[34]. In the absence of better information, we thus use this as an indicator of likely costs, suggesting that it may be possible to use ($174M ≈ 0.25*$695M) as an estimate of the potential

[32] Using the world bank PPP conversion factors to change from English pounds to AUD, and the GDP deflator to update from 2013 to 2018 values.
[33] Their regression equations highlight variations in values for different groups of people (e.g. males apt to have lower values than females). So future research could usefully explore the extent to which that value might differ across people in Northern Australia, using the regression coefficients from (Jobstvogt et al., 2014) to define a transfer function to facilitate – see section 4.1.4
[34] https://news.abbvie.com/news/abbvie-reports-full-year-and-fourth-quarter-2017-financial-results.htm

benefit stream (p.a.) from medicines derived from corals and associated organisms. This estimate is derived using scant numbers and back-of-the envelope calculations. It is thus very uncertain, and we recommend using a wide range of values around that estimate in related sensitivity analyses. That said, our aggregate estimate converts to one that is about $7246 per hectare. This seems 'plausible' (even conservative) when compared with other estimates of gene pool/biodiversity values for coral reefs. Van der Ploeg and De Groot (2010), for example, produced a database (with 1310 separate estimates of the (monetary) value of various ecosystem services, worldwide: 6 of those estimates were focused on gene pool value for coral reefs – we converted those estimates to AUD (2015). The mean was $26,864 per hectare.

Projecting future benefits

We simplistically assumed that option values are related to reef health (as if there is a lower probability of finding a 'cure' for cancer (or other) in a large reef area that harbours relatively few species, than in a small area which is much more biodiverse), so allocated the total MOV (above) to each QFIS grid-zone, z.

For t=0:

$$MOV_0^z = \frac{RCI_0^z}{\sum_{i=1}^{Z} RCI_0^z} . MOV_0^{GBR}$$

Where:

MOV_0^{GBR} = $174M

For t= 1 to T, we assumed that changes in medicinal option values (MOV) in each zone were directly linked to changes in reef condition:

$$MOV_t^z = MOV_{t-1}^Z - \Delta MOV_t^z$$

Where:

$$\Delta MOV_t^z = \beta \Delta RCI_t^z = \beta \frac{RCI_t^z - RCI_{t-1}^z}{RCI_{t-1}^z}$$

In the absence of any better information, we set β= 0.8 (the value used for the commercial fishing industry).

Option values are the fourth largest benefit stream, so we explored the sensitivity of final values to changes in those estimates, setting β= 1. This higher sensitivity is intended to reflect the fact that declines in reef health, are likely to be associated with more general declines in biodiversity and may thus potentially have a more extreme impact on option values, with no scope to compensate (adapt to) those losses (unlike fishers).

4.4.4 Storm-surge protection

Regulating and maintenance services relate to the ecosystem processes that moderate and maintain the environment. For example, vegetation helps prevent erosion and contributes to soil fertility, vegetation and soils store carbon thus helping to regulate climate and (most relevant here), reefs provide storm surge protection (Arkema et al., 2013). In the Seychelles, coral mortality has been shown to increase wave energy on shorelines (previously) protected by reefs (Sheppard et al., 2005), but those results are for fringing reefs close to the shore, and thus not readily transferrable to the Reef.

Despite the fact that more than 1 million people live within the catchment of the Reef, many of those people live in the southern part, where the main body of the reef is more than 100km from the coast (Figure 12): Cairns is the largest regional city that is close to the Reef (Green Island, for example, is less than 30km from Cairns). When estimating storm surge protection values, we take an extremely conservative approach, focusing exclusively on the 275,000 people who live in the statistical local area termed: far north Queensland (FNQ)[35] – an area encompassing the Torres Strait and most of Cape York Peninsula. Most of the people residing in this local area are in towns and small communities along the east coast, with at least some housing and infrastructure that is close enough to the Reef to credibly assume that the reef is able to offer some storm-surge protection.

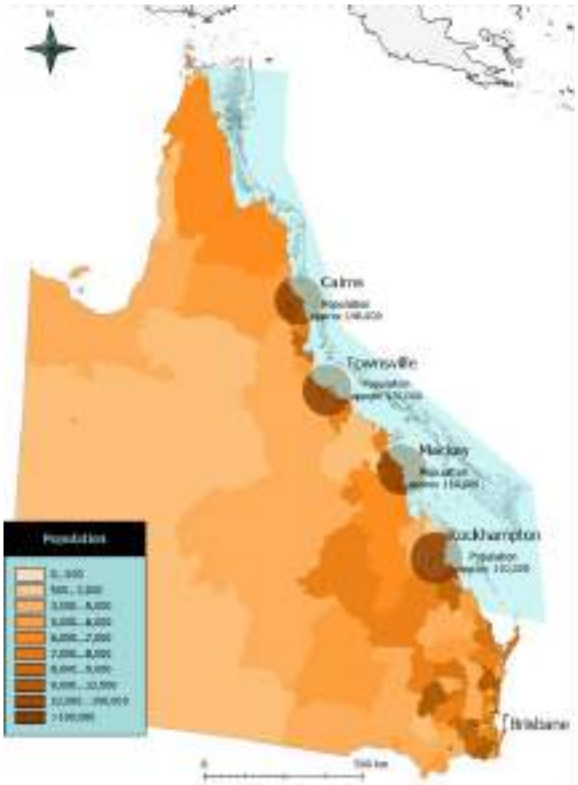

Figure 12: Populations adjacent to the Reef, by Statistical Local Area (SLA) 2, with major regional centres. Data source: ABS 2016 table builder. Major population centres selected as being by the reef and greater than 100,000 using abs Statistical Local Area (SLA) 3 data. Other regions portrayed at SLA 2 level.

Estimating current benefits

It is notoriously difficult to estimate the monetary value of the storm surge protection offered by reefs. This is because of numerous interacting variables including, but not limited to "t*he shape of near-shore, the presence of coral reefs offshore, the size of communities, value of infrastructure within, distance inland and elevation above sea level of potentially impacted areas"* (Crossman et al., 2017). There are three general approaches to estimating such values:

[35] https://rdafnqts.org.au/regional-profile/

1. Using predictive models. Here researchers build, and then combine biophysical models (in this case, ones that explicitly incorporate hydrodynamics, and the role the Reef plays), with socioeconomic ones (that describe the 'value' of infrastructure on the shoreline), to make predictions about the likely damage that would occur on-shore, if the reef were not there (or if it were damaged).
2. Using statistical models to estimate avoided costs. Here researchers collate data in regions with and without reefs, and then compare 'damages' from storms in each region (controlling for other confounding factors). Subtracting the damages that occur in the protected areas, from those that occur in the unprotected areas (for storms of 'similar' intensities), gives an estimate of the storm-protection value of the reef.
3. Using data from insurance companies (or similar) to assess *replacement costs*

We are aware of current research that is seeking to estimate such values in the Reef (using approach (2)), but it may take time to complete. We thus take an admittedly very inferior, approach – looking first, at the value of infrastructure 'protected' by the reef. Using an average household size of 2.6 persons, allows us to infer that there are likely to be about 100,000 dwellings in far north Queensland. Units comprise most sales in this region, with a median price of a little over $250,000[36], suggesting that the current value of the housing stock in far north Queensland is $25B. Only some of those houses are located directly on the shoreline – but we do not know how many, so assume that the value of the housing stock, located in far north Queensland that is vulnerable to, and thus afforded at least some storm surge protection by the Reef is in the order of $265M (one percent of all dwellings). In the absence of other information, we assume the value of other infrastructure (e.g. roads, wharfs, buildings, agriculture) to be twice that of housing, so the total value of assets afforded at least some form of storm-surge protection in far north Queensland is likely to be in the order of $530M.

Since 2009, one severe tropical cyclone has impacted the far north Queensland coast (Figure E3). If storm frequencies/intensities continue as per historical patterns, then it seems reasonable to assume that a severe tropical cyclone can be expected about once every ten years. The expected value of storm-surge damages under current climatic conditions, can thus be estimated at $26.5M per annum assuming that severe storms damage 50 percent of vulnerable assets ($530M x 0.1 x 0.5). To gauge the plausibility of our estimate, we compare it with other research that reports storm-surge protection values, on a per-hectare basis: these suggest that the storm-surge protection afforded by coral reefs is in the order of $1000-$2000 per hectare (of reef) per annum ($1845.54 using the avoided cost approach[37]; $1067.28 using direct market pricing[38]; and $2107.55 using the replacement Cost technique[39]). If we had transferred those estimates to this context, by multiplying per-hectare estimates across the entire 2.4ha of reef in the Great Barrier Reef world heritage area, the associated value estimate would be a little over $2.4B. So, while we urge caution when using our 'back of the envelope' estimate, we suggest that, by design, they underestimate actual values – perhaps substantially. We thus suggest using $26.5M per annum as the base estimate for (current) storm-surge protection values, with plausible range extending from $10M to $50M.

The calculations used to generate this estimate are set out formally below. Note that the estimates are relevant to the entire (northern) region; we did not attempt to ascribe these values at finer geographic scale.

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[36] https://www.yourinvestmentpropertymag.com.au/top-suburbs/qld-4870-cairns-north.aspx, accessed 19 May 2011
[37] Median estimated from Berg, Öhman, Troëng, and Lindén (1998),Charles (2005),Spurgeon (1992), (Aubanel, 1993), (Ebarvia & Corazón, 1999), (Riopelle, 1997) – all cited in Van der Ploeg and De Groot (2010)
[38] (LM Burke, Maidens, Spalding, Kramer, & Green, 2004)– cited (Van der Ploeg & De Groot, 2010)
[39] Median, also estimated from Berg et al. (1998),Charles (2005),Spurgeon (1992), (Aubanel, 1993), (Ebarvia & Corazón, 1999), (Riopelle, 1997) – all cited in Van der Ploeg and De Groot (2010)

For t=0, storm surge protection benefits (SSPBs) were thus calculated as:

$$SSPB_0^{GBR} = Value\ of\ Infrastructure\ at\ risk_0 \times Probability\ of\ storm_0 \times Expected\ \text{percent}\ damage\ if\ storm_0$$

Where:

$$Value\ of\ Infrastructure\ at\ risk = 2\ x\ Value\ of\ Houses\ at\ risk$$

$$Value\ of\ Houses\ at\ risk = \frac{Population\ in\ FNQ_0}{Average\ HH\ size_0} \times Median\ House\ Price_0\ \times \%\ houses\ along\ coast_0$$

$Population\ in\ FNQ_0$= 275,000

$Average\ HH\ size_0$ = 2.6

$Median\ House\ Price_0$ = 250,000

$percentage\ houses\ along\ coast_0$ = one percent

$Probability\ of\ storm$= 0.1

$Expected\ percent\ damage\ if\ storm$ = 0.5 = τ_0

Projecting future benefits

Calculated in this way, estimates of SSPBs will, by construct, change in response to: (a) changes in the value of the coastal infrastructure (driven by property prices, population, the number of properties adjacent to the coast &/or changes in the broader economy); (b) changes in the probability of a storm occurring; or (c) changes in the expected damages if a storm were to occur. The ecological models used to predict Reef condition indexes for different scenarios do not explicitly account for the frequency or intensity of storms, so for consistency, we also assumed no change to storm probabilities. As for other benefit streams, we tried to ensure that estimates of the impact of change to storm values that are attributable to changes in Reef condition index are not obfuscated by other changes, so assumed a constant value of infrastructure. Consequently, our modelled projections assume that all changes in storm surge protection benefits are driven by biophysical changes in the reef – manifest in changes to the expected damage (to the assumed given set of assets) occurring in the event of a storm.

For t=1 to T SSPBs were thus estimated as:

$$SSPB_t^{GBR} = SSPB_{t-1}^r - D(SSPB)_t^r$$

$D(SSPB)_t^r$ describes the loss of SSPBs that occurs across the entire region, during time t, as a consequence of changes in reef condition and is calculated as:

$$D(SSPB)_t^r = SSPB_t^{GBR} - SSPB_{t-1}^{rGBR}$$

$$= (Value\ of\ Infrastructure\ at\ risk_0 \times Probability\ of\ storm_0) \times (\Delta\tau_t)$$

Where: $\Delta\tau_t = \Delta RCI_{t-1}^r$

The monetary value of this benefit stream is small relative to other benefit streams (Tourism, Non-use, Indigenous and Option values) so we have not explored the sensitivity of final estimates to changes in assumptions about the relationship between FCI and damages (including lag-times) – but note it is possible to do so.

4.4.5 Tourism

Different agencies regularly report on tourism to the reef, and reef catchments. The regions for which data are available do not always align (Figure 13)[40], making direct comparisons difficult; it is nonetheless evident that only a portion of visitors to regions along the Reef coast, visit the reef (Table 8). We are interested in **Reef-dependent tourism**, and so focus on the behaviours and values of the (approximately) 2.4m tourists who visit the reef each year – and upon the tourism operators who provide goods and services to those visitors. We use EMC data, in conjunction with information from other published studies, to estimate the consumer and producer surpluses associated with reef visits; we draw on information relevant to catchment visitors (from TRA and elsewhere), when commenting on the way in which net (tourism) benefits may change in response to changes in climate and /or by RRAP.

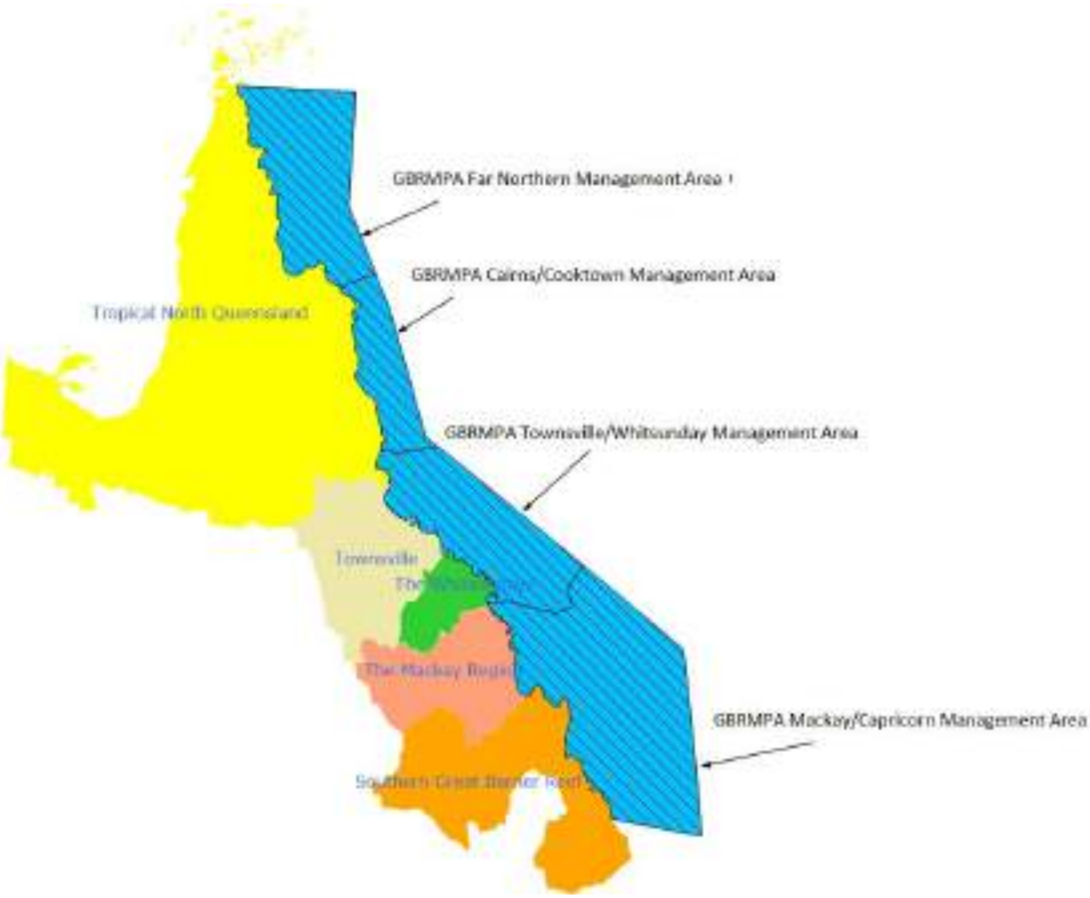

Figure 13: Boundaries used for reporting EMC data alongside (terrestrial) boundaries used by Tourism Research Australia when reporting data relevant to visitors to the Reef catchment.

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[40] The Great Barrier Reef Marine Park Authority collects data on the number of visitors going to the reef – collating information for different management areas (also for a smaller planning area within the Cairns/Cooktown area, and within the Townsville/Whitsunday area). Regular data are also collected by Tourism Research Australia – and this organisation collates information for different tourism regions. There is some (albeit imperfect) correspondence between the terrestrial and marine boundaries used by these different groups.

Table 8: Visitors, visitor nights and expenditure in and around the Great Barrier Reef year ending 2015

TRA Region	Visitors to region	Visitor nights in region	Visitor Expenditure in region	GBRMPA Region (2016 data, to 'match' fishing data)	Visitors to REEF (EMC data*)
Tropical North Queensland	5,281,000	16,930,000	3,632,000	FNQ Cairns/Cooktown	4618 1,419,311
Townsville Whitsunday	2,475,000 655,000	5,741,000 3,348,000	1,140,000,000 717,000,000	Townsville/Whitsunday	1,146,371
Mackay Central QLD	1,484,000 3,401,000	3,363,000 7,054,000	445,000,000 1,048,000,000	Capricorn	4618
Total	13,296,000	36,436,000	3,353,632,000,000		2,767,152

* EMC data provides information about full-day, part-day, scenic flight, coral viewing and exempt visitors which respectively comprise about 63%, 10%, 3%, 10% and 13% of all visitors.

Estimating current benefits

Arguably, there has been more research looking at the value of Reef-based tourism, than on any other benefit stream associated with the reef; although much of that research reports on the contribution that tourism makes to regional economies, rather than on its net benefit for use in cost-benefit analysis (effectively generating information akin to, panel a, rather than panel c, of Figure 10). We are primarily interested in information that allows us to estimate net-benefits. Discussed previously, this can be approximated by adding consumer and producer surplus (the first, generally estimated using revealed or stated preference approaches). Producer surplus is rarely considered in tourism studies, but is estimable as a percent of revenues (equal to expenditure), as demonstrated by De Valck and Rolfe (2018). Recent relevant studies are listed in Table 9.

Table 9: Empirical studies relevant to the 'current value' of Reef tourism. All values converted to AUD 2015; methods used to generate values are identified using the following symbols: CB – contingent behaviour; CM – choice modelling; CV - Contingent Valuation; E – Expenditure; TC - Travel Cost; TS- Tourism Satisfaction (related to Life Satisfaction).

Expenditure/impact studies

Tourists visiting catchments adjacent to the Reef: $153 per visitor per night[41], $419 per visit if visits 2.74 days[42]– E

Tourists visiting TRA regions adjacent to Reef: $193 per visitor per night, or $525 per visitor per visit[43] – E

Tourist expenditure Reef catchment: $190 per visitor per night; $1299 (business visitors) - $1771 (non-business) per visitor per visit[44] – E

Live aboard dive boat visitors (minke whales) in Cairns/Port Douglas region: $2506 per visitor per visit[45] – E

Hervey Bay (Whale-watching) $2392 per group per visit[46] –E

Studies on the 'value' of a visit to tourists (consumer surplus)

Hinchinbrook Island $972 per person per visit[47] –TC

Fraser Island - $1853 per person per visit[48] –TC; Lake McKenzie, Fraser Island - $307 per person per visit[49] –TC

Great Barrier Reef

$329 per person per visit (domestic & International) during 1983 [50] – TC

$849 (range: $522 - $1177) per person per trip for domestic & international visitors to the Reef during 2000[51] –TC (zonal)

$214 per diving or snorkelling per trip for visitors to the Cairns Management areas during 2006[52] – CB

$265 for those travelling to Cairns or the Whitsundays by air (range $150-$350)[53].

$635 per trip per for visitors travelling to Cairns or the Whitsundays by car during 2012 (range $500-$750) [54];

$662 per person per visit domestic visitors to the Reef during 2017[55] –TC

First, we consider consumer surplus. Leaving aside island visitors, we focus on those who visited the Reef. Median estimates of consumer surplus are $482 per person (per visit). Extrapolating to all 2.767 million reef visitors yields an aggregate estimate of about $1.33B per annum.

Second, we consider producer surplus. Leaving aside whale-watching tourists, the median expenditure estimate per visitor per night is $190. If dividing total number of visitor nights spent in the region, by total number of visitors, estimated nights per visit is: 2.7. If focusing only on over-night visitors, median length of stay is 5 nights (N. Stoeckl, Farr, Jarvis, et al., 2014). Median expenditure is thus between $520 and $950 per visit (2.74 and 5, respectively, multiplied by $190). This suggests that aggregate expenditure for all 2.767 million reef visitors is between $1.4B and $2.6B per annum. Using (De Valck & Rolfe, 2018)'s assumed profit rate for the tourism industry (10.3 percent), we can infer that producer surplus is likely to be between $148M and $271M per annum.

Adding consumer surplus to mean producer surplus, yields an estimate of the net benefits of (about) $1.54B. This is very close to the approximate $1.2B estimate of net benefit reported by De Valck and

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41 Calculated from data provided in O'Mahoney et al. (2017): $7,841M expenditure for 51m visitor nights Reef

42 O'Mahoney et al. (2017) do not report average length of stay, so this is calculated from TRA data reported in Table 9

43 Calculated from TRA data reported in Table 9

44 Mustika, Stoeckl, and Farr (2016)

45 N. Stoeckl et al. (2010)

46 N. Stoeckl, Smith, Newsome, and Lee (2005)

47 N. E. Stoeckl (1998)

48 Mean of reported range. Fleming and Cook (2008)

49 Mean of reported range Fleming and Cook (2008)

50 Hundloe (1989) cited in Hoagland, Kaoru, and Broadus (1995)

51 Estimated by dividing total CS estimates (710m-1.6b in 1992 dollars) by estimated visitors (2m). (Carr & Mendelsohn, 2003)

52 Kragt et al. (2009)

53 Buchler (2014)

54 Buchler (2014)

55 O'Mahoney et al. (2017)

Rolfe (2018), suggesting that we can be reasonably confident in this estimate. We thus suggest using an overall estimate of $1.5B per annum with a range of $1.2 to $1.8B.

Formulae used in the model are below.

At t=0, regional estimates of consumer surplus and producer surplus, PS_0^r and CS_0^r were calculated as:

$$PS_0^r = \rho V_0^r \qquad CS_0^r = \gamma V_0^r$$

Where:

ρ is the estimated per-visitor producer surplus ($75.71=10.3[56] percent of mean expenditure estimated at $735[57])

γ is the *estimated* per-visitor consumer surplus ($482[58])

V^r_0 is the number of visitors to region r, at time 0.

Projecting future benefits

When thinking about the way in which these benefits (formally, consumer and producer surplus) might change in response to reef health, we draw upon additional information from studies summarised in Table 10. Estimates of the potential change in per-visitor consumer surplus that could occur in response to changes in various factors relating to reef health (water quality, top predators, iconic wildlife) range from $9 - $150, but only one of those studies generates estimates that are directly relevant to RRAP: Kragt et al. (2009).

Table 10: Empirical studies providing information about the way tourists might respond to reef degradation. All values converted to AUD 2015; methods used to generate values are identified using the following symbols: CB – contingent behaviour; CM – choice modelling; CV - Contingent Valuation; E – Expenditure; TC - Travel Cost; TS- Tourism Satisfaction (related to Life Satisfaction).

Studies on the potential impacts of marine degradation on tourism expenditure
Could lose between $200-$250 of tourism revenues if a 50 percent reduction in coral cover[59] – E, CB
Reduction in water clarity could reduce number of repeat visitors in the Reef catchment [60] – TS, CB
Studies into visitor willingness to pay for 'change' (predicted changes in consumer surplus)
To see (Iconic) Marine species Reef: Whales, Rays, Sharks Turtles $17 - $74 per visitor[61]; large fish $30 – CV
To improve water clarity in the Reef: $14 per visitor, per visit[62] – CV
To protect top predators and/or reduce risk of shipping accidents: $9 and $15.50 per visitor, per visit, respectively[63] – CV
Study of likely impact of a change in consumer surplus if reef degradation
Fall in consumer surplus of as much as $150 per visitor per visit in response to substantial reef degradation[64] – CB

Kragt et al. (2009) surveyed tourists visiting the reef during September 2004 from Port Douglas and used a *contingent behaviour* model to predict changes in visitation and consumer surplus, from 'reef

[56] De Valck and Rolfe (2018) 's profit rate for the tourism industry
[57] Leaving aside whale-watching tourists, the median expenditure per visitor per night is $190. If dividing total number of visitor nights spent in the region, by total number of visitors, estimated nights per visit is: 2.7. If focusing only on over-night visitors, median length of stay is 5 nights (N. Stoeckl, Farr, Jarvis, et al., 2014). Median expenditure per visit is thus between $520 and $950 (2.74 and 5, respectively, multiplied by $190) – so we use $735.
[58] Median CS per visitor per visit
[59] Mustika et al. (2016)
[60] Jarvis, Stoeckl, and Liu (2016)
[61] Depending on species (Farr, Stoeckl, & Beg, 2014)
[62] Farr, Stoeckl, Esparon, Larson, et al. (2016)
[63] N. Stoeckl, Farr, Jarvis, et al. (2014)
[64] Kragt et al. (2009)

degradation'[65]. Their estimates are larger than estimates from other studies in Table 10 and this difference could be attributable to one or more of several factors: (1) general reef health is, in fact, up to 10 times more important than the other factors considered in the other studies; (2) their sample is not representative of the general population of reef visitors (in time, or in place); (3) their methodological approach is one that may inherently generate higher estimates of value than other methodological approaches. All are likely to have some influence, the core question being: how much? Mustika et al. (2016) used contingent behaviour-type questions to explore the sensitivity of Reef catchment visitors to changes in coral (specifically, asking whether they would still have come to the region if coral cover were 50 percent less than existing levels, and if so, how long they would have stayed). They considered the problem of 'hypothetical response bias' (a common problem in stated preference studies) concluding that respondents are likely to have over-stated actual reactions by as much as three times. If Kragt et al. (2009)'s respondents were similarly inclined to overstate responses, then actual changes in consumer surplus, could be closer to $50 per visitor (per visit), than to $150.

We thus suggest using $50 per person as a plausible estimate of the likely fall in consumer surplus that would occur in the event of "significant degradation" (with no adaption); $150 is perhaps best thought of as an upper bound, and Farr et al. (2014)'s estimate of willingness to pay (WTP) for increased sightings of (reef dependent) large fish may be a good lower bound ($30). Extrapolating to all 2.4M visitors, this suggests that reef degradation could generate consumer surplus losses in the tourism industry of about $120M over an entire year [ranging between $72M and $360M].

Losses in producer surplus could be about $23 per visitor (10.3 percent of a potential $225 reduction in tourism expenditure/revenues predicted by Mustika et al. (2016) which – extrapolated to all 2.4M visitors – amounts to about $55M.

Adding producer and surplus estimates, suggests that total losses, if sustained over an entire year, could be about $175M (range: $127M to $415M).

But these are not figures that can be used without further consideration.

The per-visitor value estimates are derived from non-market valuation studies that are (as discussed in sections 4.1.2) 'static' and 'partial equilibrium'. To naively multiply per-person estimates by annual estimates of visitors (as above) is to risk overstating likely actual changes, unless (a) there is blanket degradation of all reefs along the entire Reef and (b) no adaptive responses at all from either tourists or tourism operators. Although recent coral bleaching events suggests that blanket degradation can (and indeed has) occur, to assume there will be *no adaption at all* is not realistic. We recommend thinking of those estimates as the defining the maximum annual losses likely to occur, with actual losses dependent upon adaptive responses.

The literature tells us that tourism destinations transform naturally over time – perhaps starting as a region visited only by the most adventurous, then evolving to one that supports niche groups, and maybe even, some decades later, become one that supports mass tourism (Butler, 1980). This dynamic transformation is a collective outcome of the simultaneous (but interactive) adaptations of

[65] Kragt et al. (2009), p 219-220 "The reef degradation scenario was based on scientific evidence that coral cover and coral biodiversity declines when a reef has been exposed to pollution. Changes in fish abundance are usually not apparent while fish diversity generally declines on degraded reefs (Fabricius et al. 2005). Following Bhat (2003) and Wielgus et al. (2003), the reef degradation scenarios were represented using photographic material. The picture sets represented degradations in coral and fish biodiversity. The choice of pictures was based on scientific material, provided by marine biologist Dr Katharina Fabricius. The first picture set showed a healthy coral reef, representing the current quality of the Reef. The second set included pictures of a degraded coral reef, representing a possible future quality of the Reef. The pictures showed a visible decline in coral cover, coral diversity and fish diversity of approximately 80, 30 and 70 per cent, respectively".

tourists, tourism operators and the destinations in which the tourism exists. It is thus likely (indeed probable), that reef degradation could trigger transformation of the tourism industry currently operating along the Reef coast.

Different types of adaption are likely to play out at different spatial and temporal scales – perhaps with some regions declining and stagnating for years following a mass event, others rejuvenating, and perhaps some even benefiting over the long term. Ignoring spatial complexities for the moment, we expect adaption to occur in several ways, e.g.:

- Tourism operators may change locations (taking visitors to reefs that are not degraded, either within the same region, elsewhere in the Reef or elsewhere in the world).
- Tourism operators may change the foci of their operations (e.g. offering crocodile-viewing tours instead of reef tours).
- Tourists may choose to visit reefs that are not degraded (elsewhere in the Reef, or in the world), or take holidays that are not reef dependent.

So, although it is possible to estimate initial 'impacts' of change (here termed *damages)* at regional scale, one needs to account for adaptations (discussed in more detail in Appendix E).

We assume that tourism operators could apply for (and would likely be granted) permission to move operations from one region to another, should existing sites become markedly degraded – providing, of course, that other 'suitable' sites can be found nearby. We use distance from (mid-point of) QFish grid zone to nearest port to assess the suitability of reef-based alternatives/adaptions. We acknowledge that some adaptations will be 'within- Reef' (tourism operators taking their visitors to undamaged (or less damaged) parts of the reef) and that other adaptions may be 'external' (tourists still coming to the Queensland coast, but spending time in the rain-forest, or on beaches instead). We focus exclusively on 'within-Reef' adaptions, for the moment, ignoring options for tourists (and tourism operators) to visit sites other than the Reef.

For t=1 to T, producer surplus and consumer surplus were thus calculated as:

$$PS_t^r = PS_{t-1}^r - D(PS)_t^r \qquad CS_t^r = CS_{t-1}^r - D(CS)_t^r$$

Whole-of reef values are assumed to be equal to the simple sum of values within each region.

$D(PS)^r_t$ and $D(CS)^r_t$ describe the loss of producer surplus and consumer surplus (the damage) that occurs within region r, during time t, as a consequence of changes in Reef condition, and are calculated as:

$$D(PS)_t^r = \beta^{producer}\, \Delta TWRCI_t^r\, PS_{t-1}^r$$

$$D(CS)_t^r = \beta^{consumer}\, \Delta TWRCI_t^r\, CS_{t-1}^r$$

Where:

$$\Delta TWRCI_t^r = \frac{(TWRCI_t^r - TWRCI_{t-1}^r)}{TWRCI_t^r}$$

$TWRCI_t^r$ is the *tourism-weighted Reef Condition Index* for region, r, calculated as:

$$TWRCI_t^r = \sum_{z=1}^{Z} TWRCI_t^z \; for\; all\; QFISH\; gridzones\; in\; region\; r$$

Where

$$TWRCI_t^z = \frac{TW^z}{\sum_{i=1}^{Z} TW^z} . RCI_t^z$$

$$TW^z = \frac{Number\; of\; reefs\; within\; zone\; z\; that\; are > 0.6ha\; in\; size}{Distance\; from\; nearest\; port}$$

0.6 ha is the size of Moore's reef, a 'proven', viable size for tourism-focused reefs.

Distance from nearest port was calculated by first, identifying plausible ports along the eastern coast of Queensland, and secondly, using the 'great circle distance' formula to calculate the distance from the centre of each QFish grid, to each port, selecting the minimum for use in the index.

$\beta^{producer}$= percent loss in producer surplus likely to occur as a result of a percent fall in RCI. We use an estimate of 0.2 as an initial starting point.

$\beta^{consumer}$= percent loss in consumer surplus likely to occur as a result of a percent fall in RCI. We use an initial estimate of 0.2 to predict the fall in consumer surplus associated with a fall in RCI.

Tourism values are the largest benefit stream, so we explored the sensitivity of final values to changes in those estimates, setting β= 0.4.

We tentatively suggest that adaptions in Reef condition index in the Cairns region may be slower than in the Whitsundays. We do not explicitly account for that in our models, but we flag it as a potentially important issue to be explored in more detail later.

4.4.6 Recreational fishing

Recreational fishing is prevalent along the entire Reef coast – with most activity concentrated near major regional centres (Marine Biodiversity Decline Working Group 2008). In 2017, there were almost 90000 registered recreational vessels in the Reef catchment area (Great Barrier Reef Marine Park Authority 2017b); more than 75 percent of which are likely to be used for recreational fishing (Taylor *et al.* 2012).

Although the QFish data set (used to assess commercial fishing values) has provision to report recreational catches, most recreational fishing activity is unrecorded, or not recorded in a way that can be integrated into QFish. It is thus not possible to obtain recreational fishing data at high spatial resolution.

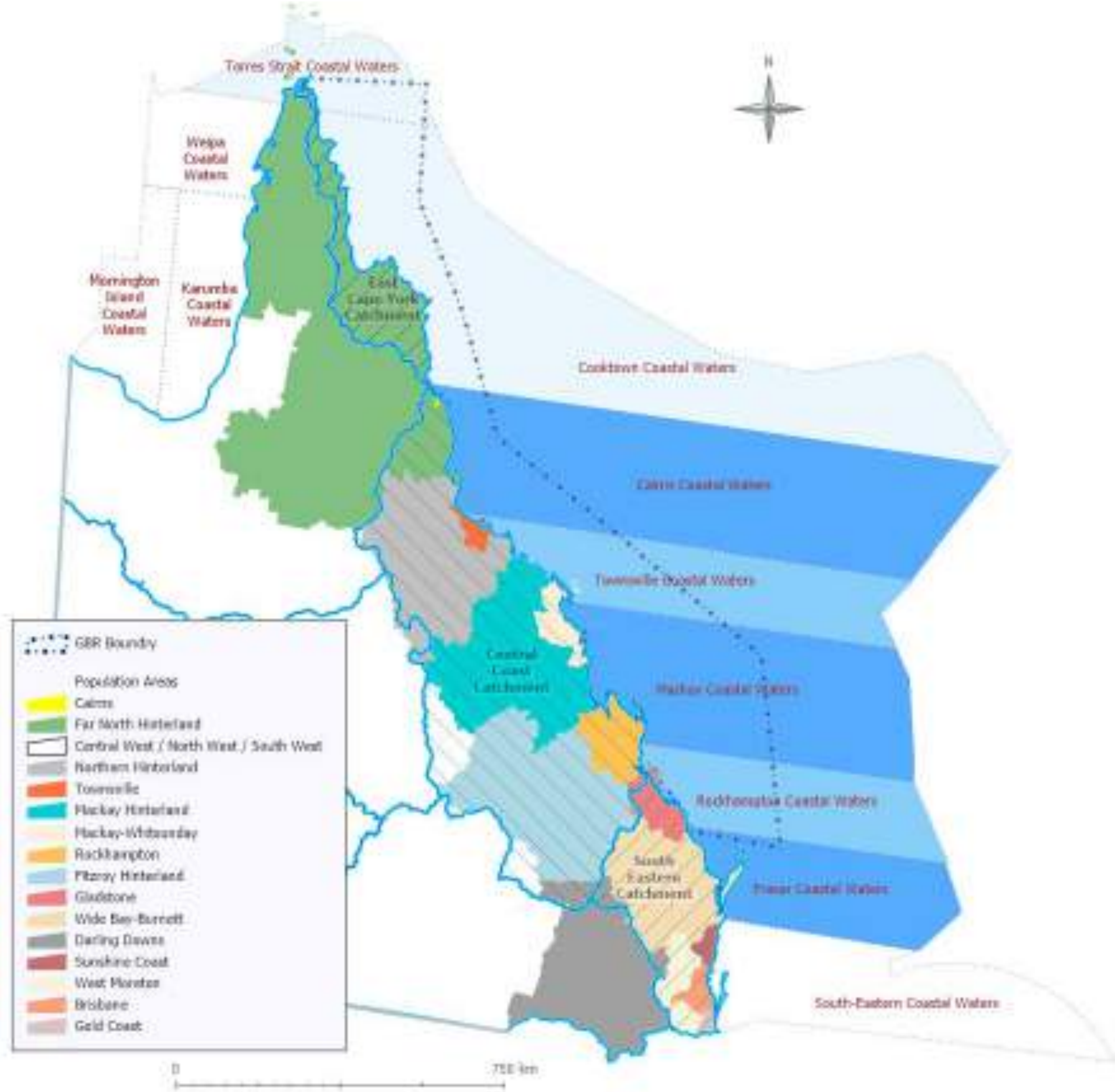

Figure 14: Department of Agriculture and Fisheries terrestrial and marine boundaries used to collate data relevant to recreational fishing, 2013-14.

If one wishes to estimate the economic 'value' of recreational fishing, one needs to consider (a) expenditure on goods and services required for fishing (associated with the 'producer surplus'), and (b) the recreational fishing experience itself (the 'consumer surplus' that accrues to the fisher). These values do not translate simply to individual fish species or fish abundance. They require information on the number of fishers, and on fishing trips.

The Queensland Department of Agriculture and Fisheries conducts regular surveys of recreational fishers (Webley, McInnes, Teixeira, Lawson, & Quinn, 2015) – giving a reasonably comprehensive overview of recreational fishing activity. Different types of data collected by the department, are available for different areas (depicted in Figure 14) at different spatial resolutions. For example:

- Data on the number of fishers and participation rates (fishers per head of population), relates to residential areas (available for SLA's – coloured regions, Figure 14) - and for groups of river catchments (boundaries shown in blue, Figure 14). Across all residential regions in Queensland, there were an estimated 642,000 recreational 'fishers' during 2013-14, approximately 243,000 of whom live in regions adjacent to the Reef (shaded cells, Table 11).

Table 11: Estimated number of recreational fishers during 2013-14, by residential region (data source: Webley et al. 2015)

Residential region	Number of fishers
Brisbane	236,000
Gold Coast	42,000
Sunshine Coast	59,000
West Moreton	17,000
Wide Bay-Burnett	52,000
Darling Downs	33,000
CW/NW/SW	12,000
Gladstone	12,000
Rockhampton	22,000
Fitzroy Hinterland	12,000
Mackay-Whitsunday	34,000
Mackay Hinterland	8,000
Townsville	36,000
Northern Hinterland	11,000
Cairns	26,000
Far North Hinterland	30,000
Total	**642,000**

- Fishers do not only fish in the regions in which they live: they often travel to do so. Data on fishing effort (days spent fishing) is reported for coastal areas (shown in Figure 14, with different colours in the marine environment), except the far north, where survey numbers are small. In 2013-14, there were an estimated 143,000 fishers who fished in the Reef, spending a total of 563,000 days doing so (Table 12).

Table 12: Estimated number of recreational fishers and estimated number of fisher days, in coastal waters of the Reef 2013-14 (data source: Webley et al. (2015)).

Coastal region	Est. number of fisher-days	Est number of recreational fishers using these waters
Cairns coastal waters	103,000	24,839
Townsville coastal waters	93,000	25,762
Mackay coastal waters	83,000	20,000
Rockhampton coastal waters	75,000	19,182
Fraser coastal waters	209,000	52,250
TOTAL	**563,000**	**142,033**

- Species-specific data (e.g. total number of fish caught) are only reported on for all of Queensland (including regions in the Gulf of Carpentaria, and fresh-water species) – with no spatially explicit information. Throughout Queensland, more than 14 million fish, prawns and crab were caught during 2013-14, approximately 1.4 million of the fish caught were 'reef dependent' (highlighted rows, Table 13). We do not have detailed information about all species, but the Department of Agriculture and Fisheries report has a special section on coral trout – reporting that almost all were caught from boats, off-shore, in the coastal waters of the Great Barrier Reef Marine Park.

Table 13: Estimated number of fish caught, by species group, by recreational fishers 2013-14 (data source: Webley et al., 2015).

Species group all (marine only)	Total number caught	Number caught as a % of total number caught (excluding prawns)
Prawn (Numbers estimated)	2,400,000	
Crab	1,976,000	16
Whiting	1,783,000	15
Bream	1,417,000	12
Finfish (other)	1,100,000	9
Tropical snapper and sea perch	653,000	5
Mollusc	560,000	5
Trevally and amberjack	520,000	4
Herring and pilchard	466,000	4
Catfish	452,000	4
Flathead	412,000	3
Javelin	383,000	3
Mullet	243,000	2
Cod and groper	242,000	2
Snapper	203,000	2
Emperor	201,000	2
Shark and ray	193,000	2
Barramundi	174,000	1
Tailor	170,000	1
Coral trout	170,000	1
Mackerel	155,000	1
Grunter and trumpeter	143,000	1
Jewfish	121,000	1
Garfish	104,000	1
Threadfin and Australian salmon	103,000	1
Morwongs and sweetlips	73,000	1
Wrasse	67,000	1
Parrotfish	53,000	0
Pike	33,000	0
Eel	27,000	0
Cephalopod	26,000	0
Pearl perch	25,000	0
Tuna	13,000	0
Non-fish (other)	12,000	0
Cobia	7,600	
TOTAL	**14,680,600**	**100**

The marine fishing regions used by the Department of Agriculture and Fisheries can be imperfectly allocated to the tourism regions used by the Great Barrier Reef Marine Park Authority (far north Queensland, Cairns, Central and Southern) – as shown in the far-left column of Table 14. This table shows that more than 40 percent of coral trout were caught in waters in the Cairns Coastal Waters.

Table 14: Estimated number of coral trout caught by recreational fishers in coastal waters of the Great Barrier Reef Marine Park, 2013-14 (data source: Webley et al., 2015).

Broader Reef Region	Coastal waters (DAF)	Number harvested	Number released	Total catch	% of total catch
FNQ	Torres Strait	2,000	1,000	3,000	1.76
FNQ	Cooktown	7,000	2,000	9,000	5.29
Cairns	Cairns	47,000	24,000	71,000	41.76
Central	Townsville	22,000	8,000	30,000	17.65
Central	Mackay	15,000	17,000	32,000	18.82
Southern	Rockhampton	8,000	4,000	12,000	7.06
Southern	Fraser	2,000	3,000	5,000	2.94
Not in Reef	South-eastern	1,000	7,000	8,000	4.71
	Total	104,000	66,000	170,000	100

Estimating current benefits

To estimate producer surplus, we looked for studies that estimate expenditure, combining that information with estimates from the preceding tables. Some studies estimate fishing and boating values together[66]; here we use only those studies that report expenditure associated with recreational fishing (O'Mahoney et al. (2017), Driml (1987) and Murphy (2002a), Murphy (2002b)). We work with the most recent expenditure estimate from Deloitte Access (O'Mahoney et al., 2017): $70M spent on recreational fishing related goods, during 2015/16 (approximately $124.33 for each of the 563,000 fisher days – Table 12). We multiply that estimate by 10 percent to estimate the producer surplus associated with recreational fishing in the Reef region (using the profit rate associated with tourism (De Valck & Rolfe, 2018)), which, like recreational fishing, has a large retail component but also some boating): $7M in total. We are unaware of any study that provides information to guide us when determining what portion of that surplus should be allocated to reef-dependent species, so use the Department of Agriculture and Fisheries data on number of species caught – 11 percent of the total catch (Table 13) – generating an aggregate estimate of about $770,000. We allocate the $770,000 regionally, using Department of Agriculture and Fisheries data on the percentage of coral trout caught in different coastal waters along the Reef (Table 15) to do so.

To estimate consumer surplus, we used a conservative estimate of $167 per angler, per trip from Prayaga et al. (2010), which is at the lower end of estimates from Farr and Stoeckl (2018). Multiplying that by the department's estimates of the total number of fisher-days in different coastal regions of the Reef (563,000), allows us to generate regionally specific estimates of the consumer surplus associated with recreational fishing ($94,021,000). Here too, we are unaware of any research that allows us to determine what portion of that surplus is attributable to reef-dependent fish, so use the Department of Agriculture and Fisheries estimates of total catch (11 percent being reef-dependent) to scale – generating an estimate of reef-dependent recreational fishing consumer surplus of $10,342,310. As for estimates of producer surplus, we allocate that amount regionally, using departmental data on the percentage of coral trout caught in different coastal waters along the Reef (Table 15) to do so.

[66] Recreational fishing and boating ≈ $400M per annum – IO (Access Economics, 2007).

Together, this suggests that the monetary value of the current benefit stream associated with reef-dependent recreational fishing in the Reef is in the order of $11M per annum. We note the considerable uncertainties associated with this estimate, suggesting that a plausible ‘range’ of estimates is thus likely between $5M and $15M.

Table 15: Estimated producer and consumer surplus associated with recreational fishing in coastal waters of the Great Barrier Reef Marine Park, 2013-14, by region (coastal waters).

Coastal region (DAF)	**Broader Reef Region**	**% of total catch**	**Estimated (reef dependent) producer surplus**	**Estimated (reef dependent) consumer surplus**	**Estimated (reef dependent) producer + consumer surplus**
Torres Strait	Far north	1.76	13,552	182,025	195,577
Cooktown	Far north	5.30	40,810	548,142	588,952
Cairns	Cairns	41.76	321,552	4,318,949	4,640,501
Townsville	Central	17.65	135,905	1,825,418	1,961,323
Mackay	Central	18.82	144,914	1,946,423	2,091,337
Rockhampton	Southern	7.06	54,362	730,167	784,529
Fraser	Southern	2.94	22,638	304,064	326,702
South-eastern (not Reef)		4.71	36,267	487,123	523,390
TOTAL		**100**	**770,000**	**10,342,311**	**11,112,311**

Formalising this for the model, we note that recreational fishing benefits are estimated by multiplying estimates of the number of fishing trips taken each year, by estimates of consumer and producer surplus, making adjustments to allow for the fact that not all recreational fishing trips target ‘reef dependent’ species

For t=0, regional estimates of benefits were calculated as:

$$PS_0^r = \rho \times PS\ per\ trip\ \times N_0^r \qquad CS_0^r = \rho \times CS\ per\ trip\ \times N_0^r$$

Where:

N^r_0 is the number of fishing trips per region r, at time 0 (2016), estimated from (Webley et al., 2015);

ρ = 11 percent (catch that is ‘reef dependent’, estimated from data on fish species caught - Webley et al. 2015)

Producer surplus per trip = $12.72 (10.3 percent of estimated fishing expenditure per trip (expenditure estimates derived from Deloitte Access - O'Mahoney et al. (2017); percentage of expenditure associated with PS - inferred from De Valck and Rolfe (2018));

consumer surplus per trip = $167 (from Prayaga et al. (2010))

Whole-of reef values were assumed to be equal to the simple sum of values within each region.

Projecting future benefits

The figures above describe current benefits; but additional information is required to comment on the way in which those benefits might change in response to changes in reef health.

Research has shown that the 'value' of a fishing trip extends far beyond the meat value of fish caught – with numerous confounding factors including, but not limited to those associated with the weather, the phase of the moon, the number of people on the trip, the boat type and personal attitudes having significant impact. Even if fishers do not catch any fish, they still get 'value' from a trip. Studies that consider the value of a recreational fishing trip thus seek to collect data to control for multiple interacting factors, isolating the 'marginal' impact of changes in catch. We draw upon information from two studies which estimate the response of fishers (and thus losses in consumer surplus) to changes in catch. The first study used a combination of contingent behaviour, and travel cost approaches (with loss estimates at $1.26 for a 10 percent reduction in catch, and $7 for 25 percent reductions in catch) (Prayaga et al., 2010). This was from a base of approximately 1.44 fish caught, per angler group (average size 2.31), per trip[67], suggesting that losses are in the order of $8.75 -$19 per fish per group ($4.38 - $8.22 per angler). The second study used travel cost alone, with loss estimates in the range of $3 - $33 associated with catching 0 rather than 1 fish (the actual catch of these fishers averaged 1.57 fish per fisher per trip – see Farr and Stoeckl (2018)). This study also found that inexperienced fishers tended to overestimate the chance of catching a fish, and this tended to generate a downward bias in monetary estimates of losses from reduced catch – an implication being that the Prayaga et al. (2010) estimates are likely to be conservative.

We thus suggest using $8 as an estimate of the loss of consumer surplus that fishers are likely to experience (per fisher, per trip) should they catch one-less fish. Dividing predicted losses in consumer surplus given a loss in catch ($8) by estimates of the total consumer surplus associated with a fishing trip ($167) gives an indication of the likely percent fall in consumer surplus which could occur in response to a fall in catch. This is quite low (5 percent) – consistent with observations from the literature about the (lack of) sensitivity of recreational fishing values to changes in catch.

As regards producer surplus, we are unaware of any studies that have sought to estimate the sensitivity of producer surplus to changes in catch – let alone changes in reef-dependant recreational catch and/or reef health. But we do not anticipate significant reductions. Producer surplus is linked to sales of fishing supplies for recreational fishers – if there are fewer reef fish, fishers are still likely to purchase fishing equipment – perhaps in the hope of still catching reef fish or catching other types of fish. Arguably, the equipment needed to fish on the reef is more expensive than that required to fish onshore or in estuaries (e.g. bigger boats are required; more fuel will be used), so some effects are expected, but these are likely to be relatively small.

Like the tourism industry, distance is important to recreational fishers: the further they must travel to a fishing location, the less frequently they will go. As such, we expect changes in the condition of reefs that are a long way from shore, will have less impact on recreational fishing values, then changes to the condition of in-shore reefs.

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[67] With 18.72 fish, on average, caught during 12.98 trips during the previous 12 months.

For t=1 to T, producer surplus and consumer surplus were thus calculated as:

$$PS_t^r = PS_{t-1}^r - D(PS)_t^r$$

$$CS_t^r = CS_{t-1}^r - D(CS)_t^r$$

$D(PS)^r_t$ and $D(CS)^r_t$ describe the loss of producer surplus and consumer surplus (the 'damage') that occurs within region r, during time t, as a consequence of changes in reef condition, calculated as:

$$D(PS)_t^r = \beta^{producer}\ \Delta RFWRCI_t^r\ PS_{t-1}^r$$

$$D(CS)_t^r = \beta^{consumer}\ \Delta RFWRCI_t^r\ CS_{t-1}^r$$

Where

$$\Delta RFWRCI_t^r = \frac{(RFWRCI_t^r - RFWRCI_{t-1}^r)}{RFWRCI_t^r}$$

$\beta^{producer}$= percent loss in producer surplus likely to occur as a result of a percent fall in RFWRCI and

$\beta^{consumer}$= percent loss in consumer surplus likely to occur as a result of a percent fall in RFWRCI.

β is set equal to 0.05 (reflecting significant adaptive capacity if only reef fish are impacted, and other recreational fishing species are still prevalent).

$RFWRCI_t^r$ is the recreational fishing-weighted Reef condition index (RCI) for region, r, calculated as:

$$RFWRCI_t^r = \sum_{z=1}^{Z} RFWRCI_t^z \ for\ all\ QFish\ gridzones\ in\ region\ r$$

Where

$$RFWRCI_t^z = \frac{RFW^z}{\sum_{i=1}^{Z} RFW^z} . RCI_t^z$$

$$RFW^z = \frac{1}{Distance\ from\ nearest\ port}$$

Distance from nearest port was calculated in an identical manner as for the tourism estimates.

The monetary value of this benefit stream is small relative to other benefit streams (Tourism, Non-use, Indigenous and Option values) so we have not explored the sensitivity of final estimates to changes in assumptions about the size of β – but note it is possible to do so.

4.4.7 Learning and Inspiration

In the online supplementary materials that support Díaz et al. (2018)'s paper on *Natures contribution to people,* this benefit stream is described as follows:

> Provision, by landscapes, seascapes, habitats or organisms, of opportunities for the development of the capabilities that allow humans to prosper through education, acquisition of knowledge and development of skills for well-being, information, and inspiration for art and technological design (e.g. biomimicry).

The lack of empirical information about the benefits of the reef-related benefits associated with learning and inspiration, almost certainly reflects the fact that the contribution that these ecosystem services make to human wellbeing are an archetypal example of complex social goods (N. Stoeckl et al., 2018) generating value at a broad social scale immeasurable with current methods that focus on the contribution that goods and services make to an individual's welfare/utility (section 4.1.3).

Reef-related research is but one example of the way in which the reef supports learning and inspiration. Measuring research values requires calculating the benefit to society of research undertaken minus the cost of undertaking the research. There are several examples of studies that have calculated marine focused research expenditure in the Reef, and the contribution that this expenditure makes to the regional, state, and national economy – see, for example, Deloitte Access Economics (2013). We could use expenditures to approximate costs: the challenge being to estimate research benefits. We could find no empirical studies of this value for the Reef (or indeed elsewhere) which likely reflects the difficulties of attempting to assess the benefits of research which are often intangible and may not be apparent until many years after the research has taken place.

Other benefits associated with learning and inspiration are similarly difficult to estimate: The Reef undoubtedly makes a profound contribution to society, through its ability to inspire creativity (not only for art, but also for innovation and entrepreneurship). A significant body of research highlights the role that the 'creative classes' play in economic development (Florida, 2005; Hein, Van Koppen, De Groot, & Van Ierland, 2006). At the risk of oversimplifying, Florida's theory is built upon three important, and linked observations.

1) Economic growth and development are crucially dependent on talented, creative people (be they CEO's, artists, or academics)
2) "Talent is mobile, it flows, and the places that it flows to are the ones that are the most welcoming" ((Florida, 2014), p 201).
3) "While the economy is obviously the subject of much attention … attachment [to place] is most closely related to how accepting a community is of diversity, its wealth of social offerings, and its aesthetics" ((Florida, 2014), p 203).

Not only does the Reef provide an aesthetic background, with social and recreational opportunities that enhance the quality of life of those who live nearby, the Reef inspires creativity (starkly evidenced in local art, photographs and other images); which, from Florida and other's work has been unambiguously shown to contribute to economic growth. It thus has real and (in principal) measurable economic 'value', although we have not been able to find a relevant empirical study that quantify these types of value.

We thus omit these benefit streams from our quantitative assessment noting that the omission generates an unambiguous and perhaps substantial downward bias in final value estimates.

4.4.8 Non-use values

It was more than 80 years ago that environmental economists highlighted that people do not have to 'use' the environment (for extraction of goods, for recreation, or for aesthetics) to benefit from it *(Krutilla, 1967; Weisbrod, 1964)*: some people 'feel better' knowing that the environment exists by and for its own sake (*existence values),* that it is preserved for future generations (*bequest values)*, and/or that it is preserved 'in case' mankind determines other uses for it in the future (*option values).* The terminology used to describe these values differs across studies, as do the categories used, but the essence remains. In their study of the Reef, Deloitte Access for example, discuss non-use values, although they do not use that terminology, instead referring to bequest, existence, altruist and icon values (O'Mahoney et al., 2017).

The fact that different studies have different foci and use different terminology, reflects the critical need to contextual values when attempting to assess the 'value' of nature's contribution to people (Díaz et al., 2018), since these types of non-material benefits are diverse, and highly variable cross-culturally:

> Landscapes, seascapes, habitats or organisms [are] the basis for religious, spiritual, and social-cohesion experiences.
>
> - [They provide] opportunities for people to develop a sense of place, belonging, rootedness or connectedness, associated with different entities of the living world (e. g. cultural, sacred and heritage landscapes, sounds, scents and sights associated with childhood experiences, iconic animals, trees or flowers) (*187-198*)
> - [They are the] basis for narratives, rituals and celebrations provided by landscapes, seascapes, habitats, species or organisms (*13, 21 169, 188, 189, 191, 199*)
> - [They provide a] source of satisfaction derived from knowing that a particular landscape, seascape, habitat or species exists (*200, 201*)
>
> Supplementary materials, (Díaz et al., 2018).

Noting (a) the importance of contextualising; and (b) that Indigenous cultural values are inherently different from non-Indigenous values, we focus first, on generic studies that provide information about bequest, existence, altruist and icon values (collectively referred to here as non-use values), devoting a separate section to Indigenous cultural values.

Estimating current benefits

Worldwide, there have been countless studies seeking to quantify various non-use values, most using stated preference techniques such as contingent valuation and choice modelling (see Appendix B). In recent decades, the Life Satisfaction (LS) approach has emerged as another way of eliciting environmental values without relying on peoples stated behavioural responses (e.g. to pay, or to select a particular option) in hypothetical situations. Recent studies relevant to the Reef are listed in Table 16. Estimates from Jarvis, Stoeckl, and Liu (2017) do not allow us to separate use and non-use (cultural) values, so we do not use them in this assessment (to do so, might risk double-counting, since use-values are considered above). Instead, we use the mean value of the other two studies reporting on 'current' values: $108 per household per annum.

Table 16: Recent studies relevant to the estimation of non-use values (non-material benefits that support identities). All values converted to AUD 2015; methods used to generate values are identified using the following symbols: BT – benefit transfer; CM – choice modelling; CV - Contingent Valuation; TC - Travel Cost; LS- Life Satisfaction.

Australian residents: Willing to pay $76.43 per household per annum for non-use values of the Reef[68] - BT
Australian residents: Willing to pay $141.18 per household per annum to protect the Reef[69] - CV
Residents of the Reef catchment: $15,000 - $30,000 p.a. per household as one-off lump sum compensation for complete loss of cultural services of the Great Barrier Reef World Heritage Area (includes use and non-use cultural values associated with beaches, mangroves, islands and the reef)[70]

Non-use values do not only accrue to Australian Residents. That the Reef is on the 'world heritage' listing, itself speaks to the non-use values of people across the globe. But as previously, we limit our social scale to include only current residents of Australia (24 million persons with approx. 9.4 million households). At $108 per household, this suggests that for Australian residents, non-use values are in the order of $980M per annum. We note that there are no businesses ('producers') involved in the creation of non-use values, so there is no need to make further adjustments for producer surplus – the $980M represents a (true) net benefit that accrues to residents of Australia. If we were to include people from around in the world in this assessment, these estimates would rise markedly since they are, by definition, estimated as value per household, multiplied by number of households. In their assessment of the value of ecosystem services associated with Panda reserves in China, for example, Wei et al. (2018) found that non-use values were ≈ $700M p.a. if considering only the population of China, but perhaps as much as $5B per annum, if including populations from around the world (the approximately 470 m households within the OECD). Deloitte Access note that if they were to use the data they collected in the international study to model WTP responses for the US, the UK and France, Germany and Canada, then their estimate of non-use values would rise from approximately $1.2B (Australian residents) to at least $5B per annum (O'Mahoney et al., 2017).

Methods used to assess non-use values are not always well understood outside the economic mainstream and thus considered somewhat contentious by non-economists. But much of that assumed contention is underserved. The idea of using surveys to elicit preferences/values was first suggested in 1947 and in the last (almost) 7 decades methods for doing so, and for analysing data collected in the surveys have markedly advanced. While not 'definitive', we can be reasonably confident in the robustness of estimates generated for the AUSTRALIAN population and thus suggest using $980M per annum as the base, with the range of estimates varying from $490M (allowing for uncertainty regarding the proportion of that estimate which is strictly reef dependent), to $1200M (the estimate used by Deloitte Access in O'Mahoney et al. (2017)).

We note that this estimate cannot be allocated spatially within the Reef. It is simply not possible to identify specific reefs or locations within the marine park that 'produce' these benefit streams which are inherently, aspatial. That said, while current, per-person non-use benefits are seemingly similar

[68] Oxford Economics (2009), inferring values from work undertaken by Hundloe (1990) and Jill Windle and Rolfe (2005)
[69] O'Mahoney et al. (2017). Estimates are reported per person (and total for Australia). The O'Mahoney et al. (2017) sample included only persons aged 18 years and over. In June 2017, there were an estimated 18,795,674 people, over the age of 18, living in Australia (http://www.abs.gov.au/Ausstats/abs@.nsf/mf/3101.0), suggesting aggregate values of $1.27B. Dividing by the estimated number of households in Australia (9m) gives a comparable estimate of value, expressed as $ per annum per household,
[70] Jarvis et al. (2017)

throughout Australia, research shows that responses to changes in the Reef condition index are likely to differ geographically (see below). So, when developing formulae for use in our model, we estimated initial values for residents of Queensland and residents of the rest of Australia separately (i.e. two ‘regions’).

For t=0, non-use benefits were estimated as:

$$CS_0^r = \Phi_0 \, HH_0^r$$

Where:

Φ_0 is the estimated per-household benefit associated with non-use values, during 2016 ($108, the mean of estimates from Oxford_Economics (2009) and Deloitte Access in O’Mahoney et al. (2017)).

$HH^r{}_0$ is the estimated number of resident households in region r, at time 0. HH numbers were estimated by dividing estimates of total population for Queensland and the rest of Australia by average household size (2.55). This gives 1,895,999 HH in Queensland, and 7,504,401 HH in the rest of Australia.

Projecting future benefits

To estimate likely responses of this benefit stream to changes in reef health, we looked for studies that estimate marginal values (Table 17). Arguably, the most relevant is that of Rolfe and Windle (2012). They used choice modelling to assess non-use values for residents of Townsville, Brisbane, Sydney, Melbourne, Adelaide and Perth – separating each of those samples into three groups (those who had visited the reef, those who had not visited the reef but planned to do so, and those who hand not visited the reef, and had no plans to do so). Core to this analysis is their conclusion that outside Queensland, the non-use values associated with the reef, do not appear to suffer from ‘distance decay’; they are relatively similar – although generally lower than the (similar) values within Queensland. For Townsville and Brisbane residents, mean WTP was about $38 per household per annum (for a one percent improvement in the condition of the Reef); in cities outside Queensland, WTP was about $18. Looking at various sub-sets of data, they were also able to conclude that at least some (recreational) option values were included in expressions of WTP – specifically, respondents who lived outside Queensland and who had plans to visit the reef in the future, had higher WTP than those without such intentions. We use $15 (rather than $18) as the estimate of WTP for non-Queensland residents (mean values for those without plans to visit).

Table 17: Estimates of likely changes in non-use values that could result from a change in Reef condition index. All values converted to AUD 2015 and drawn from Rolfe and Windle (2012)’s choice modelling study

Australian residents: WTP $23.63 per household per annum for a one percent improvement in reef condition; $9.36 - $15.10 per household per annum for ‘improvements’ in health of seagrass, fish and reef - CM

Queensland residents: WTP $38.00 per household per annum for a one percent improvement in reef condition – CM

Residents of other Australian States: WTP $18.00 per household per annum for a one percent improvement in reef condition – CM

Given the way in which we have developed formulae to estimate current values, non-use benefits will change if there are changes to either per-household benefits or to changes to population. We focused on changes associated with per-household benefits to ensure that estimates of changes in aggregate non-use benefits were not obfuscated by changes in population. In other words, we assumed that $HH_t^r = HH_0^r$ for all t. Changes in estimates of non-use benefits were thus assumed to be driven entirely by changes in estimates of per-household non-use benefits (Φ).

For t=1 to T, non-use benefits were estimated as:

$$CS_t^r = \Phi_t \, HH_0^r$$

With

$$\Phi_t^r = \Phi_{t-1}^r + \mathrm{D}(\Phi)_t^r$$

$\mathrm{D}(\Phi)_t^r$ describes the loss of per-household non-use benefits (the 'damage') that occurs as a consequence of changes in reef condition. These benefits are not tied to a particular place, so are *a spatial*. We thus link responses to in non-use values to changes in reef condition using a single (average) Reef condition index for the entire Reef.

We use two different damage functions, for Queensland ($\mathrm{D}(\Phi)_t^{QLD}$) and the rest of Australia ($\mathrm{D}(\Phi)_t^{RoA}$), each of which is a function of changes in reef condition, across the entire Reef:

$$\mathrm{D}(\Phi)_t^{QLD} = \eta^{QLD} \, \Delta RCI_t^{GBR}$$

$$\mathrm{D}(\Phi)_t^{RoA} = \eta^{RoA} \, \Delta RCI_t^{GBR}$$

Where

η^{QLD} is the estimated fall in per-household non-use benefits for residents of Queensland that is likely to occur as a result of declines in RCI. It is, in the first instance set to 0.35[71].

η^{RoA} is the estimated fall in per-household non-use benefits for residents outside Queensland that is likely to occur as a result of declines in RCI. In the first instance, we set it equal to 0.14[72].

Non-use values are the second largest benefit stream, so we explored the sensitivity of final values to changes in those estimates, raising η^{QLD} to 0.4 and η^{RoA} to 0.2.

4.4.9 Indigenous cultural values

At the time of the last census, approximately one million people lived in the Natural Resource Management regions that comprise the Reef catchment, almost 10 percent of which were of Aboriginal and/or Torres Strait Islander descent (Australian Bureau of Statistics 2006). There are more Indigenous people (in total, and as a percent of the population) residing in the Cape, than in more southern parts (Figure 15).

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[71] Rolfe and Windle (2012) estimate that residents of QLD are WTP $38 to prevent a one percent deterioration in reef health. So we divided the $38, but estimates of current values ($108) .

[72] Rolfe and Windle (2012) estimate that residents of Australian states outside QLD are WTP $18 to prevent a one percent deterioration in reef health – although some of that WTP seems to be associated with intention to visit in later years. We use information from their paper to adjust that WTP estimate to $15, and divide through by estimates of current values ($108).

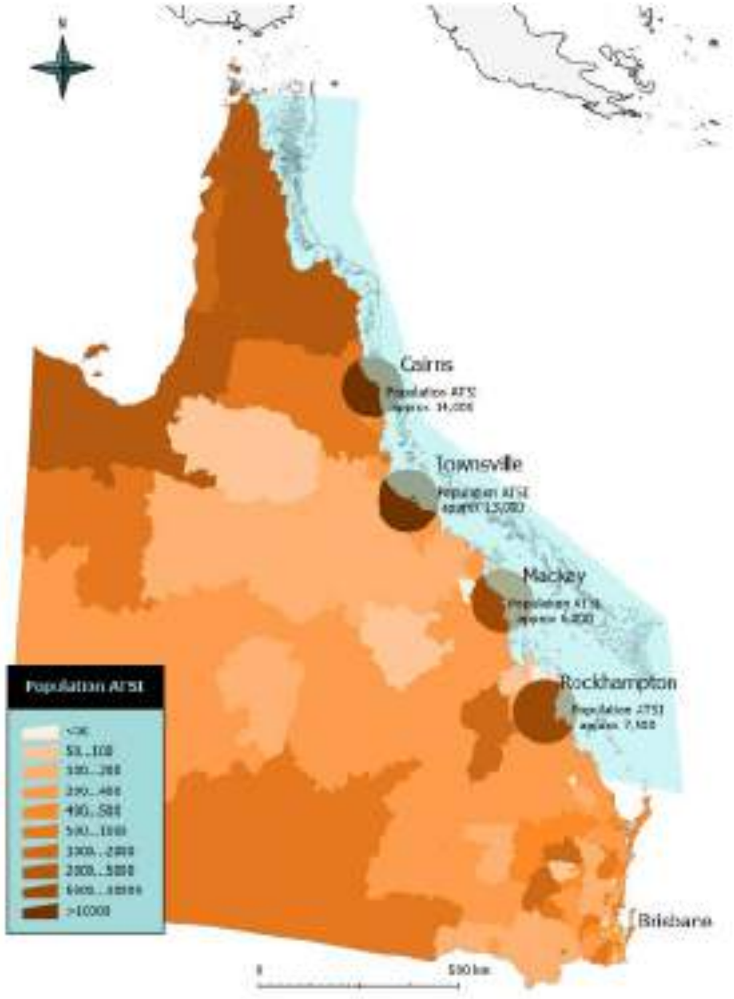


Figure 15: Indigenous populations of Queensland. Data source: Australian Bureau of Statistics 2016 table builder. Major population centres selected as being by the reef and greater than 100,000 using Australian Bureau of Statistics SLA3 data. Other regions portrayed at SLA 2 level.

The inextricable link between Indigenous cultural values and the health/condition of land and sea country (referred to simply as ‘country’) is widely documented (Hill, Walsh, Davies, & Sandford, 2011). Some benefits which Indigenous people derive from country are ‘tangible’ (e.g. food harvested). Other benefits, such as those associated with culture, tradition and spirituality, are intangible, but nonetheless crucially important. For Indigenous people, going out ‘on country’ generates documented improvements in mental and physical health and in social wellbeing (Burgess, Johnston, Bowman, and Whitehead (2005), Garnett et al. (2009)) – similar to the physical and mental health impacts that have also been observed for non-Indigenous urban dwellers who are able to spend time ‘with nature’ (Bratman, Hamilton, & Daily, 2012). Being out on country also provides Indigenous people with opportunities to gather food and bush medicines for personal consumption, ceremony and tradition. Eco-enterprises associated with land and sea management activities create employment for the Indigenous people and active involvement in other industry sectors such as mining and tourism, help reduce welfare dependence (Zander & Garnett, 2011)). Healthy ecosystems are known to contribute to education outcomes with visits ‘on country’ providing appropriate forums for cultural knowledge exchange (Abah, Mashebe, & Denuga, 2015; ALSC, 2004; Ammann, 2007; ANKN, 2008; Casimirri, 2003).

The significance of these values is demonstrated in numerous ways, including, but not limited to the TUMRAs (traditional use of Marine Resource Agreements) between Traditional Owners of sea country in the Great Barrier Reef Marine Park and the Great Barrier Reef Marine Park Authority. As noted by Deloitte Access, eight traditional use of Marine Resource Agreements cover 16 of Indigenous groups and nations of the Great Barrier Reef[73], and these traditional use of Marine Resource Agreements are associated with more than 70 language groups (O'Mahoney et al., 2017).

Estimating current benefits

Both tangible and intangible benefits have been shown to support or improve (Indigenous) wellbeing (Larson et al., 2018), although there are relatively few empirical studies that have used techniques like those described in Appendix B, to convert those documented improvements in wellbeing, into monetary estimates. Some relevant studies are summarised below[74]. We use information from those studies to draw inferences about potential values but note that our decision to do so is not uncontroversial. We have conferred with several Indigenous scholars, who have given 'in principal' support to the idea of including these very rough estimates within our broader assessment. There is collective agreement on the need to ensure that more detailed work is undertaken to properly assess these values, and that this work is led by Indigenous scholars to ensure that the investigation is undertaken in a culturally appropriate manner and to, crucially, provide the 'space' for truly innovative thought. Numerous non-Indigenous scholars have tried (and failed) to describe Indigenous cultural values using knowledge developed from non-Indigenous (Western science) perspectives; it is time to allow for new perspectives (which may properly blend Indigenous and Western knowledges) that may allow for significant scientific breakthroughs.

- Some studies have sought to infer monetary values by determining how much it would cost to achieve similar outcomes (e.g. health, education, self-confidence) using formal western methods of doing so. We are unaware of any such study that has been done in the Reef, but direct readers to a recent study of ecosystem service values on an Indigenous property in the Northern Territory (Sangha et al. 2017). This study used monies expended on Indigenous people in the form of social security to generate estimates of the value of these services to Indigenous people. The logic for using this expenditure for the value of services people accrue from their coastal and marine resources is that social security payments contribute to health, education and security – all of which are services that ecosystems provide to Indigenous people. Final estimates were in the order of $22,000 per person per annum.

- With/without studies are also considered an appropriate means of estimating values that are not directly observable. A study that looked at the opportunity cost of poverty in Thamarrurr (Wadeye) in the Northern Territory (Taylor & Stanley, 2005) compared what was actually produced/earned in Wadeye, with what *could* potentially be produced if none of the problems associated with poverty were present (including, but not limited to poor health and educational outcomes). The report concluded that there was a foregone output opportunity, associated with poverty, equal to $43.8M per annum, and that an additional $4M per annum was spent on 'remedial' costs (e.g. court fees) that would not need to be paid, should conditions be improved. Together, these costs were about

[73] http://www.gbrmpa.gov.au/our-partners/traditional-owners/traditional-owners-of-the-great-barrier-reef

[74] For numerous reasons stated preference valuation techniques, which are based on the construction of hypothetical markets are not generally useable in Indigenous settings (Farr, Stoeckl, Esparon, Grainger, & Larson, 2016; N. Stoeckl et al., 2018; Venn & Quiggin, 2007), so we do not include such estimates here. Problems with using these techniques, which have been developed in (mostly) urban, non-Indigenous settings within remote, Indigenous settings include, but are not limited to the fact that: lower incomes bias value estimates downwards (willingness to pay depends on ability to pay), some values are held at the community, rather than the individual level, and socio-cultural taboos make it inappropriate to ask people about their willingness to pay for some things.

$22,761 per person (per annum) – an amount almost equal to that generated by (Sangha et al. 2017), above.

- In the Reef catchment, Social Ventures Australia Consulting (2016) completed a study of the social return on investment in the Girrigun people's Indigenous protected area (IPA) north of Townsville, and their associated ranger programs. These programs manage the land and sea environment (e.g. threatened and invasive species management and monitoring, feral animal and weed control, fire management, cultural site maintenance, public area maintenance and research, monitoring and data collection) and support Traditional Owners of land and sea within the Girringun IPA to take ownership of the natural and cultural heritage management of their country. So the estimates generated in this study include, but are not limited to those associated with the Reef (since many are linked to terrestrial and other ecosystem management activities and values). Collectively, the programs were estimated to have generated returns for members of the (Indigenous community which amount to approximately $2902 per person per annum. These were divided between benefits accruing to rangers ($1105 per person per annum for rangers[75], the benefits being increased skills through training and experience, increased confidence, better health and wellbeing, increased pride and sense of self, better caring for country), and benefits accruing to the community at large ($1797 per person per annum[76], the benefits being associated with: more role models for young people, rangers and families living on country, less violence, IPA leveraged for additional funding and economic opportunities, increased respect from non-Indigenous community, better cultural asset management, connection to country strengthened, culture and language conserved, more burning using cultural practices, less noxious weeds, and fewer feral animals).
- In the Torres Strait: Delisle et al. (2017) found that the benefits of the traditional hunting of Dugong and Turtle could be roughly divided into three separable groups – 'community', 'individual' and 'family' (with all family values related to food). Researchers used the replacement cost technique to estimate the market value of 'family' (food values) – these amounted to between $500 and $900 per person per annum, having subtracted the cost of harvest (e.g. fuel for boats). Community and individual values were in all cases considered by Torres Strait Islanders, to be worth more than market values), suggesting that they were each also worth more than $500-$900 per annum. This gives a minimum value for all benefits combined (community, individual and family/market) between $1500 and $2700 per person per annum (mean $2100).

We could not find any studies that have attempted to measure, in monetary terms, the aesthetic/amenity/lifestyle values of the Reef for Indigenous people. We suggest, however, that these values (or, at least, related, but different interpretations of these types of values) are likely to be very important in Indigenous communities – evidenced by the strongly expressed desires to return to *country,* the nation-wide campaign in support of communities targeted for closure in various jurisdictions, and (Indigenous) people's willingness to forgo urban incomes for the much lower (often non-existent) incomes available on-country.

Acknowledging that these studies do not even begin to adequately describe the importance of Indigenous values – particularly to Indigenous people – we nonetheless suggest that it is possible to surmise that the Indigenous cultural values associated with the Reef would at the barest minimum amount to at least $1500 per person per annum (Delisle et al., 2017), more likely about $3000 per person per annum (as per the values, to Girrigun people, of caring for country - (Social Ventures

[75] $4,642,219 divided by 6 (years) divided by estimated community population (700).
[76] $7,551,437 divided by 6 (years) divided by estimated community population (700).

Australia Consulting, 2016)) – and perhaps as much as $22,000 per household annum (if acknowledging the inherent inseparability of land, sea and Indigenous wellbeing and thus using the more 'holistic' valuation approaches of (Sangha, Russell-Smith, Morrison, Costanza, & Edwards, 2017) and (Taylor & Stanley, 2005). The mean value is $8833 per person per annum. Acknowledging that the value of the whole is likely to be worth more than the sum of its parts, we nonetheless generate a very minimum estimate of value by multiplying these per-person estimates by estimates of the numbers of Indigenous people living adjacent to the Reef (71,212 – see Figure 16 and Table 18).

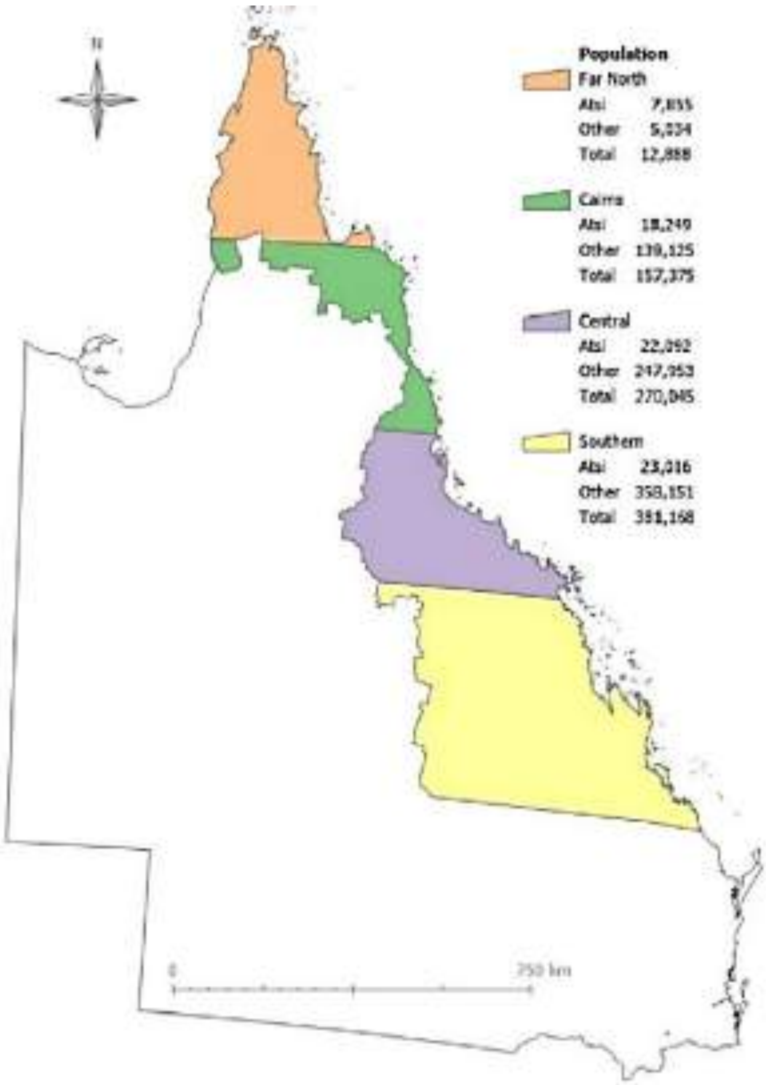


Figure 16: Identifying terrestrial regions (and associated populations) to match latitudes used for marine regions. Population estimates derived by first defining terrestrial regions which are (a) within Natural Resource Management regions that are adjacent to the Reef[77] and (b) match to the latitudes used to define marine regions for other benefit streams. We then used Australian Bureau of Statistics census data (usual place of residence, 2016 census) to estimate populations within each region so defined. If an Australian Bureau of Statistics region lay entirely within our regions, all people were allocated; if less than 100 percent of a region lay within our region, we allocated population by area.

[77] Mean of estimates provided by O'Mahoney et al. (2017)and Oxford Economics (2009) (the latter, inferring values from work undertaken by (Hundloe, 1990) and (Jill Windle & Rolfe, 2005)).

Table 18: Estimated number of Indigenous households, by region, 2016.

Region	Estimated number of Aboriginal &/or Torres Strait Islanders
Far North Qld	7,855
Cairns	18,249
Central	22,092
Southern	23,016
Total Reef	**71,212**

This suggests that for the entire Reef catchment area Indigenous cultural values, are, at minimum 'worth' $107M per annum, most likely close to $214M per annum, and perhaps even as much as $2.4B per annum. The mean, estimated as mean per-person value multiplied by populations, is our 'best' estimate: $629M per annum.

We use that information to generate very crude formulae describing current Indigenous cultural values by multiplying per-person estimates of benefits by relevant populations.

For each region, r, at time t = 0 (2016), CS_0^r is calculated as:

$$CS_0^r = \vartheta_0 \, ATSIpop_0^r$$

Where:

ϑ_0 is the estimated per-person associated with Indigenous cultural values ($8833)

$ATSIpop^r_0$ is the estimated number of Indigenous persons in region r, at time 0.

At least some of these values may correspond to particular locations, adding a spatial element to these values. Anecdotal evidence certainly suggests that Indigenous people retain knowledge of and connection to culturally significant sights that are now beneath sea-level. We do not, however, have the resources to add such spatial information, and suggest that such an exercise could, at any rate, only be appropriately conducted by Indigenous people (likely different TOs for each area).

We note also that Indigenous cultural values are an archetypal example of a complex social good, and that these estimates are very poor representations of true 'value'. They are a minimum indication only and miss numerous immeasurable values. They also fail to allow for the fact that protecting Indigenous cultural values is not only not of benefit Indigenous people – these cultures are the oldest on earth, and their protection is of benefit to mankind the world over.

Projecting future benefits

Indigenous cultural values are crucially place-based, but are inherently 'systems oriented', encompassing a diverse range or interconnected and inseparable 'values' (including, but extending far beyond social, biophysical, and cultural values). We are unaware of any study that has sought to estimate, in monetary terms, the potential impact of reef degradation on Indigenous Cultural values but suggest that impacts are likely to be substantial. This stems from the inherent inseparability of values – which leaves open the possibility that even relatively small changes in just one small, but nevertheless integral part of the system (e.g. Reef health) could be associated with large changes in Indigenous cultural values.

In the absence of better information, we suggest that one could either (a) omit these potential changes altogether (equivalent to imposing a value of zero, and thus possibly in danger of underestimating total benefits of RRAP), or (b) use a simple heuristic to generate ‘place holding’ values until better methods for including Indigenous values into broader cost-benefit analysis type assessments are developed. We tentatively suggest that (b) is ‘doable’ and have sought advice from Indigenous scholars who give ‘in principal’ support for keeping something as a placeholder – as above, noting the need to have Traditional Owners lead further research to better inform decisions that impact these values.

When attempting to generate crude ‘place holder’ estimates of potential changes to Indigenous cultural values that could be associated with changes in reef heath, we start by looking at current values for ATSI people living adjacent to the reef. We then assume that a general decline in reef health can be linked to declines in Indigenous cultural values for Indigenous people. The equations that we develop are similar to those used for (non-Indigenous) non-use values: simplistically assuming that an X percent fall in reef health will coincide with a Y percent fall in values. For any given fall in reef health we have, however, assumed a larger fall in Indigenous values, than in non-Indigenous non-use values. This is intended to reflect the absolute non-substitutability of Indigenous place-based values. If Traditional Owners’ country is degraded, they cannot make up for that by connecting to someone else’s country.

Formally, we assume that $ATSIpop_t^r = ATSIpop_0^r$ for all t, for all places/communities, so:

$$CS_t^r = \vartheta_t ATSIpop_0^r$$

Changes in estimates of value are thus driven entirely by changes in estimates of ϑ, estimated as:

$$\vartheta_t^r = \vartheta_{t-1}^r + \mathrm{D}(\vartheta)_t^r$$

Where $\mathrm{D}(\vartheta)_t^r$ describes the loss of benefits (the ‘damage’) that occurs as a consequence of changes in reef condition. We use a crudely simplistic function:

$$\mathrm{D}(\vartheta)_t^r = \lambda\, \Delta RCI_t^r$$

Where:

λ is the estimated fall in Indigenous cultural values for the ATSI people living in the region. It can be easily changed, but is, in the first instance set to 0.50 (higher than the loss in non-use values associated with changes in RCI that apply to (mostly) non-Indigenous people).

Indigenous cultural values are the third largest benefit stream, so we explore the sensitivity of final values to changes in those estimates, raising λ to 0.7.

We note that actual changes may look very different to the ones used as ‘place holders’ here.

4.4.10 Relational Values and other complex social goods

That relational values and complex social goods are of importance in the context of the Reef is of little doubt –Deloitte Access, for example, discuss the ‘brand value’ of the Reef, and stress that protecting the reef is not only about doing what is economically ‘efficient’ (the goal of cost-benefit analysis), but also about doing *what is right* for society as a whole (O'Mahoney et al., 2017).

The non-market valuation methods discussed in section 4.1 (see also Appendix B) were developed from within a branch of microeconomics, that defines 'value' in utilitarian terms – specifically as the contribution that a good or service makes to an Individual's welfare. These methods either seek to measure 'utility' functions directly (as per the *Life Satisfaction Approach),* or indirectly (most other methods, including those that use direct market prices, related market prices, or hypothetical market prices). They are well-suited to assessing the 'value' of simple individual goods and are becoming more adept at assessing the value of complex individual goods (also commonly referred to as *instrumental, or intrinsic* values). But these methods struggle to assess the value of complex social goods – those that generate a diverse array of interrelated benefits which accrue to society as a whole (rather than to individuals, upon which valuation methods focus) (N. Stoeckl et al., 2018) a subset of these complex social goods are strongly related to the notion of *relational values* (Chan et al., 2016)).

When non-market values are used in cost-benefit analysis, analysts almost always implicitly assume that what generates most value to most individuals will reflect what is of most value to society as a whole (this assumption is at least in part 'hidden' in the idea that social value is the sum of individual values). Arguably some respondents to (stated preference) surveys that include descriptions of hypothetical markets to assess non-market values may consider what is best for society as a whole before determining willingness to pay, but to assume that all respondents do so, is akin to assuming that all fishers, in an open access fishery, will consider the 'greater good' when determining how many fish to harvest. Open-access fisheries are generally associated with sub-optimal outcomes if fishers consider only their individual interests (although social norms may ameliorate some negative impacts).

Hardin (1968)[78] wrote on the problem of over-population:

> *"In economic affairs, The Wealth of Nations (1776) popularised the 'invisible hand,' the idea that an individual who 'intends only his own gain,' is, as it were, 'led by an invisible hand to promote…the public interest.'" [5]*
>
> *Adam Smith did not assert that this was invariably true, and perhaps neither did any of his followers.*
>
> *But he contributed to a dominant tendency of thought that has ever since interfered with positive action based on rational analysis, namely, the tendency to assume that decisions reached individually will, in fact, be the best decisions for an entire society.*

Hardin states: ***We can make little progress in working toward optimum population size until we explicitly exorcise the spirit of Adam Smith in the field of practical demography.*** Schulz and Martin-Ortega (2018) argue that existing methods of considering human-environment systems have the capacity to measure relational values, but it may also be necessary for environmental economists to 'explicitly exorcise the spirit of Adam Smith', if hoping to elevate complex social goods. Until that time, all we can say is that they are important- vitally so for the Reef (to wit, its *world heritage status')* and to exclude such values from broader cost-benefit analysis is to risk allowing Hardin's 'tragedy of the commons' to prevail.

Empirical research has been undertaken in the Reef catchment that sheds some light on the importance of 'social' values relative to environmental values. Esparon, Farr, Larson, and Stoeckl (2018) report on a study undertaken in the wet tropics world heritage area (WTWHA) adjacent to the

[78] Reprinted in: (Hardin, 2009).

Reef, noting that family/social factors were consistently selected as the most important contributor to wellbeing from a list of 27 factors that also included economic and environmental factors. Jarvis (2016) looked at that same data using geographically weighted regression to explore relationships across space. She reports that in all regions, social factors were more important contributors to overall quality of life than other factors: in northern parts of her study area environmental factors were second-most important; in southern sectors, economic factors were more important than environmental ones. This suggests that the social values, omitted in our assessment of benefit streams thus far, may collectively be worth 'more' than other factors combined (those that allow people to earn incomes through tourism and/or fishing; in addition to bequest, existence and other intrinsic values). Beyond that, we do not have numerical data to guide our assessment. The gap in knowledge is particularly important because relational values and the benefits that are associated with complex social goods are broader and 'bigger' than social values alone. They include the 'extra' bits of value that are created when any benefit stream (be it associated with the environment, the economy, or society) incurs values on individuals and also on society more broadly. A simplistic example relates to the case where by sharing food with those who have none, one creates a nutritional benefit, but also creates more 'equity', the absence of which is known to be associated with social dysfunction (Wilkinson & Pickett, 2009).

We are aware of current research work that is developing methods to measure relational values/complex social goods, but results are as yet unpublished. We are unaware of any other research that could be used to generate empirical estimates of relevant current values, or to make predictions about the way in which changes in reef health might impact them. They are thus omitted from the analysis, generated yet another unambiguous downward bias in our final estimates.

4.5 Choosing scenarios for the assessment

The equations (with parameters) that describe the way in which benefit streams are likely to respond to changes in reef condition (formally, the Reef Condition Index, RCI, predicted within ecological models) can, in principle, be used to project benefit streams for any set of Reef condition indexes that are associated with any intervention/climate scenario. The ecological modellers considered a suite of combinations of climate change scenarios and interventions (see Table 19, and **T6—Modelling Methods and Findings** for further information) – the task being to select a subset that could be used to help assess the likely (economic) efficacy of particular interventions. A more extensive rational for the selection and exploration of scenarios are presented in **T5—Future Deployment Scenarios and Costing** and **R3—Intervention Analysis and Recommendations**.

The focus on the business-as-usual climate change trajectory (RCP 8.5) in this report is deliberate, reflecting the most likely climate trajectory, although we have also included several RCP 2.6 simulations for comparative purposes.

For each scenario, the equations described in section 4.3 were used to generate benefit-stream projections from 2016, through to 2075. We generated two additional sets of (eight) benefit projections for scenario 14 (RCP 8.5, business-as-usual (BAU) crown-of-thorns starfish (COTS) without interventions) and scenario 23 (RCP 8.5, business-as-usual, crown-of-thorns starfish with high-level efforts to outplant warm-adapted corals and a high efficacy level for regional-scale solar radiation, here cloud brightening). These projections were produced using larger different parameters in the equations linking benefit streams to Reef condition indexes. Here we assumed that the four largest benefit streams (tourism, non-use values, Indigenous cultural values, and medicinal option values) were more sensitive to changes in Reef condition indexes than our base equations (see sub-sections 4.4.3, 4.4.5, 4.4.8, and 4.4.9) for details. Crown-of-thorns starfish strong refers to further enhancement of conventional coral measures but was later omitted from model scenarios because of uncertainty around how those additional vessels would operate (see details in the modelling report).

Table 19: The suite of combinations of climate change scenarios and interventions considered by RRAP ecological modellers. BAU = business-as-usual (crown-of-thorns starfish, CoTS) control, Strong COTS control = further enhancement of conventional coral measures. For more information see T6—Modelling Methods and Findings.

Identifying scenario number	Climate change scenario	COTS control	Levels of coral out-planting	Solar radiation management effectiveness
1	RCP 2.6	BAU	None	None
2		Strong	None	None
4		BAU	10m (Low)	0.3°C (Low)
7		BAU	10m (Low)	0.7°C (High)
10		BAU	100m (High)	0.7°C (High)
34		Perfect	100m (High)	0.7°C (High)
14	RCP 8.5	BAU	None	None
15		Strong	None	None
16		Perfect	None	None
17		BAU	10m (Low)	0.3°C (Low)
18		Strong	10m (Low)	0.3°C (Low)
19		Perfect	10m (Low)	0.3°C (Low)
20		BAU	10m (Low)	0.7°C (High)
21		Strong	10m (Low)	0.7°C (High)
22		BAU	100m (High)	0.3°C (Low)
23		BAU	100m (High)	0.7°C (High)
24		BAU	10m (Low)	None
25		BAU	100m (High)	None
26		BAU	None	0.7°C (High)
44		Perfect	100m (High)	0.7°C (High)
Additional projections assuming benefits more sensitive to changes in coral condition				
14s	RCP 8.5	BAU	None	None
23s		BAU	100m (High)	0.7°C (High)

As such, we focus on just 20 of the 44 intervention/climate scenarios evaluated by the ecological modellers. In all cases we assume there is just one intervention for the entire 60 years. This does not allow for more adaptive implementation strategies (where, for example, on intervention could be pursued for several years, with another brought online later), which could yield much greater overall benefits of RRAP.

5 SUMMARY OF FINDINGS

5.1 Estimates of current benefits

Estimates of the current monetary value of benefits streams are summarised in Table 20. The dashes for categories 7 and 10 do not signify zero values – rather they are included to highlight that there is no empirically quantifiable information about the monetary value of the benefits, but that their values is almost certainly greater than zero. Figure 17 shows our 'best' estimates graphically, highlighting that cultural values comprise the most significant (known) benefits.

Table 20: Estimates of the monetary 'value' of reef-dependent benefit streams, $B AUD (2015), per annum.

Type of benefit	'Best' estimate (used as starting value in simulations	Range		Key references and associated estimates
		Min	Max	
Provisioning service				
1. Food (commercial fishing)	0.006b	0.002b	0.008b	O'Mahoney et al. (2017) $0.118B for ALL fish; QFish data suggests that reef-dependent fish ≈ 11 percent of total catch; values inferred from ABARE export price data[79]
2. Materials (coral harvesting),	0.003b	0.0002b	0.006b	No known published estimates; ours are generated from QFish data on tonnes harvested, and commercially advertised prices.
3. Medicinal (options for the future).	0.174b	0.020b	1.000b	No known published data for Reef; our estimates are generated from insights provided by Jobstvogt et al. (2014) in a U.K. study, and by the financial reports of AbbVie Inc.
Regulating services				
4. Storm surge and wave mitigation	0.026b	0.010b	0.050b	No known published data; our estimates are generated using population and median house price estimates, with storm probabilities
Cultural services				
5. Tourism	1.524b4	1.200b	1.800b	De Valck and Rolfe (2018)[80] - $1.2B p.a.; Deloitte Access (O'Mahoney et al., 2017), $1.5B p.a.
6. Recreational fishing	0.011b	0,005b	0.015b	Deloitte Access (O'Mahoney et al., 2017) reports expenditure ($70M) and Prayaga et al. (2010) report consumer surplus for all recreational fishing; we combine this with data from QDPI to infer estimates relevant to reef-dependent recreational fishing,
7. Learning and Inspiration	-	-	-	No published studies that we are aware of; large body of research highlights importance of learning inspiration for creativity which supports economic development (Florida, 2005; Hein et al., 2006)
8. Non-use values (bequest, existence, identity, etc.)	1.015b	0.490b	1.200b	Deloitte Access (O'Mahoney et al., 2017), $1.2B p.a.
Other benefits				
9. **<u>Placeholder</u>** Indigenous values	0.629B	0.170B	2.000B	No published studies that we are aware of; 'placeholder' values inferred from other studies
10. Relational values and benefits from complex social goods.		-	3.600B +	Jarvis (2016)'s work in the Wet Tropics suggests social values may be more important than all other values combined;
TOTAL per annum	$3.4B	$0.7B	$8B	Deloitte Access (O'Mahoney et al., 2017) – Great Barrier Reef World Heritage Area, but only Tourism, Non-use and recreation ≈ $2.9B p.a. Stoeckl et al (2014) – GBRWHA, ALL benefit streams > $15B p.a.

[79] Estimate derived from data provided by ABARES.

[80] Deloitte Access frequently reports on tourism values, but generally on expenditure, not surpluses (our focus).

When selecting a discount rate, we were cognizant of the fact that although constant discount rates are widely used, a substantive body of literature suggests that *social discount rates* (those associated with non-market goods) – decline over time. Weitzman (2001) undertook a survey of more than 2000 economists. He reports that even if every respondent had in mind a constant discount rate, the diversity of individual views about what constitutes an appropriate (constant) discount rate, ensured that the *effective* (observed) social discount rate declined rapidly over time. In an idea world, one would not use constant discount rates, instead working with hyperbolic or quasi-hyperbolic (declining) discount rates (Laibson, 1997) or similarity relations (Rubinstein, 2003). Recognising that this is not always feasible Weitzman (2001) suggests that what constitutes an appropriate social discount rate, depends upon the time horizon considered. He suggests using ≈ four percent if one's time horizon is one to five years from now; ≈ three percent for time horizons in the range of six to 25 years; ≈ two percent for time horizons in the range of 26–75 years; ≈ one percent for time horizons in the range of 75-300 years; and 0 percent if one's time horizon exceeds 300 years. Our choice of a constant 3.5 percent discount rate is thus, if anything, high. A lower discount rate would generate higher estimates of the NPV of these benefit streams. Our projections consider a time-horizon of 60 years, suggesting that one percent may be more appropriate.

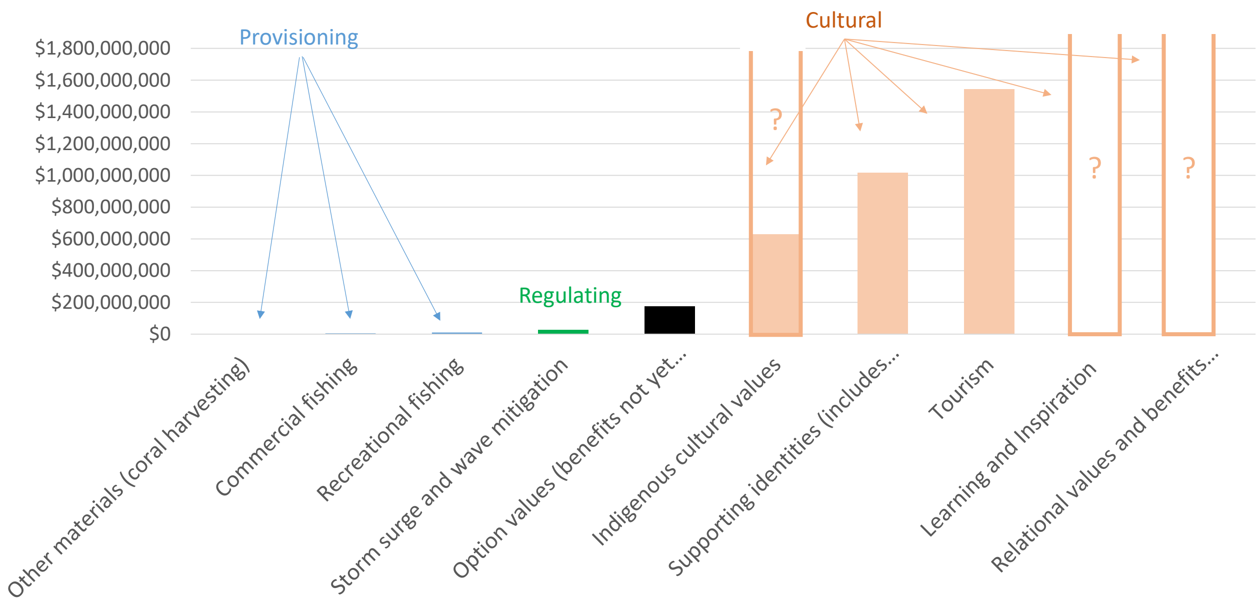


Figure 17: 'Best' estimates of the monetary value of current reef dependent (RRAP relevant) benefits. Question-marks indicate that current knowledge precludes us from estimating these benefits with any degree of accuracy.

5.2 Benefits projected under different scenarios

Annual estimates of benefits from 2016 to 2075 for each scenario are provided in Appendix G and analysed more completely in **T9—Cost Benefit Analysis**, alongside relevant cost estimates. Our projections and estimates, summarised in Table 21, are sensitive to the assumptions (and data) underpinning them. We have used relatively conservative assumptions when estimating current benefits and also when estimating the fall in benefits that could be associated with a fall in reef health (the percent fall in benefits is always less than the percent fall in Reef condition index). If we use somewhat fewer conservative assumptions, our estimates of the damages that could be avoided by interventions are larger. We underscore the importance of using sensitivity analysis to explore the extent to which data deficiencies (uncertainties, ambiguities, unknowns and unknowable's) influence final estimates.

In the sub-sections that follow the table, we provide a brief discussion of a small subset of estimates, to highlight key issues of relevance; a more thorough analysis of data is in **T9—Cost Benefit Analysis** when combining with information on costs, and undertaking sensitivity assessments (including the use of different discount rates).

Table 21: Summary of estimates: current values and predicted benefits of RRAP – mean (and range), by benefit stream.

Benefit stream	Current value in $M p.a. (range)	Mechanisms through which RRAP could impact	Predicted undiscounted* damages avoided via RRAP, mean $M p.a. added to 2075 (range)		Considerations
			RCP 8.5 (14 scenarios)	RCP 2.6 (6 scenarios)	
1. Commercial fishing	5.6 (2–8)	Maintenance of habitat and complexity	66 (8–111)	67 (50-78)	Some adaptive capacity (location)
2. Recreational fishing	10.6 (5–15)	Maintenance of habitat and complexity	11 (0–16)	6 (5-6)	Moderate adaptive capacity (location, target species)
3. Coral harvesting	0.25 (0.02–0.60)	Maintenance of habitat and species	3 (1–6)	6 (5-7)	Some adaptive capacity (location and species)
4. Medical options for the future	174 (20–1000)	Support of biodiversity	2209 (254–3608)	2557 (1833–3028)	Biodiversity most important
5. Coastal protection	26 (10–50)	Support of reef structure	439 (67–791)	612 (416-725)	Choice of coral species would be critical
6. Reef tourism	1543 (1200–1800)	Biophysical state and 'image'	6214 (999–10 517)	4877 (3240–5705)	Adaptive capacity within regions; image crucial; worldwide competition
7. Non-use (bequest, existence, identity)	1015 (490–1200)	Holistic, including 'image'	3382 (647–5192)	2409 (1782–2835)	Rarely place-specific; perceptions crucial
8. 'Placeholder' Indigenous cultural values	More than 629 (179 to more than 2000)	Unknown, but likely holistic	5332 (1045–8887)	4450 (3340–5157)	Highly place-specific. No capacity for substitution
All benefits (added)	**3404 (700–8000)**		**17 657 (3021–29 128)**	**14 985 (10 672–17 522)**	

* undiscounted damages, noting that insights from the literature suggest the longer the relevant time horizon, the lower the rate should be. T9—Cost Benefit Analysis includes a sensitivity of estimates, using different discount rates.

5.2.1 Comparing projections under RCP 2.6 and 8.5

Figure 18 shows projections under RCP 8.5 (assuming current crown-of-thorns control measures and no other interventions). In this scenario, the projected declines in reef health (red line, measured on the right axis) are marked. By construct the percentage reductions in benefits are smaller than those of the Reef condition index, but at $1.2B (per annum), still large (more than 30 percent of starting values). If using parameters that reflect a higher sensitivity of benefits to changes in reef health, the sum of all benefits streams falls further (to just $1.8B per annum by 2075, suggesting an almost 50 percent loss of benefits over the next few decades).

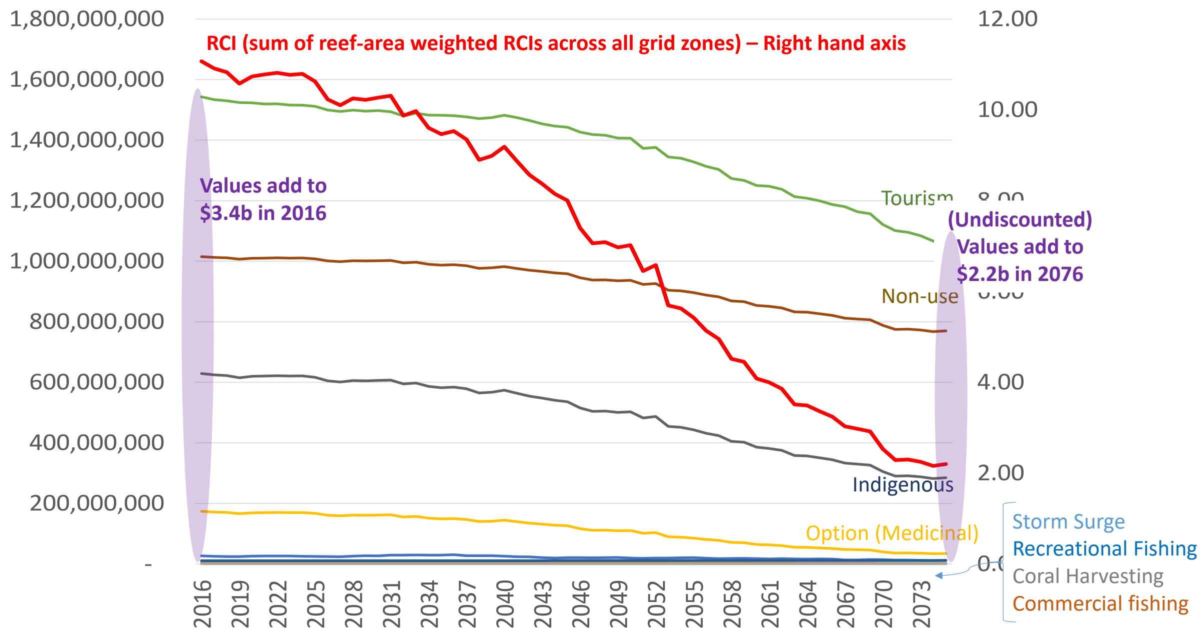


Figure 18: Projected monetary value of individual benefit streams from 2016 to 2075 under RCP8.5. Crown-of-thorns starfish control is 'business as usual', no other interventions are undertaken, and the estimates are generated using conservative assumptions about the sensitivity of benefit streams to changes in Reef condition index.

Figure 19 compares projections (all benefits added) under RCP 2.6 and RCP 8.5. Subtracting the undiscounted sum of all benefits from 2016 to 2075 accruing under RCP 8.5 from those accruing under RCP 2.6 allows us to generate and estimate of the undiscounted damages (to benefit streams) that could be avoided by adhering to RCP 2.6: these are in the order of $28.5B. Importantly, this estimate of potential damages avoided only describes the damages that could be avoided for the reef-dependent benefit streams considered in this assessment. The damages that could be avoided for other ecosystems in the Great Barrier Reef World Heritage Area (and elsewhere throughout the world) far exceed these estimates. This underscores the importance of treating our estimates with care. As highlighted in section 3, they relate to:

- Only one subset of benefits (relevant to reef restoration activities) that are crudely quantifiable in monetary terms;
- Which accrue to Australian residents and reef tourists (ignoring those in the rest of the world)

They do not describe all benefits, or potential impacts on all benefits, relevant to the Great Barrier Reef World Heritage Area.

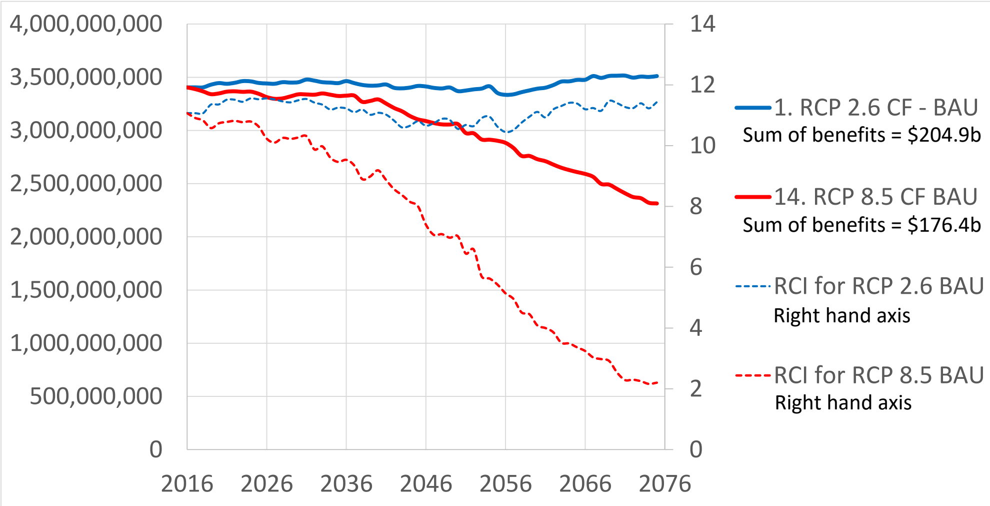


Figure 19: Projected monetary value of all benefit streams (added) from 2016 to 2075 under RCP2.6 and RCP 8.5. In both scenarios, crown-of-thorns starfish control is 'business as usual', no other interventions are undertaken, and the estimates are generated using conservative assumptions about the sensitivity of benefit streams to changes in Reef condition index.

5.2.2 Estimating the benefits of interventions (formally, damages avoided)

Crown-of-thorns starfish control

Figure 20 compares projections (all benefits added) under RCP 8.5 for three different levels of crown-of-thorns starfish control (business as usual, 'strong', and 'perfect' – as described in **T6—Modelling Methods and Findings**. Comparing the undiscounted sum of all benefits from 2016 to 2075 for each scenario, allows us to estimate the benefit of different crown-of-thorns starfish control measures:

- Strong measures generate an extra $1.7B of benefits, compared with business as usual;
- Perfect measures generate an extra $8.7B of benefits, compared with strong measures; and,
- Perfect measures generate an extra $10.4B of benefits, compared with business as usual.

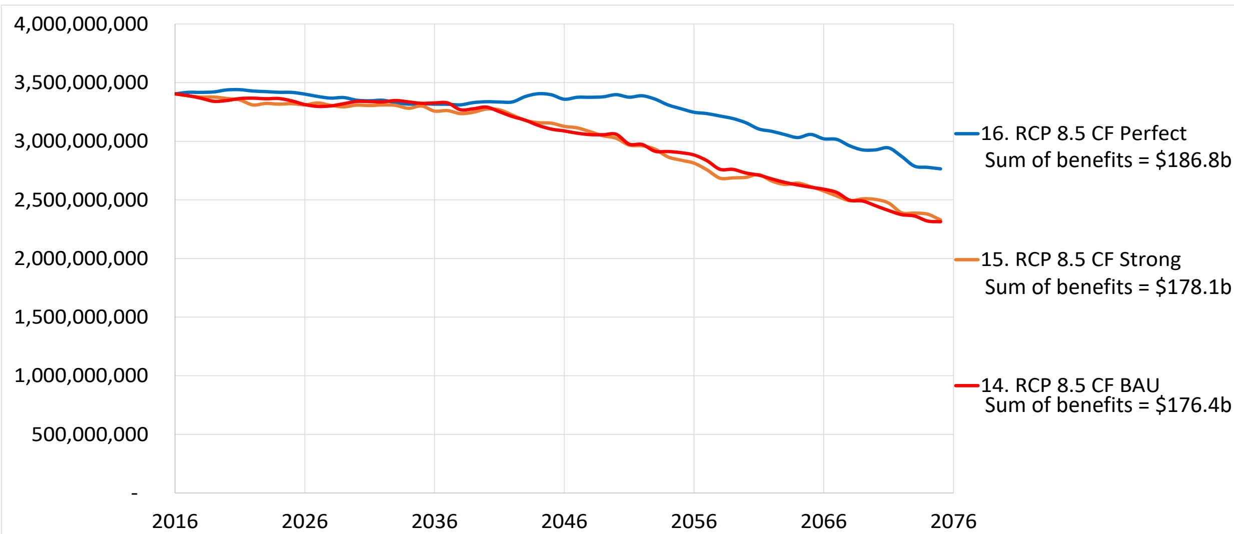


Figure 20: Projected monetary value of all benefit streams (added) from 2016 to 2075 under RCP 8.5 with existing (business as usual), strong and perfect crown-of-thorns starfish control. In each of these scenarios, no other interventions are undertaken, and the estimates are generated using conservative assumptions about the sensitivity of benefit streams to changes in Reef condition index.

Cloud brightening (with enhanced corals)

Figure 21 compares projections (all benefits added) under RCP 8.5 to facilitate the assessment of benefits relating to cloud brightening. It focuses on 'no', 'low', and 'high' cloud brightening, in all cases assuming crown-of-thorns starfish control is business as usual. The top panel shows benefit estimates that were generated when low levels of enhanced corals were also being used; the bottom shows estimates for high levels of enhanced corals. As discussed in section 4.4, estimation errors are likely to be large, but the sum of benefits with high cloud brightening is about $15B more than benefits with no cloud brightening when used in conjunction with low numbers of enhanced corals; and about $25B with high numbers of enhanced corals – presumably because the cloud brightening has more (enhanced) coral to protect in the second scenario.

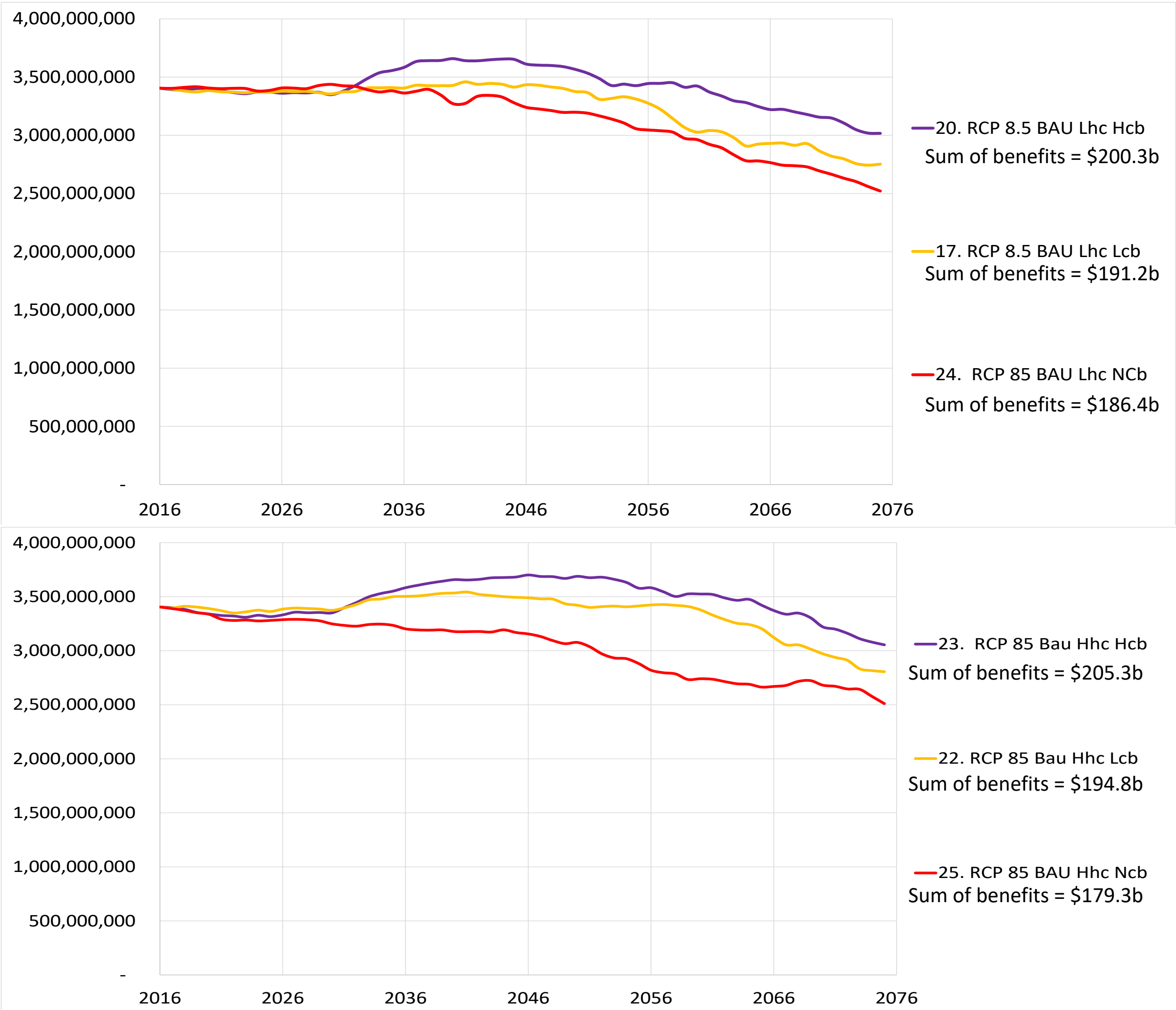


Figure 21: Projected monetary value of all benefit streams (added) from 2016 to 2075 under RCP 8.5 with no, low and high cloud brightening with low enhanced corals (top) and high enhanced corals (bottom). In each of these scenarios, crown-of-thorns starfish control is business as usual and estimates are generated using conservative assumptions about the sensitivity of benefit streams to changes in Reef condition index.

Enhanced corals (with cloud brightening)

Figure 22 compares projections (all benefits added) under RCP 8.5 to facilitate the assessment of benefits relating to enhanced corals. It focuses on 'no', 'low', and 'high' interventions relating to enhanced corals in all cases assuming crown-of-thorns starfish control is business as usual and that significant (high) cloud brightening is taking place. Comparing the undiscounted sum of all benefits from 2016 to 2075 for each scenario, allows us to estimate the benefit of interventions that focus on enhanced corals (given business as usual crown-of-thorns starfish and low cloud brightening):

- Low hard corals generate an extra $0.2B of benefits compared with no enhanced corals
- High enhanced corals generate an extra $5B of benefits compared with low enhanced corals
- High enhanced corals generate an extra $5.2B of benefits compared with no enhanced corals.

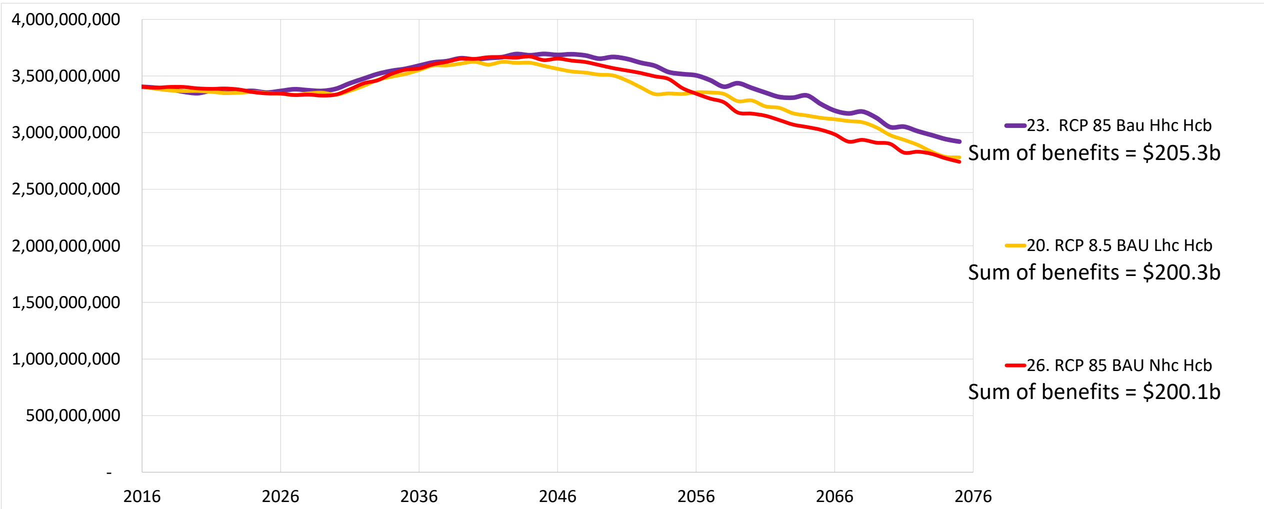


Figure 22: Projected monetary value of all benefit streams (added) from 2016 to 2075 under RCP 8.5 with no, low and high enhanced corals. In each of these scenarios, crown-of-thorns starfish control is business as usual, (high) cloud brightening is taking place and estimates are generated using conservative assumptions about the sensitivity of benefit streams to changes in Reef condition index.

5.2.3 Exploring the sensitivity of estimates to assumptions about the way in which benefits change in response to changes in Reef condition index

We investigated the sensitivity of our estimates of 'damages avoided' to assumptions about the response of benefits to changes in Reef condition index – simplistically, the *slope* parameters in our benefit equations. We did this by looking at the intervention that generates the highest sum of undiscounted benefits (scenario 26: business as usual, crown-of-thorns starfish control, enhanced corals and high cloud brightening). We calculate the damages that could be avoided through this intervention by comparing it with the appropriate counterfactual (business as usual, crown-of-thorns starfish control, no enhanced corals, no cloud brightening).

Figure 23 compares projections using parameters which assume first, that benefits are relatively insensitive to changes in Reef condition index (in line with all previous projections) and, second, that benefits are more sensitive to changes in Reef condition index.

When using those projects to estimate the 'value' of an intervention, one needs to compare benefits with and without the intervention. I we do this using our conservative equations (solid red line compared with solid blue line); we find that difference in benefit streams is approximately $28.9B of damages. If we instead do these using equations that assume benefits are more sensitive to changes in Reef condition index, then the with/without difference in benefit streams is closer to $42B of damages.

Estimates of the damages avoided by interventions are, as one would expect, sensitive to assumptions about the way in which benefits will degrade in response to degradation in reef health. We discuss this issue in detail in section 4.4, the key point being that data and other knowledge deficiencies prevent us from being able to generate more accurate parameter estimates with existing resources. We flag this as an area in need of more research.

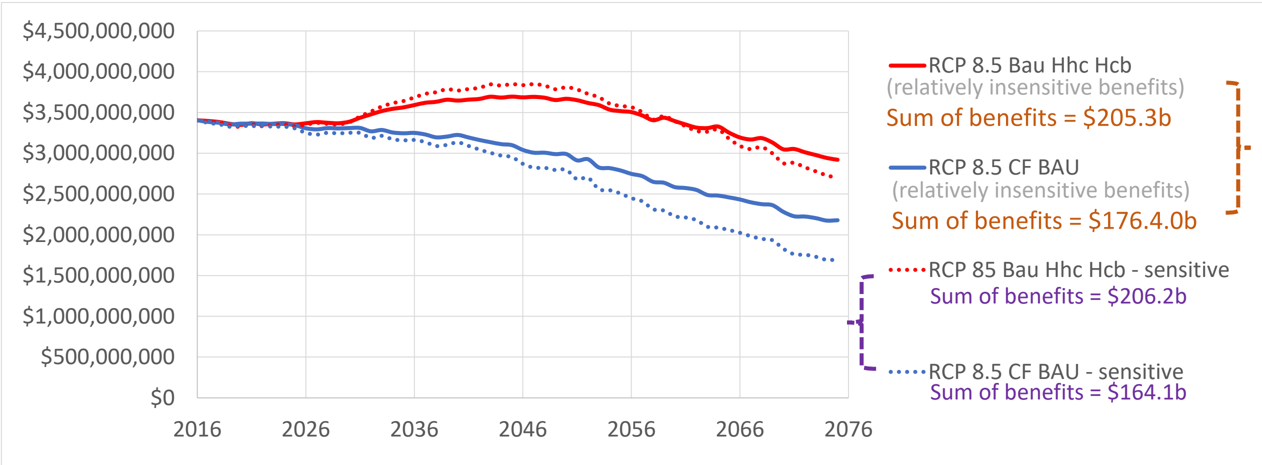


Figure 23: Projected monetary value of all benefit streams (added) from 2016 to 2075 under RCP 8.5 with no, low and high enhanced corals. In each of these scenarios, crown-of-thorns starfish control is business as usual, some (low) cloud brightening is taking place and estimates are generated using conservative assumptions about the sensitivity of benefit streams to changes in Reef condition index.

5.3 Take home messages

- There are numerous non-market valuation methods, capable of assessing wide range of goods and services associated with environment. These methods have been used extensively in the environmental economics literature, with innumerable applications relevant to the reef.

- Whilst able to provide useful insights about a wide variety of non-market values, we do not yet have the ability to assess all goods and services in monetary terms. In particular, existing methods struggle to provide insights on the benefits of goods with relational values and on some ‘collective’ / common goods (sometimes termed *complex social goods)*.

- Non-market valuation methods have been developed from the sub-field of microeconomics, for use in partial equilibrium evaluations of ‘impact’. They are well suited to the task of monetising the potential short-run impact, to an individual, of a single threat, on a single type of good or service (e.g. the potential economic impact of a reduction in water clarity on the tourism industry). But they generally measure impacts at too small a scale[81] to provide ‘whole of system’ value estimates and have not been designed for use

[81] Defined in terms of number of people, number of threats, and number of impacts considered

in ‘general equilibrium’ or complex systems where ‘disequilibrium’ is the norm, rather than the exception.

- It is costly to undertake good quality non-market valuation studies so large-scale assessments almost always involve benefit transfer. Different studies generate different types of value estimates (e.g. net benefit, economic impact), so one must select value estimates carefully.

- In principal, one could conduct a large-scale benefit transfer and then estimate the total value of the system by adding partial-equilibrium estimates, but:

    - different studies assess different types of impacts (e.g. on industry, on individuals) and assume different scales of impact (marginal degradation or improvements in reef health, versus a situation of complete loss of reef)

    - there are numerous links between and within biophysical and human sub-systems.

  As such the value of the whole will not necessarily equal the sum of component parts.

- We are unaware of the existence of any socio-economic data sets that allow us to model spatio-temporal interactions between or across sub systems. We lack the resources to collect such data or to build a model that can adequately predict impacts, so have instead devised a systematic framework for thinking about the whole of system (economic) benefits of the reef and generating estimates of the damages that could be avoided by restoration.

- We used the CICES framework to guide the compilation of benefit estimates for use in our overall assessment. For each benefit listed in the CICES, we asked: ***Is it relevant to the Reef? Is it likely to be impacted by changes in reef condition (i.e. by interventions)***? We selected only the benefits for which the answer to both questions was yes. Grouped into four broad categories, these were:

  Material benefits (termed provisioning benefits in the MEA/CICES):

  1. Commercial fishing.
  2. Coral harvesting.
  3. Medicinal option values (reflecting some biodiversity/gene pool values).

  Regulating services:

  4. Storm surge protection.

  Non-material (cultural) benefits:

  5. Tourism.
  6. Recreational fishing.
  7. Learning/inspiration.
  8. Non-use values.
  9. Indigenous cultural values.
  10. relational and other values associated with complex social goods.

- Different benefits accrue to different groups of people, with different opportunities to adapt (e.g. altering behaviours across time or space) and relevant data for different benefit streams are generally available at different spatial and temporal scales. Some benefits are inherently non-spatial and do not map to specific locations (e.g. a desire to "know that the Reef is healthy" and/or a desire to "leave the Reef in good health for future generations"), and human adaptations transcend geographic areas. When one fishing ground is denuded, for example, fishers may move to another region to fish (permits allowing). Although data relevant to some benefits are available for particular geographic locations (e.g. commercial fish harvest) and although it is possible to measure biophysical changes at fine geographic scale, it is not sensible to assume that a measurable biophysical change at location X translates exactly to a measurable economic change at that same location. All estimates generated for use in **T9—Cost Benefit Analysis**, were thus aggregated across the entire reef area (one estimate, for all the Reef).

- We were unable to find data to estimate benefits associated with Learning/inspiration and Relational/Complex social goods. Our estimates of the benefits associated with Indigenous cultural values are woefully inadequate but retained here, as a 'place holder', to ensure that this important benefit is not, by omission, given an implicit value of zero.

- Our 'best' estimates suggest that the monetary value of measurable benefits is equivalent to at least $3.4B per annum: this has a net present value of approximately $100B, assuming a 3.5 percent discount rate. Cultural services (tourism, non-use values, Indigenous cultural value) together account for more than 90 percent of measurable benefits; option values are the next most important benefit.

- We used insights from the literature to develop equations that allow us to make predictions about the way in which measurable benefits might change in response to changes in reef condition (formally, the Reef condition index). We used those equations to predict benefits, each year between 2016 and 2075 under 15 different 'scenarios', selected in consultation with the ecological modellers and Aurecon, who undertook **T9—Cost Benefit Analysis**. We compared the (undiscounted) sum of benefits under different scenarios, to make the following observations:

    - Under RCP 8.5 annual benefits are likely to fall by at least one-third (possibly one half) between 2016 and 2075. If one were able to mitigate climate changes to ensure RCP 2.6, then our estimates suggest that one could avoid at least $28.5B in damages to these benefits. The damages that could be avoided by mitigating climate in other ecosystems in the Great Barrier Reef World Heritage Area (and elsewhere throughout the world) would add substantially to this.

    - Under RCP 8.5 our estimates suggest that

        - Being able to prevent of fully suppress crown-of-thorns starfish outbreaks (in the absence of other measures) could prevent up to $10.4B in damages.

        - Regional solar radiation management (cloud brightening) could prevent up to $25B in damages

        - Out-planting of warm-adapted corals could prevent up to $8B in damages.

    - Whether or not the benefits of such interventions outweigh their costs remains to be determined. Hence the importance of the cost-benefit analysis.

Our projections and estimates are sensitive to the assumptions (and data) underpinning them. We have used relatively conservative assumptions when estimating current benefits and when estimating the fall in benefits that could be associated with a fall in Reef health (the percent fall in benefits is always less than the percent fall in Reef condition index). If we use somewhat less conservative assumptions, our estimates of the damages that could be avoided by interventions are larger. Similarly, when estimating benefits, we have assumed that there is just one intervention strategy undertaken for the entire 60 years. This does not allow for more adaptive implementation strategies (where, for example, on intervention could be pursued for several years, with another brought online later), which could yield much greater overall benefits of RRAP.

Our estimates thus likely represent a minimum, or 'benchmark' for use in **T9—Cost Benefit Analysis**. We underscore the importance of using sensitivity analysis to explore the extent to which data deficiencies (uncertainties, ambiguities, unknowns and unknowable's) influence final estimates. If, when compared with the costs of the interventions, the overall Net Present Value is positive in a range of different situations, then there should be no doubt for decision-makers that the interventions are welfare enhancing. If, on the contrary, Net Present Value is close to zero or negative, no conclusive argument can be made and a more in-depth investigation, involving the collection of primary data may need to be carried out to improve the accuracy of estimates.

Finally, we reiterate a point made in the introduction: data and knowledge deficiencies abound, so our estimates and projections are – like all estimates – far from perfect. But we are unaware of any other model/data that provides less imperfect information. We have done our best to make assumptions transparent and to ensure that our 'model' can be updated and improved as knowledge is improved. We hope that this work advances our overall understanding of various economic benefits of the Reef and of the benefit of different numerous reef-related interventions, while providing a system for thinking about the benefits of intervention that can adapt and change over time. We welcome suggestions that help to improve our estimates/approach.

5.4 Integration and links with other RRAP activities

This report describes how economic data were compiled and combined with estimates of coral health (the Reef Condition Index), derived from outputs of T6—Modelling Methods and Findings, to generate estimates of the benefit of an example set of RRAP interventions, under different climate change scenarios. This was combined with cost data from T5—Future Deployment Scenarios and Costing, to produce T9—Cost Benefit Analysis.

REFERENCES

Abah, J., Mashebe, P., & Denuga, D. (2015). Prospect of Integrating African Indigenous Knowledge Systems into the Teaching of Sciences in Africa. *American Journal of Educational Research, 3*(6), 668-673.

Access Economics. (2007). Measuring the economic and financial value of the Great Barrier Reef Marine Park 2005/06. *Report by Access Economics Pty Limited for Great Barrier Reef Marine Park Authority. Great Barrier Reef Marine Park Authority, Townsville*.

Akerlof, G. A. (1978). The market for "lemons": Quality uncertainty and the market mechanism *Uncertainty in economics* (pp. 235-251): Elsevier.

Akter, S., & Grafton, R. Q. (2010). Confronting uncertainty and missing values in environmental value transfer as applied to species conservation. *Conservation biology, 24*(5), 1407-1417.

Albright, R., Caldeira, L., Hosfelt, J., Kwiatkowski, L., Maclaren, J. K., Mason, B. M., . . . Ricke, K. L. (2016). Reversal of ocean acidification enhances net coral reef calcification. *nature, 531*(7594), 362.

ALSC. (2004). Comparisons between traditional and scientific knowledge. Retrieved from http://www.nativescience.org/html/traditional_and_scientific.html

Ammann, K. (2007). Reconciling Traditional Knowledge with Modern Agriculture: A Guide for Building Bridges. In A. Krattiger, R. Mahoney, L. Nelsen, & e. al. (Eds.), *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices* Oxford, U.K: MIHR & PIPRA.

ANKN. (2008). Indigenous Knowledge Systems and Higher Education: Preparing Alaska Native PhD's for Leadership Roles in Research. Retrieved from http://www.ankn.uaf.edu/curriculum/Articles/RayBarnhardt/PreparingPhDs.html

Arkema, K. K., Guannel, G., Verutes, G., Wood, S. A., Guerry, A., Ruckelshaus, M., . . . Silver, J. M. (2013). Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change, 3*(10), 913.

Asafu-Adjaye, J., Brown, R., & Straton, A. (2005). On measuring wealth: a case study on the state of Queensland *Journal of Environmental Management, 75*(2), 145-155

Aubanel, A. (1993). Socioeconomic values of coral reef ecosystems and of its resources: a case study of an oceanic island in the South Pacific (Moorea, Society Islands). *Universety Michel de Montange, Bordeaux. Report# URA CNRS, 1453*.

Auffhammer, M. (2018). *Climate adaptive response estimation: Short and long run impacts of climate change on residential electricity and natural gas consumption using big data*. Retrieved from

Bagstad, K. J., Semmens, D. J., Waage, S., & Winthrop, R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. *Ecosystem services, 5*, 27-39.

Baker, R., & Ruting, B. (2014). *Environmental Policy Analysis: A guide to non-market valuation*. Retrieved from Canberra:

Barnett, J., & O'neill, S. J. (2011). Islands, resettlement and adaptation. *Nature Climate Change, 2*(1), 8.

Bateman, I. J., Carson, R. T., Day, B., Hanemann, M., Hanley, N., Hett, T., . . . Pearce, D. (2002). Economic valuation with stated preference techniques: a manual. *Economic valuation with stated preference techniques: a manual.*

Bennett, N., Dearden, P., Murray, G., & Kadfak, A. (2014). The capacity to adapt?: communities in a changing climate, environment, and economy on the northern Andaman coast of Thailand. *Ecology and Society, 19*(2).

Berg, H., Öhman, M. C., Troëng, S., & Lindén, O. (1998). Environmental economics of coral reef destruction in Sri Lanka. *Ambio*, 627-634.

Blair, P., & Buytaert, W. (2016). Socio-hydrological modelling: a review asking" why, what and how?". *Hydrology and Earth System Sciences, 20*(1), 443-478.

Bohensky, E., Butler, J. R., Costanza, R., Bohnet, I., Delisle, A., Fabricius, K., . . . Pert, P. (2011). Future makers or future takers? A scenario analysis of climate change and the Great Barrier Reef. *Global environmental change, 21*(3), 876-893.

Boithias, L., Terrado, M., Corominas, L., Ziv, G., Kumar, V., Marqués, M., . . . Acuña, V. (2016). Analysis of the uncertainty in the monetary valuation of ecosystem services—A case study at the river basin scale. *Science of the Total Environment, 543*, 683-690.

Boumans, R., & Costanza, R. (2007). The multiscale integrated Earth Systems model (MIMES): the dynamics, modeling and valuation of ecosystem services. *Issues in Global Water System Research, 2*, 10-11.

Bowen, B., Chesson, J., Mazur, K., & Buetre, B. (2012). *Options for incorporating non-market impacts in the Biosecurity Risk Return Project*. Retrieved from

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences, 1249*(1), 118-136.

Brereton, F., Clinch, J., & Ferreira, S. (2008). Happiness, geography and the environment. *Ecological economics, 65*(2), 386-396.

Brosnan, S. F., & De Waal, F. B. (2003). Monkeys reject unequal pay. *nature, 425*(6955), 297-299.

Brown Jr, G., & Mendelsohn, R. (1984). The hedonic travel cost method. *The review of economics and statistics*, 427-433.

Bruckner, A. W. (2002). Life-saving products from coral reefs. *Issues in Science and Technology, 18*(3), 39-44.

Buchler, D. (2014). *A pragmatic solution to the problem of international visitors in the travel cost method: a case study from the Great Barrier Reef.* (Honours), James Cook University.

Burgess, C. P., Johnston, F. H., Bowman, D. M., & Whitehead, P. J. (2005). Healthy country: healthy people? Exploring the health benefits of Indigenous natural resource management. *Australian and New Zealand Journal of Public Health, 29*(2), 117-122.

Burke, L., Greenhalgh, S., Prager, D., & Cooper, E. (2008). Coastal capital: economic valuation of coral reefs in Tobago and St. Lucia. *Coastal capital: economic valuation of coral reefs in Tobago and St. Lucia.*

Burke, L., Maidens, J., Spalding, M., Kramer, P., & Green, E. (2004). Reefs at Risk in the Caribbean: World Resources Institute Washington: DC.

Butler, R. W. (1980). The concept of a tourist area cycle of evolution: implications for management of resources. *Canadian Geographer, 24*(1), 7.

Camp, E. F., Suggett, D. J., Gendron, G., Jompa, J., Manfrino, C., & Smith, D. J. (2016). Mangrove and seagrass beds provide different biogeochemical services for corals threatened by climate change. *Frontiers in Marine Science, 3*, 52.

Carbone, J. C., & Smith, V. K. (2013). Valuing nature in a general equilibrium. *Journal of Environmental Economics and Management, 66*(1), 72-89.

Carleton, T. A., & Hsiang, S. M. (2016). Social and economic impacts of climate. *Science, 353*(6304), aad9837.

Carr, L., & Mendelsohn, R. (2003). Valuing coral reefs: a travel cost analysis of the Great Barrier Reef. *AMBIO: A Journal of the Human Environment, 32*(5), 353-357.

Carroll, N., Frijters, P., & Shields, M. A. (2009). Quantifying the costs of drought: new evidence from life satisfaction data. *Journal of Population Economics, 22*(2), 445-461.

Casimirri, G. (2003). *Problems with integrating traditional ecological knowledge into contemporary resource management*. Paper presented at the XII World Forestry Congress, Quebec City, Canada. http://www.fao.org/docrep/ARTICLE/WFC/XII/0887-A3.HTM

Cesar, H. S., & van Beukering, P. (2004). Economic valuation of the coral reefs of Hawai'i. *Pacific Science, 58*(2), 231-242.

Chan, K. M., Balvanera, P., Benessaiah, K., Chapman, M., Díaz, S., Gómez-Baggethun, E., . . . Klain, S. (2016). Opinion: Why protect nature? Rethinking values and the environment. *Proceedings of the National Academy of Sciences, 113*(6), 1462-1465.

Chan, K. M., Gould, R. K., & Pascual, U. (2018). Editorial overview: Relational values: what are they, and what's the fuss about? : Elsevier.

Charles, M. (2005). Functions and socioeconomic importance of coral reefs and lagoons and implication for sustainable management: Case Study of Moorea, French Polynesia. *Wageningen University*.

Costanza, R. (2008). Ecosystem services: multiple classification systems are needed. *Biological conservation, 141*(2), 350-352.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., . . . Paruelo, J. (1997). The value of the world's ecosystem services and natural capital. *nature, 387*(6630), 253-260.

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., . . . Grasso, M. (2017). Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosystem services, 28*, 1-16.

Costanza, R., Pérez-Maqueo, O., Martinez, M. L., Sutton, P., Anderson, S. J., & Mulder, K. (2008). The value of coastal wetlands for hurricane protection. *AMBIO: A Journal of the Human Environment, 37*(4), 241-248.

Crossman, N., Stoeckl, N., Sangha, K. K., & Costanza, R. (2018). Values of the Northern Territory Marine and Coastal Environments. *Australian Marine Conservation Society, Darwin, Australia.*

Czembrowski, P., & Kronenberg, J. (2016). Hedonic pricing and different urban green space types and sizes: Insights into the discussion on valuing ecosystem services. *Landscape and Urban Planning, 146*, 11-19.

Darryl, C., & Choy, L. (2013). *Aboriginal reconnections: understanding coastal urban and peri-urban indigenous people's vulnerability and adaptive capacity to climate change*: National Climate Change Adaptation Research Facility.

Daw, T. M., Coulthard, S., Cheung, W. W., Brown, K., Abunge, C., Galafassi, D., . . . Munyi, L. (2015). Evaluating taboo trade-offs in ecosystems services and human well-being. *Proceedings of the National Academy of Sciences*, 201414900.

De Valck, J., & Rolfe, J. (2018). Linking water quality impacts and benefits of ecosystem services in the Great Barrier Reef. *Marine pollution bulletin, 130*, 55-66.

Deaton, A., & Muellbauer, J. (1980). An almost ideal demand system. *The American Economic Review, 70*(3), 312-326.

DeFries, R., Pagiola, S., Adamowicz, W., Akcakaya, H. R., Arcenas, A., Babu, S., . . . Falconí, F. (2005). Analytical approaches for assessing ecosystem condition and human well-being. *Ecosytems and Human Well-being: Current state and trends, by Millenium Ecosystem Assessment. Washington: World Resources Institute*.

Delisle, A., Kiatkoski Kim, M., Stoeckl, N., Watkin Lui, F., & Marsh, H. (2017). The socio-cultural benefits and costs of the traditional hunting of dugongs and green turtles in Torres Strait, Australia. *Oryx – The International Journal of Conservation*, 1-12.

Deloitte Access Economics. (2013). *Economic contribution of the Great Barrier Reef*. Retrieved from http://elibrary.gbrmpa.gov.au/jspui/handle/11017/2996:

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., . . . Brauman, K. A. (2018). Assessing nature's contributions to people. *Science, 359*(6373), 270-272.

Diener, E., Suh, E. M., Lucas, R. E., & Smith, H. L. (1999). Subjective Well-Being: Three Decades of Progress. *Psychological Bulletin, 125*(2), 276-302. doi:10.1037/0033-2909.125.2.276

Dodd, A., Spring, D., Schneider, K., Hafi, A., Fraser, H., & Kompas, T. (2017). *Year 1 Report: Valuing Australia's Biosecurity System, CEBRA Project 1607A - Milestone 6*. Retrieved from

Dolan, P., & Metcalf, R. (2008). *Comparing willingness-to-pay and subjective well-being in the context of non-market goods*: Centre for Economic Performance, London School of Economics and Political Science.

Drakou, E. G., Pendleton, L., Effron, M., Ingram, J. C., & Teneva, L. (2017). When ecosystems and their services are not co-located: oceans and coasts. *ICES Journal of Marine Science, 74*(6), 1531-1539.

Driml, S. (1987). Economic impacts of activities on the Great Barrier Reef.

Dwyer, L., Forsyth, P., & Spurr, R. (2004). Evaluating tourism's economic effects: New and old approaches. *Tourism Management, 25*(3), 307-317.

Ebarvia, M., & Corazón, M. (1999). *Total economic valuation: coastal and marine resources in the straits of Malacca. MPP-EAS Technical Report No. 24*. Retrieved from

Emslie, M. J., Cheal, A. J., & Johns, K. A. (2014). Retention of habitat complexity minimizes disassembly of reef fish communities following disturbance: a large-scale natural experiment. *PloS one, 9*(8), e105384.

Esparon, M., Farr, M., Larson, S., & Stoeckl, N. (2018). Social values and growth and their implications for ecosystem services in the long-run. *Australasian Journal of Regional Studies, The, 24*(3), 327.

Esparon, M., Stoeckl, N., Farr, M., & Larson, S. (2015). The significance of environmental values for destination competitiveness and sustainable tourism strategy making: insights from Australia's Great Barrier Reef World Heritage Area. *Journal of sustainable tourism, 23*(5), 706-725.

Estrada, F., Tol, R. S., & Gay-García, C. (2015). The persistence of shocks in GDP and the estimation of the potential economic costs of climate change. *Environmental Modelling & Software, 69*, 155-165.

Evans, L. S., Fidelman, P., Hicks, C., Morgan, C., Perry, A. L., & Tobin, R. (2011). *Limits to climate adaptation in the Great Barrieer Reef: scoping ecological and social limits.* . Retrieved from

Eyre, B. D., Cyronak, T., Drupp, P., De Carlo, E. H., Sachs, J. P., & Andersson, A. J. (2018). Coral reefs will transition to net dissolving before end of century. *Science, 359*(6378), 908-911.

Fabricius, K. E., De'Ath, G., Puotinen, M. L., Done, T., Cooper, T. F., & Burgess, S. C. (2008). Disturbance gradients on inshore and offshore coral reefs caused by a severe tropical cyclone. *Limnology and Oceanography, 53*(2), 690-704.

Farber, S., Costanza, R., Childers, D. L., Erickson, J., Gross, K., Grove, M., . . . Troy, A. (2006). Linking ecology and economics for ecosystem management. *BioScience, 56*(2), 121-133.

Farr, M., & Stoeckl, N. (2018). Overoptimism and the undervaluation of ecosystem services: A case-study of recreational fishing in Townsville, adjacent to the Great Barrier Reef. *Ecosystem services*.

Farr, M., Stoeckl, N., & Beg, R. A. (2014). The non-consumptive (tourism)'value'of marine species in the Northern section of the Great Barrier Reef. *Marine Policy, 43*, 89-103.

Farr, M., Stoeckl, N., Esparon, M., Grainger, D., & Larson, S. (2016). *Economic values and Indigenous protected areas across Northern Australia*. Retrieved from http://www.nespnorthern.edu.au/wp-content/uploads/2017/04/Economic_Values_and_IPAs_final_web.pdf:

Farr, M., Stoeckl, N., Esparon, M., Larson, S., & Jarvis, D. (2016). The importance of water clarity to Great Barrier Reef tourists and their willingness to pay to improve it. *Tourism Economics, 22*(2), 331-352.

Fernandez, C., Stoeckl, N., & Welters, R. (2019). The cost of doing nothing in the face of climate change: A case study, using the life-satisfaction approach to value the tangible and intangible costs of flooding in the Philippines. *'Climate and Development, https://www.tandfonline.com/doi/abs/10.1080/17565529.2019.1579697*.

Filatova, T., Polhill, J. G., & van Ewijk, S. (2016). Regime shifts in coupled socio-environmental systems: Review of modelling challenges and approaches. *Environmental Modelling & Software, 75*, 333-347.

Fitzpatrick, L., Parmeter, C. F., & Agar, J. (2017). Threshold Effects in Meta-Analyses With Application to Benefit Transfer for Coral Reef Valuation. *Ecological Economics, 133*, 74-85.

Fleming, C. M., & Cook, A. (2008). The recreational value of Lake McKenzie, Fraser Island: An application of the travel cost method. *Tourism Management, 29*(6), 1197-1205.

Florida, R. (2005). *Cities and the creative class*: Routledge.

Florida, R. (2014). The creative class and economic development. *Economic Development Quarterly, 28*(3), 196-205.

Fu, B.-J., Su, C.-H., Wei, Y.-P., Willett, I. R., Lü, Y.-H., & Liu, G.-H. (2011). Double counting in ecosystem services valuation: causes and countermeasures. *Ecological research, 26*(1), 1-14.

Fujiwara, D., & Campbell, R. (2011). *Valuation techniques for social cost-benefit analysis: stated preference, revealed preference and subjective well-being approaches: a discussion of the current issues*: HM Treasury.

Fulton, E. (2011). Interesting times: winners, losers, and system shifts under climate change around Australia. *ICES Journal of Marine Science, 68*(6), 1329-1342.

Garnett, S. T., Sithole, B., Whitehead, P. J., Burgess, C. P., Johnston, F. H., & Lea, T. (2009). Healthy country, healthy people: policy implications of links between Indigenous human health and environmental condition in tropical Australia. *Australian Journal of Public Administration, 68*(1), 53-66.

GBRMPA. (2012). *Informing the outlook for Great Barrier Reef coastal ecosystems*. Retrieved from

GBRMPA. (2014). *Great barrier reef outlook report 2014*. Retrieved from

Getzner, M., Spash, C., & Stagl, S. (2004). *Alternatives for environmental valuation* (Vol. 4): Routledge.

Glenk, K., & Martin-Ortega, J. (2018). The economics of peatland restoration. *Journal of Environmental Economics and Policy, 7*(4), 345-362.

Gómez-Baggethun, E., & Ruiz-Pérez, M. (2011). Economic valuation and the commodification of ecosystem services. *Progress in Physical Geography, 35*(5), 613-628.

Gopalakrishnan, S., Smith, M. D., Slott, J. M., & Murray, A. B. (2011). The value of disappearing beaches: a hedonic pricing model with endogenous beach width. *Journal of Environmental Economics and Management, 61*(3), 297-310.

Grainger, D., & Stoeckl, N. (in review). The importance of social learning for non-market valuation.

Haines-Young, R., & Potschin, M. (2012). Common international classification of ecosystem services (CICES, Version 4.1). *European Environment Agency, 33*.

Hamilton, J. M. (2007). Coastal landscape and the hedonic price of accommodation. *Ecological Economics, 62*(3), 594-602.

Hansjürgens, B., Schröter-Schlaack, C., Berghöfer, A., & Lienhoop, N. (2017). Justifying social values of nature: economic reasoning beyond self-interested preferences. *Ecosystem Services, 23*, 9-17.

Hardin, G. (2009). The tragedy of the commons. *Journal of Natural Resources Policy Research, 1*(3), 243-253.

Harriott, V. J. (2001). *The sustainability of Queensland's coral harvest fishery*: Citeseer.

Harriott, V. J. (2003). Can corals be harvested sustainably? *AMBIO: A Journal of the Human Environment, 32*(2), 130-133.

Hein, L., Van Koppen, K., De Groot, R. S., & Van Ierland, E. C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. *Ecological Economics, 57*(2), 209-228.

Hicks, J. R. (1939). *Value and Capital*. Oxford: The Clarendon Press.

Hill, R., Walsh, F., Davies, J., & Sandford, M. (2011). Our country our way: guidelines for Australian indigenous protected area management plans.

Himes, A., & Muraca, B. (2018). Relational values: the key to pluralistic valuation of ecosystem services. *Current opinion in environmental sustainability, 35*, 1-7.

Hoagland, P., Kaoru, Y., & Broadus, J. M. (1995). A methodological review of net benefit evaluation for marine reserves. *Environment Department Papers, Environmental Economics Series., Paper No 027*.

Holmes, T. P., Liebhold, A. M., Kovacs, K. F., & Von Holle, B. (2010). A spatial-dynamic value transfer model of economic losses from a biological invasion. *Ecological Economics, 70*(1), 86-95.

Hundloe, T. (1990). Measuring the value of the Great Barrier Reef. *Australian Parks & Recreation, 26*(3), 11-15.

Hunt, B., & Vincent, A. C. (2006). Scale and sustainability of marine bioprospecting for pharmaceuticals. *AMBIO: A Journal of the Human Environment, 35*(2), 57-64.

Hurley, M. V., Lowell, K. E., Cook, D. C., Liu, S., Siddique, A.-B., & Diggle, A. (2010). Prioritizing biosecurity risks using a participatory decision-making tool. *Human and Ecological Risk Assessment, 16*(6), 1379-1394.

Ivanic, M., & Martin, W. (2014). Short-and long-run impacts of food price changes on poverty.

Jackson, S., Finn, M., & Scheepers, K. (2014). The use of replacement cost method to assess and manage the impacts of water resource development on Australian indigenous customary economies. *Journal of Environmental Management, 135*, 100-109.

Jarvis, D. (2016). *The contribution of economic, social and environmental factors to life and tourist satisfaction.* James Cook University.

Jarvis, D., Stoeckl, N., & Liu, H.-B. (2016). The impact of economic, social and environmental factors on trip satisfaction and the likelihood of visitors returning. *Tourism Management, 52*, 1-18.

Jarvis, D., Stoeckl, N., & Liu, H.-B. (2017). New methods for valuing, and for identifying spatial variations, in cultural services: A case study of the Great Barrier Reef. *Ecosystem services, 24*, 58-67.

Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., & Witte, U. (2014). Twenty thousand sterling under the sea: estimating the value of protecting deep-sea biodiversity. *Ecological Economics, 97*, 10-19.

Johnston, R. J., Besedin, E. Y., & Stapler, R. (2017). Enhanced geospatial validity for meta-analysis and environmental benefit transfer: an application to water quality improvements. *Environmental and Resource Economics, 68*(2), 343-375.

Johnston, R. J., Rolfe, J., Rosenberger, R. S., & Brouwer, R. (2015). *Benefit transfer of environmental and resource values* (Vol. 14): Springer.

Jones, A. M. (2011). Raiding the coral nurseries? *Diversity, 3*(3), 466-482.

Kahn, A. S., Yahel, G., Chu, J. W., Tunnicliffe, V., & Leys, S. P. (2015). Benthic grazing and carbon sequestration by deep-water glass sponge reefs. *Limnology and Oceanography, 60*(1), 78-88.

Kahneman, D., & Tversky, A. (2013). Prospect theory: An analysis of decision under risk *Handbook of the fundamentals of financial decision making: Part I* (pp. 99-127): World Scientific.

Kallis, G., Gómez-Baggethun, E., & Zografos, C. (2013). To value or not to value? That is not the question. *Ecological Economics, 94*, 97-105.

Kelly, R. A., Jakeman, A. J., Barreteau, O., Borsuk, M. E., ElSawah, S., Hamilton, S. H., . . . Rizzoli, A. E. (2013). Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software, 47*, 159-181.

Kenter, J. O., O'Brien, L., Hockley, N., Ravenscroft, N., Fazey, I., Irvine, K. N., . . . Bryce, R. (2015). What are shared and social values of ecosystems? *Ecological Economics, 111*, 86-99.

Knapman, B., & Stoeckl, N. (1995). Recreation user fees: an Australian empirical investigation. *Tourism Economics, 1*(1), 5-15.

Kountouris, Y., & Remoundou, K. (2011). Valuing the welfare cost of forest fires: a life satisfaction approach. *Kyklos, 64*(4), 556-578.

Kragt, M. E., Roebeling, P. C., & Ruijs, A. (2009). Effects of Great Barrier Reef degradation on recreational reef-trip demand: a contingent behaviour approach. *Australian Journal of Agricultural and Resource Economics, 53*(2), 213-229.

Kristoffersen, I. (2010). The metrics of subjective wellbeing: Cardinality, neutrality and additivity. *Economic Record, 86*(272), 98-123.

Krutilla, J. V. (1967). Conservation reconsidered. *The American Economic Review, 57*(4), 777-786.

Kubiszewski, I., Costanza, R., Dorji, L., Thoennes, P., & Tshering, K. (2013). An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem services, 3*, e11-e21.

Laibson, D. (1997). Golden eggs and hyperbolic discounting. *The Quarterly Journal of Economics, 112*(2), 443-478.

Lantz, V., & Slaney, G. (2005). *An evaluation of environmental valuation databases around the world*. Paper presented at the International Workshop on Benefits Transfer and Valuation Databases: Are we heading in the right direction?, Washington D.C.

Larson, S., Stoeckl, N., Farr, M., & Esparon, M. (2015). The role the Great Barrier Reef plays in resident wellbeing and implications for its management. *Ambio, 44*(3), 166-177.

Larson, S., Stoeckl, N., Jarvis, D., Addison, J., Prior, S., & Esparon, M. (2018). Using measures of wellbeing for impact evaluation: Proof of concept developed with an Indigenous community undertaking land management programs in northern Australia. *Ambio*, 1-10.

Lin, Y., Deng, X., & Jin, Q. (2013). Economic effects of drought on agriculture in North China. *International Journal of Disaster Risk Science, 4*(2), 59-67.

Liu, J., Mooney, H., Hull, V., Davis, S. J., Gaskell, J., Hertel, T., . . . Kremen, C. (2015). Systems integration for global sustainability. *Science, 347*(6225), 1258832.

Liu, S., Costanza, R., Troy, A., D'Aagostino, J., & Mates, W. (2010). Valuing New Jersey's ecosystem services and natural capital: a spatially explicit benefit transfer approach. *Environmental Management, 45*(6), 1271-1285.

Liu, S., Sheppard, A., Kriticos, D., & Cook, D. (2011). Incorporating uncertainty and social values in managing invasive alien species: a deliberative multi-criteria evaluation approach. *Biological Invasions, 13*(10), 2323.

Lovelock, C. E., Adame, M. F., Bennion, V., Hayes, M., O'Mara, J., Reef, R., & Santini, N. S. (2014). Contemporary rates of carbon sequestration through vertical accretion of sediments in mangrove forests and saltmarshes of South East Queensland, Australia. *Estuaries and Coasts, 37*(3), 763-771.

MacKerron, G. (2012). Happiness economics from 35 000 feet. *Journal of Economic Surveys, 26*(4), 705-735.

MacKerron, G., & Mourato, S. (2009). Life satisfaction and air quality in London. *Ecological Economics, 68*(5), 1441-1453.

Mallon, K., Hamilton, E., Black, M., & Beem, B. (2013). Adapting the community sector for climate extremes. *National Climate Change Adaption Research Facility, Gold Coast*.

Martin-Ortega, J., Glenk, K., & Byg, A. (2017). How to make complexity look simple? Conveying ecosystems restoration complexity for socio-economic research and public engagement. *PloS one, 12*(7), e0181686.

Martins, A., Vieira, H., Gaspar, H., & Santos, S. (2014). Marketed marine natural products in the pharmaceutical and cosmeceutical industries: Tips for success. *Marine drugs, 12*(2), 1066-1101.

MEA, M. E. A. (2005). Ecosystems and human well-being: synthesis. *Island, Washington, DC*.

Measey, G., Vimercati, G., Villiers, F. d., Mokhatla, M., Davies, S., Thorp, C., . . . Kumschick, S. (2016). A global assessment of alien amphibian impacts in a formal framework. *Diversity and Distributions, 22*(9), 970-981.

Mervar, A., & Payne, J. E. (2007). Analysis of foreign tourism demand for Croatian destinations: Long-run elasticity estimates. *Tourism Economics, 13*(3), 407-420.

Milon, J. W., Gressel, J., & Mulkey, D. (1984). Hedonic amenity valuation and functional form specification. *Land Economics, 60*(4), 378-387.

Mongin, M., Baird, M. E., Hadley, S., & Lenton, A. (2016). Optimising reef-scale CO2 removal by seaweed to buffer ocean acidification. *Environmental Research Letters, 11*(3), 034023.

Murphy, I. (2002a). *Mackay and Whitsunday Region: Spending Habits of Recreational Fishermen and Their Contribution to the Economy*. Retrieved from Margate, QLD:

Murphy, I. (2002b). *Townsville and Thuringowa: Spending Habits of Recreational Fishermen and Their Contribution to the Economy*. Retrieved from Margate, QLD:

Mustika, P. L. K., Stoeckl, N., & Farr, M. (2016). The potential implications of environmental deterioration on business and non-business visitor expenditures in a natural setting: a case study of Australia's Great Barrier Reef. *Tourism Economics, 22*(3), 484-504.

Norman-Lopez, A., Pascoe, S., & Hobday, A. J. (2011). Potential economic impacts of climate change on Australian fisheries and the need for adaptive management. *Climate Change Economics, 2*(03), 209-235.

Norton, B., Costanza, R., & Bishop, R. C. (1998). The evolution of preferences: whysovereign'preferences may not lead to sustainable policies and what to do about it. *Ecological Economics, 24*(2-3), 193-211.

O'Mahoney, J., Simes, R., Redhill, D., Heaton, K., Atkinson, C., Hayward, E., & Nguyen, M. (2017). *At what price? The economic, social and icon value of the Great Barrier Reef*. Retrieved from

Orru, K., Orru, H., Maasikmets, M., Hendrikson, R., & Ainsaar, M. (2016). Well-being and environmental quality: Does pollution affect life satisfaction? *Quality of Life Research, 25*(3), 699-705.

Oxford Economics. (2009). *Valuing the effects of Great Barrier Reef bleaching*. Retrieved from

Polhill, J. G., Filatova, T., Schlüter, M., & Voinov, A. (2016). Modelling systemic change in coupled socio-environmental systems. *Environmental Modelling & Software, 75*, 318-332.

Prayaga, P., Rolfe, J., & Stoeckl, N. (2010). The value of recreational fishing in the Great Barrier Reef, Australia: a pooled revealed preference and contingent behaviour model. *Marine Policy, 34*(2), 244-251.

PZJA. (2015). *Protected Zone Joint Authority Annual Report 1 July 2014 to 30 June 2015*. Retrieved from www.pzja.gov.au/resources/publications/annual-reports:

Quiggin, J. (2010). Drought, climate change and food prices in Australia. *Melbourne: Australian Conservation Foundation*.

Rehdanz, K., & Maddison, D. (2005). Climate and happiness. *Ecological Economics, 52*(1), 111-125.

Richardson, L., Loomis, J., Kroeger, T., & Casey, F. (2015). The role of benefit transfer in ecosystem service valuation. *Ecological Economics, 115*, 51-58.

Riopelle, J. M. (1997). The economic valuation of coral reefs: a case study of West Lombok, Indonesia.

Roelofs, A., & Silcock, R. (2008). A sustainability assessment of marine fish species collected in the Queensland marine aquarium trade. *Department of Primary Industries & Fisheries, Brisbane*.

Rolfe, J., Gregg, D., & Tucker, G. (2011). Valuing local recreation in the Great Barrier Reef, Australia. *Environmental Economics Research Hub, Crawford School of Economics and Government, Australian National University, Canberra*, 88.

Rolfe, J., & Windle, J. (2012). Distance decay functions for iconic assets: assessing national values to protect the health of the Great Barrier Reef in Australia. *Environmental and Resource Economics, 53*(3), 347-365.

Rosenberger, R. S., & Loomis, J. (in press). Benefit Transfer. In P. A. Champ, K. J. Boyle, & T. C. Brown (Eds.), *A primer on nonmarket valuation*.

Rubinstein, A. (2003). “Economics and psychology”? The case of hyperbolic discounting. *International Economic Review, 44*(4), 1207-1216.

Sadovy, Y., Donaldson, T., Graham, T., McGilvray, F., Muldoon, G., Phillips, M., . . . Yeeting, B. (2003). While stocks last: The live reef food fish trade.

Sangha, K. K., Russell-Smith, J., Morrison, S. C., Costanza, R., & Edwards, A. (2017). Challenges for valuing ecosystem services from an Indigenous estate in northern Australia. *Ecosystem services, 25*, 167-178.

Schlueter, M., McAllister, R., Arlinghaus, R., Bunnefeld, N., Eisenack, K., Hoelker, F., . . . Quaas, M. (2012). New horizons for managing the environment: A review of coupled social-ecological systems modeling. *Natural Resource Modeling, 25*(1), 219-272.

Schulz, C., & Martin-Ortega, J. (2018). Quantifying relational values—why not? *Current Opinion in Environmental Sustainability*.

Sheppard, C., Dixon, D. J., Gourlay, M., Sheppard, A., & Payet, R. (2005). Coral mortality increases wave energy reaching shores protected by reef flats: examples from the Seychelles. *Estuarine, Coastal and Shelf Science, 64*(2-3), 223-234.

Simon, H. A. (1955). A behavioral model of rational choice. *The Quarterly Journal of Economics, 69*(1), 99-118.

Smith, A. J. (1987). *An ethnobiological study of the usage of marine resources by two Aboriginal communities on the east coast of Cape York Peninsula, Australia.* James Cook University of North Queensland.

Social Ventures Australia Consulting. (2016). Social Return on Investment analysis of the Girringun: Indigenous Protected Area and associated Indigenous ranger programme. *Available at:* https://www.pmc.gov.au/sites/default/files/publications/Girringun-SROI.pdf.

Spring, D., Dodd, A., & Kompas, T. (2017). *Interim Report: Economic methods for estimating the value of Australia's biosecurity system, CEBRA Project 1607A - Milestone 4*. Retrieved from

Spurgeon, J. P. (1992). The economic valuation of coral reefs. *Marine pollution bulletin, 24*(11), 529-536.

Stoeckl, N., Birtles, A., Farr, M., Mangott, A., Curnock, M., & Valentine, P. (2010). Live-aboard dive boats in the Great Barrier Reef: regional economic impact and the relative values of their target marine species. *Tourism Economics, 16*(4), 995-1018.

Stoeckl, N., Farr, M., Jarvis, D., Larson, S., Esparon, M., Sakata, H., . . . Costanza, R. (2014). *The Great Barrier Reef World Heritage Area: its 'value' to residents and tourists Project 10-2 Socioeconomic systems and reef resilience. Final Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited*. Retrieved from

Stoeckl, N., Farr, M., Larson, S., Adams, V. M., Kubiszewski, I., Esparon, M., & Costanza, R. (2014). A new approach to the problem of overlapping values: A case study in Australia′ s Great Barrier Reef. *Ecosystem services, 10*, 61-78.

Stoeckl, N., Hicks, C., Farr, M., Grainger, D., Esparon, M., Thomas, J., & Larson, S. (2018). The Crowding Out of Complex Social Goods. *Ecological Economics, 144*, 65-72.

Stoeckl, N., Hicks, C. C., Mills, M., Fabricius, K., Esparon, M., Kroon, F., . . . Costanza, R. (2011). The economic value of ecosystem services in the Great Barrier Reef: our state of knowledge. *Annals of the New York Academy of Sciences, 1219*(1), 113-133.

Stoeckl, N., Kompas, T., & Dodd, A. (in review). *Assessing the market and non-market value of Australia's Biosecurity system: Review of literature, conceptual framework and empirical case-study showing proof of concept for whole-of system valuation method*. Retrieved from Melbourne:

Stoeckl, N., Smith, A., Newsome, D., & Lee, D. (2005). Regional economic dependence on iconic wildlife tourism: case studies of Monkey Mia and Hervey Bay. *Journal of Tourism Studies, 16*(1), 69.

Stoeckl, N. E. (1998). *Pricing and Functional Form in the Travel Cost Model: A Monte Carlo and Empirical Investigation.* Australian National University.

Stutzer, A., & Frey, B. S. (2010). Recent Advances in the Economics of Individual Subjective Well-Being. *Social Research, 77*(2), 679.

Sumaila, U. R., Cheung, W. W., Lam, V. W., Pauly, D., & Herrick, S. (2011). Climate change impacts on the biophysics and economics of world fisheries. *Nature Climate Change, 1*(9), 449.

Taylor, J., & Stanley, O. (2005). The opportunity costs of the status quo in the Thamarrurr Region.

Unsworth, R. K., Collier, C. J., Henderson, G. M., & McKenzie, L. J. (2012). Tropical seagrass meadows modify seawater carbon chemistry: implications for coral reefs impacted by ocean acidification. *Environmental Research Letters, 7*(2), 024026.

van den Belt, M., Schiele, H., & Forgie, V. (2013). Integrated freshwater solutions—A New Zealand application of mediated modeling. *JAWRA Journal of the American Water Resources Association, 49*(3), 669-680.

Van der Ploeg, S., & De Groot, R. (2010). The TEEB Valuation Database–a searchable database of 1310 estimates of monetary values of ecosystem services. *Foundation for Sustainable Development, Wageningen, The Netherlands*.

Venn, T. J., & Quiggin, J. (2007). Accommodating indigenous cultural heritage values in resource assessment: Cape York Peninsula and the Murray–Darling Basin, Australia. *Ecological Economics, 61*(2), 334-344.

Watkin Lui, F., Stoeckl, N., Delisle, A., Kiatkoski Kim, M., & Marsh, H. (2016). Motivations for sharing bushmeat with an urban diaspora in Indigenous Australia. *Human Dimensions of Wildlife, 21*(4), 345-360.

Webley, J., McInnes, K., Teixeira, D., Lawson, A., & Quinn, R. (2015). *Statewide Recreational Fishing Survey 2013-14*. Retrieved from Brisbane, Queensland.:

Wei, F., Costanza, R., Dai, Q., Stoeckl, N., Gu, X., Farber, S., . . . Zhang, W. (2018). The Value of Ecosystem Services from Giant Panda Reserves. *Current Biology, 28*, 1-7.

Weisbrod, B. A. (1964). Collective-consumption services of individual-consumption goods. *The Quarterly Journal of Economics, 78*(3), 471-477.

Weitzman, M. L. (2001). Gamma discounting. *American Economic Review, 91*(1), 260-271.

Wells, S., & Ravilious, C. (2006). *In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs*: UNEP/Earthprint.

Welsch, H. (2006). Environment and happiness: Valuation of air pollution using life satisfaction data. *Ecological Economics, 58*(4), 801-813.

Wilkinson, R. G., & Pickett, K. E. (2009). Income inequality and social dysfunction. *Annual Review of Sociology, 35*, 493-511.

Willig, R. D. (1976). Consumer’s surplus without apology, American Economic Reiew, 66: Ž.

Windle, J., & Rolfe, J. (2005). Assessing non-use values for environmental protection of an estuary in a Great Barrier Reef catchment. *Australasian journal of environmental management, 12*(3), 147-155.

Windle, J., & Rolfe, J. (2013). Estimating nonmarket values of Brisbane (state capital) residents for state based beach recreation. *Ocean & coastal management, 85*, 103-111.

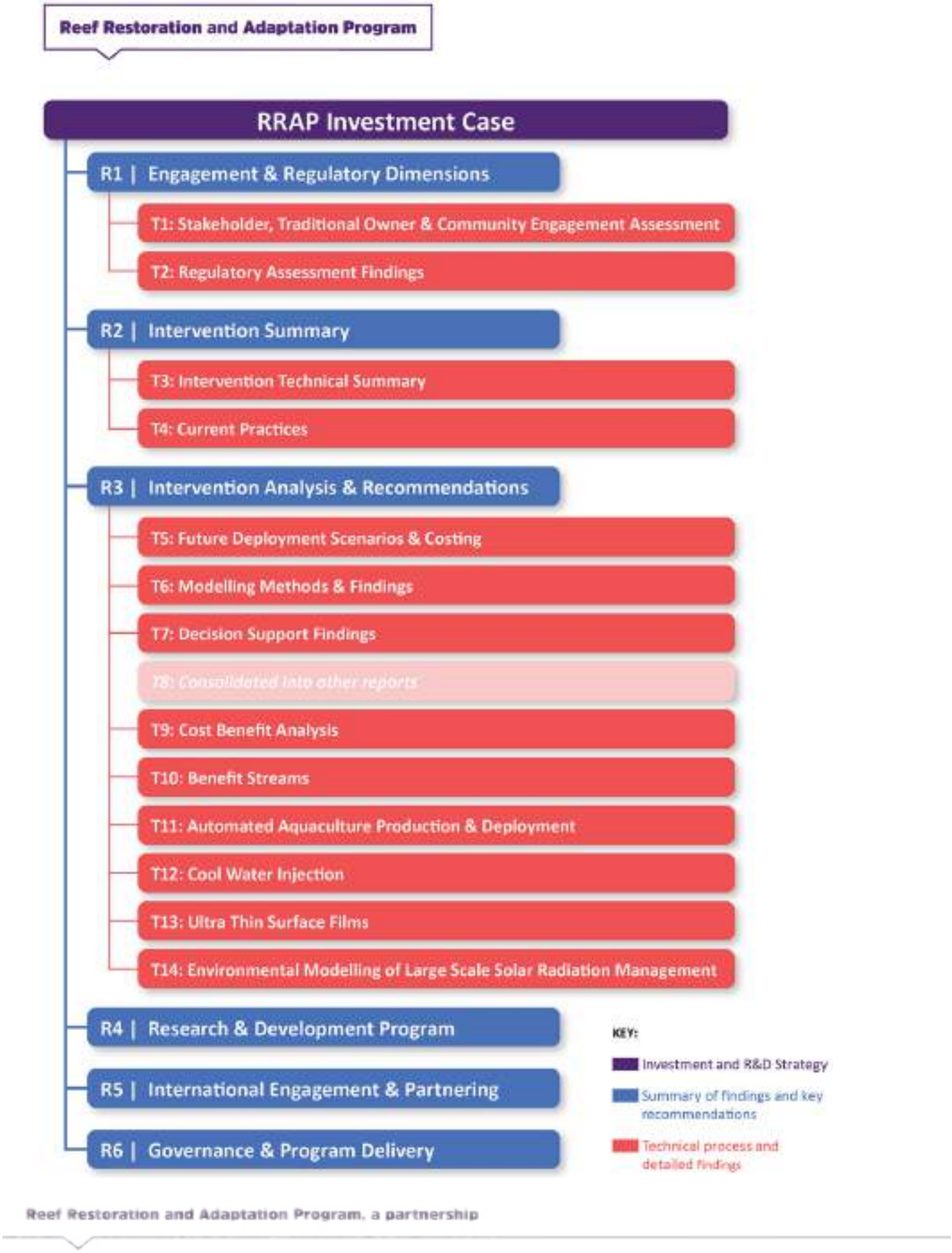
Windle, J., & Rolfe, J. (2014). Estimating the nonmarket economic benefits of beach resource management in southeast Queensland, Australia. *Australasian journal of environmental management, 21*(1), 65-82.

Wood, E., Malsch, K., & Miller, J. (2012). *International trade in hard corals: review of management, sustainability and trends.* Paper presented at the Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia.

Young, I., & Hardy, T. (1993). Measurement and modelling of tropical cyclone waves in the Great Barrier Reef. *Coral Reefs, 12*(2), 85-95.

Zander, K. K., & Garnett, S. T. (2011). The economic value of environmental services on indigenous-held lands in Australia. *PloS one, 6*(8), e23154.

APPENDIX A – RRAP DOCUMENT MAP



APPENDIX B – NON-MARKET VALUATION METHODS

Non-market valuation methods–with examples of applications from Reef and other reef-relevant literature. Adapted from Farr, Stoeckl, Esparon, Grainger, et al. (2016), N. Stoeckl et al. (2018) and N. Stoeckl et al. (in review)

General approach	Specific examples	Comments
Valuation techniques that use observable market prices: Market prices only exist for goods which are bought and sold. So these techniques are only able to provide information about 'use values' which are traded in the market and cannot quantify non-use values; they may also struggle to quantify indirect use-values	Change in the value of output (increase or decreases in earning	When used in environmental valuations, this technique simply estimates the extra earnings (or losses) associated with an environmental good or service (e.g., comparing tourism revenues or expenditure in regions with varying water quality to draw inferences about the value of changes in water quality ((Jarvis et al., 2016), see also (Mustika et al., 2016) who estimates tourist expenditure as a function of (expressed) environmental values.
	Preventative expenditures (damage avoided)	This technique looks at how much people spend to treat damages or to prevent them from occurring, using that information to draw inferences about the 'value' (e.g., by estimating how much would be spent on constructing sea walls to prevent beach erosion and storm damage, one can estimate the 'value' of fringing coral reefs or mangroves which provide similar protection ((Lauretta Burke, Greenhalgh, Prager, & Cooper, 2008) .In their larger-scale benefit transfer studies, (Oxford Economics, 2009) and (Crossman et al., 2018) incorporate values generated from other studies which use this approach
	Replacement cost or Expected cost	These approaches look at how much it costs (or is expected to cost) to replace damaged items (e.g., the cost of repairing buildings and businesses after storm surge provides an estimate of the (regulating) value of wetlands which reduce storm surge damage –(Costanza et al., 2008)).
Valuation techniques that use surrogate markets: Revealed preference approaches do not require the goods that one wishes to value to be exchanged in the market, but they require a strong connection between that good and the market (e.g., house prices and 'views'; salaries/wages and workplace safety). If one cannot establish a connection between the intangible good to be valued and the market then one cannot use these techniques. This is most likely to be the case for intangible benefits associated with IPAs such as spiritual/cultural, bequest and existence values, suggesting that	Hedonic pricing (including wage differential and property or land value approaches)	This technique assumes that multiple things contribute to the value of a house (or car, or job) – some of which are associated with the environment. Essentially, it is as if it compares the value of two houses which are identical in all respects (e.g., number of bedrooms, bathrooms) except for one: proximity to an urban park. The difference in house price between that which is near the park and that which is not, gives an indication of the value of the park – everything else constant (Czembrowski & Kronenberg, 2016).
	Travel cost	This technique notes that even if there is no monetary entry fee to a park, people must spend money travelling to and from it. The money spent travelling can be used to draw inferences about the value of a park, an activity related to the park, or the value of parks that are of different environmental 'quality' (e.g., people will travel further and spend more to visit a well-maintained park than a degraded one). This approach has been used, in conjunction with insights from the contingent behaviour literature, to assess, amongst other things, the impact of algal blooms on the value of recreational fishing trips (Prayaga et al., 2010), and to assess the likely impact of reductions in fish catch (Farr & Stoeckl, 2018).
	Acceptance of compensation	This technique considers how much people have been awarded, in the courts, as 'compensation' for damages – using those estimates as a proxy for value (Kallis et al., 2013).

General approach	Specific examples	Comments
these techniques cannot be used to monetise those benefits.		
Stated preference techniques: In principal, these techniques are capable of estimating the monetary value of anything, including use and non-use values. People are asked how much they would be 'willing to pay' if a market did exist. The quality of the estimate is only as good as the quality of the experiment designed to elicit the value – and there is a substantive body of literature that provides guidance on how best to describe the market and conduct the experiment. These techniques thus require the use of complex survey design, often draining to the respondents and requiring the use of sophisticated analytical procedures (Bateman et al., 2002; Day et al., 2012).	Contingent valuation Contingent behaviour	Contingent Valuation (CV) involves the construction of 'hypothetical' markets. Individuals are asked to indicate their willingness to pay for, for example, improved water quality/clarity to enjoy swimming, snorkelling or diving (Farr, Stoeckl, Esparon, Larson, et al., 2016). Contingent behaviour also uses hypothetical markets, although asks respondents about their likely behaviour (e.g. to go fishing or to travel) rather than willingness to pay. Examples include: (Prayaga et al., 2010), (Mustika et al., 2016)
	Choice Modelling	Choice modelling (CM) differs from CV, in that respondents are asked to choose between alternatives, rather than asked if they are willing to pay a price or to behave in a particular way. CM involves the construction of numerous different 'choice-sets', each with different characteristics (e.g., differently levels of environmental amenity) and different prices. Individuals are asked to indicate which choice-set is preferred, and these preferences are used to draw inferences about the value of the different characteristics described in the choice-sets. (see (Rolfe, Gregg, & Tucker, 2011), (Rolfe & Windle, 2012), (Jill Windle & Rolfe, 2013), (J Windle & Rolfe, 2014)).
Techniques that use subjective or other measures to assess 'value' These techniques avoid many of the strategic biases associated with stated preference approaches and both the practical and ethical problems of assessing all 'value' in monetary terms, but the approaches are not, problem free. It can, for example, be difficult to measure 'utility' and if working with the LS approach it is important to ensure that all factors likely to affect LS are included in the model (while controlling for potentially complex interactions between those variables). Moreover, without standardisation of measurement scales, assessments of value or impact collected from different studies will not be comparable	Life satisfaction (LS) approach	This approach attempts to assess the value of the environment, by asking respondents to indicate how satisfied they are with life overall on a quantifiable scale. These life satisfaction (LS) scores are regressed against a range of variables known to affect LS, in addition to variables capturing environmental quality. Regression coefficients can be used to directly estimate the income-compensation that would be required to keep LS constant should environmental quality reduce. Researchers have used the LS approach to consider the impact (on LS) of a wide range of non-priced goods and services including air pollution (Orru, Orru, Maasikmets, Hendrikson, & Ainsaar, 2016); (MacKerron & Mourato, 2009); (MacKerron, 2012); (Welsch, 2006), unfavourable weather conditions (Rehdanz & Maddison, 2005), forest fires (Kountouris & Remoundou, 2011), droughts (Carroll, Frijters, & Shields, 2009), and non-use values of the Reef (Jarvis et al., 2017). Reef-relevant examples that have generated financial estimates of 'value' include: (Jarvis et al., 2016) and (Jarvis et al., 2017)
	Rating, ranking, multi-criteria analysis and other deliberative or participatory approaches	These approaches generally use structured methods to elicit the opinion of 'experts' or other stakeholders – for example, having them rank, or prioritise threats according to perceptions of likely impact. This approach is often used when information is scare or when uncertainty is the norm. Relevant biosecurity examples include: (Hurley et al., 2010),(S. Liu, Sheppard, Kriticos, & Cook, 2011) who use deliberative multi-criteria analysis to highlight (non-market) social impacts associated with invasive pests and weeds; and (Measey et al., 2016) who use a 'generic impact' scoring metric to assess a wide variety of social, economic, and environmental impacts of invasive amphibians. Reef-relevant examples include: (Larson, Stoeckl, Farr, & Esparon, 2015) and (Esparon, Stoeckl, Farr, & Larson, 2015)

General approach	Specific examples	Comments
Benefit Transfer (BT) The practice of *transferring* valuation estimates that have been generated in one context, to another context. Sometimes the only option if resource constraints preclude the preferred option of estimating values directly. In general, the more similar are contexts, the more accurately will benefits from one region describe those in another.	Unit Value transfers Simple and meta-value function transfers	As the names suggest, unit-value transfers involve using simple (unit) estimates generated in one region in another context. Function values allow one to adjust estimates, to allow for differences across context (e.g. higher incomes, lower rainfall). BT has been used in two Reef contexts that we are aware of: by (Oxford Economics, 2009) and Asafu-Adjaye et al. (2005).

APPENDIX C – TONNES OF REEF-DEPENDENT COMMERCIAL FISH CAUGHT IN EACH QFISH GRID-ZONE DURING 2016

GRID CODE	Coral Trout	Red Emperor	Snapper	GRID CODE	Coral Trout	Red Emperor	Snapper	GRID CODE	Coral Trout	Red Emperor	Snapper
F6	0	0	0	D9	26	1	2	O24	0	0	0
F4	0	0	0	E9	0	0	0	P24	1	0	0
F5	0	0	0	F9	0	0	0	Q24	15	3	1
B4	0	0	0	G9	0	0	0	R24	15	4	1
C4	0	0	0	D10	6	0	1	S24	7	2	1
D4	0	0	0	E10	5	1	1	T24	0	0	0
E4	0	0	0	F10	0	0	0	U24	0	0	0
B5	0	0	0	G10	0	0	0	V24	0	0	0
C5	0	0	0	D11	0	0	0	O25	0	0	0
D5	0	0	0	E11	0	0	0	P25	0	0	0
E5	0	0	0	F11	5	1	2	Q25	4	1	0
X30	0	0	0	G11	14	3	2	R25	14	5	1
U30	3	2	14	H11	0	0	0	S25	22	7	1
V30	0	0	1	F12	0	0	0	T25	37	20	2
W30	0	0	0	G12	3	1	1	U25	21	9	1
S30	0	0	0	H12	19	7	2	V25	7	3	8
T30	0	0	0	G13	2	0	0	W25	0	0	0
H16	3	0	1	H13	29	14	3	O26	0	0	0
I16	10	1	3	I13	0	0	0	P26	0	0	0
J16	1	0	0	G14	1	0	0	Q26	0	0	0
H17	0	0	0	H14	34	2	3	R26	0	0	0
I17	25	0	2	I14	0	0	0	S26	0	0	0
J17	3	1	4	G15	0	0	1	T26	27	17	6
I18	12	0	2	H15	46	3	4	U26	43	20	3
J18	24	2	5	I15	0	0	1	V26	20	11	22
K18	0	0	0	J15	0	0	0	W26	0	0	0
L18	0	0	0	B6	0	0	0	P27	0	0	1
I19	0	0	1	C6	1	0	0	Q27	0	1	0
J19	41	8	6	D6	0	0	0	R27	0	0	1
K19	3	2	6	E6	0	0	0	S27	0	0	4
L19	0	0	0	M21	72	19	4	T27	0	0	4
M19	0	0	0	N21	35	14	4	U27	11	3	6
N19	0	0	0	O21	21	8	2	V27	35	27	34
I20	0	0	0	P21	0	0	0	W27	0	0	0
J20	0	0	0	Q21	0	0	0	R28	0	0	4
K20	10	2	1	L22	0	0	0	S28	0	0	0
L20	24	7	4	M22	0	0	0	T28	0	1	1
M20	6	3	1	N22	3	1	1	U28	0	0	3
N20	0	0	0	O22	41	18	5	V28	0	0	8
O20	0	0	0	P22	28	10	2	W28	0	0	0
I21		0	0	Q22	13	5	1	X28	0	0	0
J21	0	0	1	R22	0	0	0	R29	0	0	0
K21	0	0	0	S22	0	0	0	S29	0	0	0
L21	3	1	1	M23	0	0	0	T29	2	3	2
C7	8	1	1	N23	2	0	1	U29	3	3	7
D7	37	1	2	O23	0	0	0	V29	0	0	0
E7	0	0	0	P23	5	1	0	W29	0	0	0
F7	0	0	0	Q23	22	8	2	X29	0	0	0
C8	0	0	0	R23	16	6	1	T31	0	0	0
D8	20	2	2	S23	0	0	0	U31	0	1	1
E8	0	0	0	T23	0	0	0	V31	0	0	3
F8	0	0	0	N24	0	0	0	W31	0	0	4
								X31	0	0	0

APPENDIX D – TONNES OF CORAL HARVESTED IN EACH QFISH GRID-ZONE DURING 2016

Table D1: Tonnes of coral harvested in each QFish grid zone during 2016. Table only includes grid-zones with coral harvest (‘Missing’ = 0 harvest)

Table only includes grid-zones with coral harvest (‘Missing’ = 0 harvest)

GRID_CODE Coral type	S30	H16	I16	I17	I18	H15	O24	P25	P26	Q26	Q27	R29
[a stony coral]	0.89	0.03	0.07	0.01	0.08	0.03	0.17	0.2	0.04	0.16	0.06	0.21
Catalaphyllia jardinei	0	0.04	0.07	0	0	0.03	0.06	0.08	0.06	0.08	0.07	0
Clavulariidae	0	0	0.04	0	0	0	0	0	0	0	0	0
Corallimorph	0	0	0.01	0	0	0	0	0.04	0	0	0	0
Euphyllia glabrascens	0	0.01	0.04	0	0.01	0.01	0.07	0.16	0	0.04	0.01	0
Faviidae	0.02	0.03	0.13	0	0.09	0.04	0.07	0.13	0.13	0.27	0.09	0
Fungiidae	0	0.05	0.08	0	0.14	0.09	0.01	0.01	0	0	0	0
Goniopora/alvepora	0	0.02	0.16	0	0	0	0	0.09	0	0.11	0.01	0
Montipora	0	0.33	1.42	0.66	1.66	0.49	0	1.39	0	0	0	0
Nephtheidae	0	0	0.03	0	0	0.02	0	0	0	0	0	0
Other coral	0	0.18	0.43	0	0	0.23	0.09	0	0	0.1	0.03	0.08
Pectiniidae	0	0	0	0	0.07	0	0.03	0	0	0	0.01	0
Soft coral	0	0.01	0.07	0	0.04	0.03	0.01	0.01	0	0	0	0
Xeniidae	0	0.01	0.03	0	0	0.01	0	0	0	0	0	0
Zoanthidae	0.01	0	0.01	0	0	0	0	0	0	0	0	0

APPENDIX E – TOURISM ADAPTIONS

In the ‘very short term - e.g. during the first 0, 1 and 2 months following significant reef damage. Tourists and tourism operators may change the foci of their operations (e.g. offering crocodile-viewing tours instead of reef tours). Initially, changes such as these could be embryonic, as when, for example, a tourist arrives in town for a holiday that was booked several months ago, to hear that the reef that is accessible from town has been recently severely degraded. The tourist takes other regional tours, instead. There is some loss of consumer surplus (and disappointed tourists), but there may be little to no change in the ‘producer surplus’ captured by the tourism industry – what will happen is a transfer of surplus from reef operators to other operators (e.g. from reef to rainforest). Reef tourism operators will suffer, other (e.g. rainforest) tourism operators will benefit. Figure E3 and the associated explanation shows data that is consistent with this hypothesis (although we note the need to undertake detailed modelling should one wish to quantify responses more precisely).

In what we will call the ‘short term’– e.g. from 3 – 12 months following significant reef damage, other adaptations will start to emerge. If the impacted area of reef does not recover, then some reef tourism operators will probably go out of business – they will be forced to move locations (to regions where reefs are not degraded), or to change the nature of their operations. Tourists will either continue to visit the region (going to other reefs, or doing other things), or they will choose to visit other regions. The nature and extent of adaptions will depend upon biophysical, institutional and socio-economic factors. Recognising that it is not feasible to allow for all of these complexities, we assume that the preferred outcome is a return to the status quo. For this to occur, tourism operators will need to find un-degraded reefs that are not significantly further from port than the reefs normally visited. If there is such a reef, then operators may need permission to take visitors there, we understand that tourism operators generally have a good relationship with the Great Barrier Reef Marine Park Authority, who are likely to provide positive assistance in times such as this, so suggest that it will be biophysical factors that limit these adaptions.

If there are no locally ‘substitutable’ reefs, then tourists and tourism operators either need to adapt their activities and offerings to suit the non-reef environment or go elsewhere. If full (perfect) adaptation, then no further losses. The region transforms into a ‘different’ destination, but not one that is devoid of tourists. If imperfect adaption, then one would expect tourism numbers (and associated consumer and producer surpluses) to decline over time. Full adaption seems unlikely, but so too does the ‘no adaption’ option.

We also note the important of space and distance. If only one region of the reef is affected, then it is possible that at least some tourists, intent on seeing the Reef, will be able to change their destination from the impacted region to another (e.g. if degradation in Cairns, then tourism to that region may drop off, but it may rise in the Whitsundays; evidence for inter-regional substitution can be found in Figure E3; Cairns and the Whitsundays have been ‘vying’ for top-spot in the EMC visitor numbers game for several decades). To the extent that this substitution is possible, tourism losses across the entire Reef will be mitigated (with inter-regional transfers occurring). If all reefs have been degraded, then tourists and operators will never have the opportunity to substitute one region for another (e.g. going to the Whitsundays instead of to Cairns), so adaption will occur, but relatively slowly. Tourism may grow in other regions – and it is even possible that instead of having most tourists visit two regions (current state), we find that we end up with that same number of tourists – albeit in a more concentrated area.

Most reef tourism occurs within the Cairns and Whitsunday's planning areas, which differ markedly with respect to the 'tourism product' on offer, and thus their likely trajectories for adaption. Notably, reef visitors in the Cairns region generally stay overnight on the mainland, travelling to the Great Barrier Reef by boat. Some marine tourism operators have made substantial investments in infrastructure to support those visits. Quicksilver, for example, has a substantial pontoon at Agincourt reef, where the boats that take visitors to the reef can moor, and from which visitors can either dive, snorkel, take glass bottom boat trips &/or helicopter viewing trips while there[82]. If the reefs that support these visits are substantially degraded, then marine operators may struggle to adapt: they may be able to find other reefs that are close to the key ports of Port Douglas and Cairns, to which infrastructure could be moved, but options are somewhat limited by both physical space, by tides /currents and winds, and by planning regulations which restrict the numbers of visitors permitted in different areas (Figure E1 and E2). The Great Barrier Reef Marine Park Authority has a *Tourism contingency plan* – which allows tourism operators to apply for permission to substitute "like for like opportunities" (e.g. vessels that can carry more than 100 passengers could theoretically apply for permission to move from one 'red zone' to another but would not be granted permission to take the (large) vessel o more restricted areas (e.g. the orange, or yellow zones). If the reef is substantially degraded in the Cairns region and if degradation impacts key reefs (the 'red zone), the adaption options are limited: marine tourism operators are likely to suffer substantial losses; visitors can look inland (to the rainforest) for attractions, but there are relatively few beach or other marine related activities to entertain them.

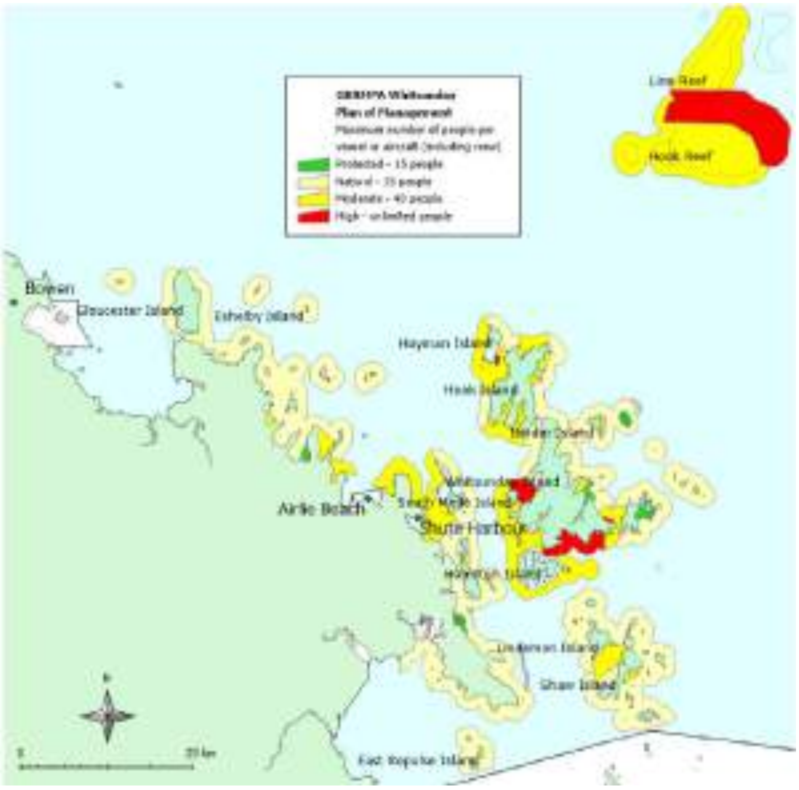
The Whitsundays, in contrast, is not so much a reef destination, as an island one. Accommodation is available on numerous islands; visitors can swim off the beach to view coral, also enjoying other beach or island-related activities. Widespread damage to all reefs in the area would still cause problems in the region, although arguably, the reef is a less centrally crucial part of the holiday experience in the Whitsundays than it is in Cairns. That this is so is partially evident in the fact that marine tourism operators in the Whitsundays region have responded to recent damage (associated with cyclones Marcia and Debbie) by highlighting non-reef dependent activities, such as stand-up paddle-boarding and kayaking[83]. Adaption options are also, arguably, more plentiful than in the Cairns/Port Douglas Region (although an area that appears to satisfy the 'like for like' requirement of the *Tourism Contingency plan,* with respect to limits on passenger numbers, may not be a suitable site to take visitors if, for example, currents are too strong to permit safe swimming).

82 https://quicksilver-cruises.com/reef-tour/wavepiercer/
83 Personal communication, Fred Nucifora, Great Barrier Reef Marine Park Authority.

Sensitive Locations	Total Hectares
1 vessel per day	18,634
2 vessels per day	986
4 vessels per day	5,034
No set limit	521

Maximum number of people per vessel or aircraft (including crew)	Total Hectares
Low - 15 people	127,622
Moderate - 60 people	67,888
Moderate - 100 people to a mooring	31,521
Intensive - unlimited people	20,392

Figure E1: Cairns/Port Douglas planning area – sensitive regions, and permitted persons per vessel.



Maximum number of people per vessel or aircraft (including crew)	Total Hectares
Protected - 15 people	2,062
Natural - 15 people	80,473
Moderate - 40 people	47,821
High - unlimited people	13,398

Figure E2: Whitsundays planning area –permitted persons per vessel.

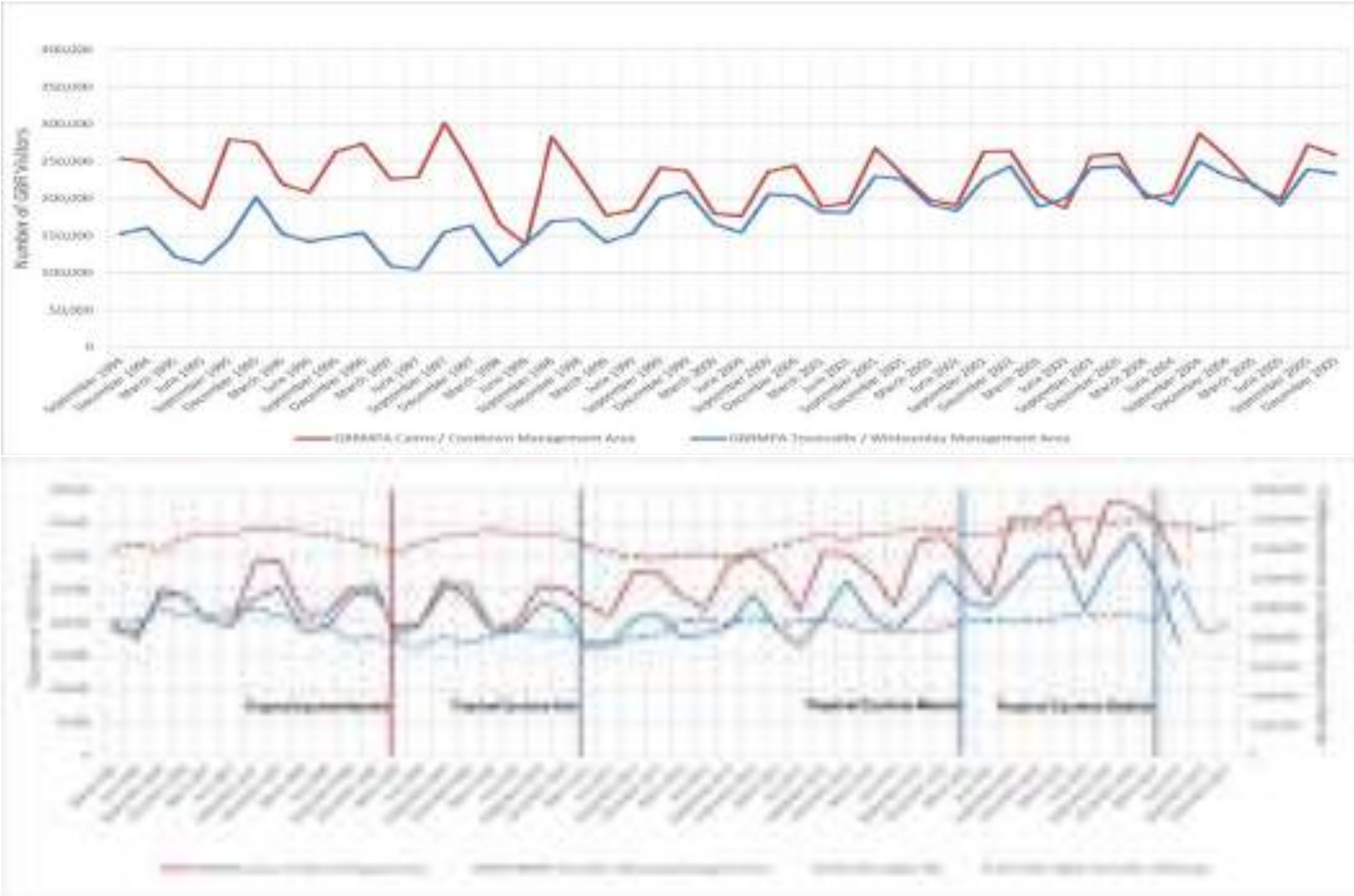


Figure E3: The number of reef visitors (from EMC data) by month from 1994 – 2017 for the Cairns/Cooktown (red lines) and the Townsville/Whitsundays (blue lines) management areas. Vertical bars show category 4 and 5 cyclones affecting each area; colour of bar shows region affected (red – Cairns/Cooktown; blue – Townsville/Whitsundays). Data are consistent with the hypothesis of no net loss of producer surplus (but transfers from reef to other operators) in the very short term. Top panel shows GBMPRA data on visitors to the reef. The bottom panel also includes data from Tourism Research Australia (dotted lines) on the total number of visitors to each region. There are observable seasonal fluctuations in reef visitor numbers, but no evidence to suggest that these short-term fluctuations are impacted by significant weather events, such as category 4 or 5 cyclones. There is no immediate and visually obvious impact from cyclone Hamish, Yasi and Marcia. Reef visitor numbers are already falling (normal seasonal variation) when Debbie hits – although regional (terrestrial) numbers markedly after Debbie – perhaps because recovery workers came from outside the region to assist, and were counted as tourists, since temporary visitors only.

APPENDIX F – DISTANCE FROM MIDPOINT OF QFISH ZONES TO NEAREST PORT

Grid-code	Distance	Nearest port	Grid-code	Distance	Nearest port	Grid-code	Distance	Nearest port
B4	590.12	Cooktown	D10	250.08	Cooktown	P24	73.84	Mackay
C4	567.37	Cooktown	E10	219.29	Cooktown	Q24	119.69	Mackay
D4	549.02	Cooktown	D11	210.55	Cooktown	R24	169.06	Mackay
E4	535.53	Cooktown	E11	172.95	Cooktown	S24	219.6	Mackay
B5	541.21	Cooktown	F11	145.81	Cooktown	T24	270.64	Mackay
C5	516.35	Cooktown	G11	135.57	Cooktown	U24	307.03	Yeppoon
D5	496.16	Cooktown	F12	96.32	Cooktown	O25	14.14	Mackay
E5	481.22	Cooktown	G12	80.01	Cooktown	P25	60.62	Mackay
U30	62.25	Agnes Water	H12	96.32	Cooktown	Q25	111.88	Mackay
S30	83.95	Agnes Water	G13	24.45	Cooktown	R25	163.48	Mackay
T30	53.71	Agnes Water	H13	58.89	Cooktown	S25	215.18	Yeppoon
H16	19.61	Cairns	G14	31.11	Cooktown	T25	233.57	Yeppoon
I16	55.27	Cairns	H14	61.9	Cooktown	U25	260.41	Yeppoon
I17	62.94	Cairns	G15	34.65	Port Douglas	V25	293.88	Yeppoon
J17	96.84	Mission Beach	H15	39.94	Port Douglas	O26	67.88	Mackay
I18	20.12	Mission Beach	I15	87.6	Port Douglas	P26	89.84	Mackay
J18	69.31	Mission Beach	B6	493.7	Cooktown	Q26	129.94	Mackay
I19	23.72	Cardwell	C6	466.38	Cooktown	R26	154	Yeppoon
J19	76.44	Cardwell	D6	443.96	Cooktown	S26	162.42	Yeppoon
K19	121.59	Cardwell	E6	427.24	Cooktown	T26	185.25	Yeppoon
L19	149.63	Townsville	M21	85.08	Bowen	U26	218.01	Yeppoon
I20	58.79	Townsville	N21	101.67	Bowen	V26	256.93	Yeppoon
J20	57.39	Townsville	O21	126.12	Hamilton Island	P27	136.53	Mackay
K20	73.19	Townsville	P21	147.75	Hamilton Island	Q27	110.86	Yeppoon
L20	113.76	Townsville	N22	62.99	Bowen	R27	98.44	Yeppoon
M20	140.61	Bowen	O22	73.43	Hamilton Island	U27	182.81	Yeppoon
N20	151.26	Bowen	P22	106.29	Hamilton Island	V27	227.68	Yeppoon
J21	6.76	Townsville	Q22	150.5	Hamilton Island	R28	42.88	Yeppoon
K21	45.87	Townsville	M23	26.34	Bowen	T28	111.2	Yeppoon
L21	98.06	Townsville	N23	24.42	Hamilton Island	V28	183.96	Agnes Water
C7	417.81	Cooktown	O23	32.44	Hamilton Island	R29	12.68	Yeppoon
D7	392.69	Cooktown	P23	83.3	Hamilton Island	S29	52.88	Yeppoon
E7	373.71	Cooktown	Q23	135.12	Hamilton Island	T29	103.19	Yeppoon
C8	371.21	Cooktown	R23	187.1	Hamilton Island	U29	112.59	Agnes Water
D8	342.75	Cooktown	S23	237.31	Mackay	T31	16.14	Agnes Water
D9	294.83	Cooktown	N24	49.32	Hamilton Island	V31	79.7	Bundaberg
			O24	44.34	Mackay	W31	114.08	Bundaberg

APPENDIX G – PROJECTED BENEFIT STREAMS

Table G1: Scenario 1 RCP 2.6, business as usual, crown-of-thorns starfish control; no other interventions - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.63	0.25	173.98	26.69	1543.51	10.57	1015.17	628.87	3404.67
2018	5.60	0.25	173.88	27.20	1540.10	10.56	1015.07	627.53	3400.20
2019	5.72	0.25	178.40	28.56	1548.76	10.57	1019.87	635.74	3427.86
2020	5.74	0.24	178.49	27.10	1548.84	10.58	1019.97	636.97	3427.93
2021	5.80	0.24	180.93	27.82	1553.23	10.59	1022.50	641.08	3442.19
2022	5.80	0.24	180.90	29.43	1552.76	10.58	1022.47	641.22	3443.40
2023	5.80	0.24	179.84	28.29	1553.14	10.58	1021.38	641.41	3440.68
2024	5.91	0.25	181.60	27.17	1561.00	10.61	1023.20	649.47	3459.21
2025	5.91	0.24	181.15	26.72	1560.27	10.61	1022.73	649.24	3456.87
2026	5.91	0.24	181.59	26.42	1560.23	10.61	1023.19	649.86	3458.05
2027	5.90	0.25	181.05	28.16	1560.21	10.60	1022.63	649.83	3458.63
2028	5.86	0.25	180.04	27.85	1556.86	10.59	1021.60	647.07	3450.12
2029	5.85	0.25	179.55	27.88	1557.72	10.59	1021.09	646.93	3449.85
2030	5.88	0.24	180.64	29.47	1557.43	10.59	1022.22	648.72	3455.19
2031	5.92	0.25	181.29	29.46	1562.02	10.59	1022.89	652.74	3465.16
2032	5.85	0.25	179.40	28.36	1557.00	10.56	1020.95	648.26	3450.63
2033	5.85	0.25	178.34	29.02	1556.20	10.56	1019.84	648.23	3448.29
2034	5.75	0.24	175.81	28.49	1550.78	10.54	1017.22	641.12	3429.95
2035	5.75	0.23	176.84	30.23	1548.12	10.54	1018.30	640.46	3430.50
2036	5.75	0.24	176.40	29.37	1548.80	10.54	1017.84	640.42	3429.35
2037	5.72	0.24	174.46	27.20	1545.34	10.56	1015.81	637.78	3417.09
2038	5.77	0.24	175.84	27.74	1549.69	10.56	1017.26	641.23	3428.32
2039	5.70	0.23	173.13	27.69	1541.83	10.57	1014.42	636.11	3409.68
2040	5.74	0.23	174.17	28.44	1541.87	10.58	1015.52	638.58	3415.13
2041	5.80	0.24	173.19	26.68	1545.63	10.60	1014.48	642.32	3418.94
2042	5.70	0.24	170.11	27.14	1540.59	10.57	1011.20	637.24	3402.78
2043	5.65	0.24	166.58	27.71	1537.17	10.56	1007.39	633.80	3389.11
2044	5.62	0.24	167.48	28.45	1535.22	10.55	1008.37	632.36	3388.30
2045	5.68	0.24	169.81	28.84	1536.55	10.55	1010.92	636.32	3398.91
2046	5.62	0.24	167.47	27.58	1533.24	10.54	1008.39	632.55	3385.62
2047	5.62	0.24	168.82	26.47	1532.64	10.53	1009.87	632.23	3386.42
2048	5.68	0.23	171.02	27.59	1534.42	10.55	1012.26	636.09	3397.84
2049	5.66	0.22	170.45	26.64	1532.13	10.55	1011.64	634.36	3391.66
2050	5.52	0.21	165.85	26.54	1519.12	10.55	1006.69	623.81	3358.28
2051	5.55	0.21	167.88	27.58	1520.54	10.54	1008.92	625.49	3366.71
2052	5.54	0.21	167.28	26.94	1521.02	10.55	1008.27	624.93	3364.73
2053	5.61	0.21	171.45	28.65	1525.32	10.55	1012.83	629.45	3384.09
2054	5.67	0.22	172.09	24.80	1528.89	10.59	1013.51	632.46	3388.22
2055	5.59	0.22	166.94	24.69	1520.47	10.59	1008.00	627.01	3363.50
2056	5.49	0.21	164.19	24.61	1511.17	10.58	1004.99	620.10	3341.34
2057	5.53	0.21	165.29	25.14	1514.10	10.58	1006.21	623.66	3350.74
2058	5.61	0.22	169.01	25.54	1519.21	10.59	1010.32	629.13	3369.63
2059	5.67	0.22	172.11	25.86	1524.49	10.58	1013.69	633.84	3386.46
2060	5.74	0.23	174.61	27.33	1529.89	10.58	1016.36	638.73	3403.47
2061	5.68	0.23	171.78	27.72	1526.63	10.57	1013.37	634.82	3390.80

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2062	5.80	0.24	175.93	30.05	1535.67	10.58	1017.82	643.14	3419.24
2063	5.85	0.23	177.66	29.83	1537.60	10.61	1019.64	645.58	3427.00
2064	5.86	0.23	179.30	31.23	1537.85	10.61	1021.35	645.93	3432.34
2065	5.84	0.22	178.89	32.27	1535.53	10.60	1020.93	644.56	3428.83
2066	5.78	0.22	175.98	34.69	1528.63	10.60	1017.90	640.16	3413.96
2067	5.87	0.23	176.62	33.39	1536.97	10.61	1018.57	646.17	3428.43
2068	5.83	0.23	175.18	33.83	1536.03	10.60	1017.06	644.47	3423.21
2069	5.91	0.22	180.29	34.58	1538.06	10.60	1022.46	649.61	3441.73
2070	5.82	0.22	179.16	35.64	1533.87	10.57	1021.29	643.72	3430.29
2071	5.75	0.22	177.16	33.84	1529.64	10.57	1019.22	638.56	3414.96
2072	5.73	0.22	176.54	33.72	1530.62	10.56	1018.57	637.79	3413.75
2073	5.81	0.23	179.05	34.58	1535.71	10.57	1021.21	643.93	3431.10
2074	5.74	0.22	176.44	34.41	1528.36	10.57	1018.50	637.97	3412.21
2075	5.80	0.22	179.67	34.77	1531.57	10.57	1021.89	642.14	3426.63

Table G2: Scenario 2 RCP 2.6 Strong crown-of-thorns starfish control; no other interventions - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.69	0.25	174.35	25.97	1546.57	10.59	1015.57	632.88	3411.88
2018	5.66	0.25	173.24	25.81	1543.88	10.59	1014.39	631.55	3405.37
2019	5.64	0.26	172.46	25.50	1541.75	10.58	1013.57	630.23	3399.97
2020	5.67	0.26	172.35	25.85	1545.19	10.58	1013.45	632.48	3405.83
2021	5.73	0.26	173.04	23.95	1549.30	10.59	1014.18	636.78	3413.82
2022	5.73	0.25	172.94	24.20	1545.61	10.59	1014.08	636.21	3409.61
2023	5.70	0.24	171.18	23.42	1543.75	10.58	1012.21	635.21	3402.32
2024	5.72	0.25	170.44	23.52	1546.38	10.58	1011.40	637.18	3405.49
2025	5.80	0.25	173.44	24.69	1548.10	10.59	1014.64	641.54	3419.07
2026	5.92	0.25	177.60	25.60	1556.98	10.60	1019.07	649.64	3445.69
2027	5.96	0.25	177.46	24.90	1559.97	10.60	1018.92	652.88	3450.99
2028	5.97	0.25	177.72	23.80	1561.57	10.60	1019.20	653.64	3452.80
2029	5.90	0.25	174.85	23.01	1553.45	10.59	1016.20	648.52	3432.84
2030	5.98	0.25	176.72	23.44	1559.55	10.60	1018.18	654.10	3448.88
2031	6.09	0.25	179.79	23.13	1566.65	10.61	1021.39	660.94	3468.92
2032	6.09	0.25	181.26	24.42	1567.08	10.61	1022.91	661.24	3473.92
2033	6.19	0.25	185.46	25.57	1573.82	10.62	1027.23	667.84	3497.03
2034	6.05	0.24	179.83	24.86	1562.44	10.61	1021.54	658.61	3464.24
2035	5.99	0.24	177.05	24.99	1556.85	10.60	1018.67	654.91	3449.36
2036	6.06	0.24	179.41	24.41	1560.08	10.61	1021.14	658.89	3460.89
2037	6.10	0.25	178.85	24.46	1563.02	10.60	1020.56	661.71	3465.64
2038	6.05	0.25	177.70	24.96	1560.07	10.60	1019.36	658.64	3457.70
2039	5.94	0.25	174.85	23.92	1555.37	10.59	1016.39	652.23	3439.58
2040	5.94	0.25	175.00	24.88	1552.91	10.59	1016.55	651.48	3437.64
2041	5.81	0.24	172.47	25.41	1542.78	10.59	1013.87	642.82	3414.02
2042	5.71	0.24	171.77	28.37	1534.37	10.58	1013.13	636.26	3400.42
2043	5.74	0.24	170.53	28.52	1537.71	10.58	1011.80	638.93	3404.05
2044	5.99	0.25	179.62	29.78	1554.12	10.61	1021.59	656.01	3457.97
2045	6.18	0.26	186.18	31.22	1569.10	10.63	1028.39	669.39	3501.32
2046	6.21	0.26	187.34	32.25	1568.81	10.63	1029.55	671.25	3506.30
2047	6.28	0.26	188.95	33.84	1570.17	10.63	1031.17	674.66	3515.98
2048	6.32	0.26	192.08	34.97	1572.52	10.64	1034.29	677.70	3528.78
2049	6.27	0.25	189.68	35.56	1567.76	10.63	1031.93	672.98	3515.08
2050	6.03	0.24	183.80	33.40	1550.66	10.62	1026.09	657.61	3468.44
2051	5.91	0.24	176.49	33.17	1544.05	10.60	1018.65	649.48	3438.59
2052	5.84	0.23	174.06	33.46	1537.63	10.59	1016.10	644.26	3422.18
2053	5.80	0.24	175.42	32.40	1536.04	10.60	1017.54	643.52	3421.52
2054	5.62	0.22	171.58	29.79	1522.45	10.58	1013.50	630.72	3384.43
2055	5.63	0.22	171.39	30.02	1521.21	10.58	1013.29	630.80	3383.11
2056	5.51	0.22	167.33	28.40	1511.14	10.57	1008.92	622.68	3354.72
2057	5.61	0.23	169.54	28.18	1519.17	10.58	1011.35	629.89	3374.51
2058	5.57	0.22	169.08	28.79	1516.51	10.58	1010.85	627.39	3368.95
2059	5.67	0.23	170.59	26.51	1524.43	10.58	1012.48	634.69	3385.15
2060	5.63	0.22	169.94	25.34	1523.83	10.58	1011.79	632.37	3379.68
2061	5.66	0.23	171.35	27.33	1526.29	10.58	1013.31	634.92	3389.61
2062	5.67	0.23	168.79	28.68	1526.75	10.58	1010.56	635.96	3387.20
2063	5.78	0.23	172.33	28.66	1536.71	10.59	1014.41	643.74	3412.43
2064	5.77	0.23	173.40	30.29	1535.35	10.59	1015.56	642.59	3413.73

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	5.70	0.23	170.50	29.77	1531.70	10.58	1012.47	638.83	3399.75
2066	5.73	0.24	170.31	30.78	1533.63	10.58	1012.26	640.83	3404.30
2067	5.69	0.24	168.67	28.10	1530.89	10.58	1010.49	638.63	3393.25
2068	5.74	0.24	170.28	29.81	1534.09	10.58	1012.24	641.56	3404.50
2069	5.67	0.23	167.86	30.22	1526.71	10.57	1009.63	636.77	3387.61
2070	5.66	0.23	168.30	30.88	1527.86	10.58	1010.11	636.34	3389.91
2071	5.46	0.23	159.09	30.58	1514.84	10.55	1000.07	622.39	3343.16
2072	5.45	0.23	160.82	30.50	1509.42	10.55	1002.04	621.38	3340.33
2073	5.44	0.23	159.93	27.19	1508.28	10.55	1001.04	620.70	3333.31
2074	5.45	0.23	160.80	26.96	1509.45	10.55	1002.03	621.81	3337.22
2075	5.53	0.22	163.22	23.99	1513.64	10.56	1004.75	627.31	3349.15

Table G3: Scenario 4 RCP 2.6, business as usual, crown-of-thorns starfish control; low enhanced corals, low cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.65	0.26	173.38	26.03	1541.17	10.59	1014.54	629.32	3400.94
2018	5.69	0.26	175.79	26.20	1543.22	10.59	1017.11	632.23	3411.10
2019	5.66	0.27	174.86	26.76	1539.58	10.59	1016.13	629.60	3403.45
2020	5.64	0.27	172.63	26.14	1538.04	10.59	1013.77	628.76	3395.84
2021	5.64	0.27	173.60	25.16	1537.37	10.59	1014.80	628.70	3396.14
2022	5.58	0.27	172.44	25.35	1532.65	10.58	1013.58	624.66	3385.12
2023	5.50	0.27	168.99	23.87	1524.38	10.57	1009.89	618.84	3362.31
2024	5.60	0.27	172.39	24.84	1530.35	10.58	1013.57	625.19	3382.79
2025	5.70	0.28	176.21	25.72	1536.79	10.59	1017.66	632.57	3405.52
2026	5.76	0.29	177.08	26.46	1540.13	10.60	1018.57	637.20	3416.08
2027	5.72	0.29	174.83	27.45	1536.74	10.59	1016.22	635.47	3407.32
2028	5.66	0.30	172.47	26.15	1532.95	10.59	1013.73	632.19	3394.04
2029	5.71	0.30	174.12	26.72	1535.91	10.59	1015.49	635.84	3404.67
2030	5.71	0.30	174.96	28.14	1533.70	10.59	1016.38	635.35	3405.12
2031	5.83	0.30	180.32	29.02	1543.45	10.60	1022.04	643.96	3435.54
2032	5.91	0.31	182.31	28.76	1549.35	10.61	1024.09	649.40	3450.74
2033	6.07	0.31	187.70	29.15	1559.67	10.63	1029.61	660.10	3483.24
2034	6.22	0.32	193.75	31.22	1567.96	10.64	1035.67	669.66	3515.44
2035	6.31	0.32	198.25	33.21	1573.09	10.65	1040.06	675.90	3537.78
2036	6.36	0.32	200.94	32.09	1576.22	10.65	1042.64	678.98	3548.20
2037	6.40	0.32	202.15	32.15	1576.96	10.66	1043.79	681.60	3554.03
2038	6.57	0.33	206.73	32.73	1589.10	10.67	1048.11	693.14	3587.38
2039	6.54	0.33	205.62	32.26	1585.92	10.67	1047.08	690.87	3579.30
2040	6.61	0.33	207.20	33.27	1591.55	10.67	1048.56	695.80	3593.99
2041	6.72	0.34	209.76	33.30	1599.40	10.68	1050.93	702.87	3614.00
2042	6.66	0.34	208.05	31.76	1596.01	10.68	1049.35	698.95	3601.80
2043	6.68	0.34	209.09	33.94	1597.20	10.68	1050.32	700.90	3609.16
2044	6.74	0.35	211.11	35.43	1602.28	10.69	1052.17	705.39	3624.15
2045	6.84	0.36	214.25	35.27	1611.03	10.70	1055.05	712.49	3645.98
2046	6.95	0.38	218.32	35.86	1619.92	10.71	1058.72	720.51	3671.36
2047	7.01	0.38	220.44	36.31	1622.96	10.71	1060.60	723.62	3682.02
2048	7.10	0.39	222.54	36.05	1628.62	10.72	1062.46	729.77	3697.65
2049	7.03	0.38	222.81	37.46	1623.27	10.71	1062.70	725.10	3689.45
2050	7.11	0.38	226.18	37.60	1629.86	10.72	1065.65	730.37	3707.87
2051	7.16	0.39	228.54	39.16	1633.32	10.72	1067.69	734.23	3721.21
2052	7.19	0.39	227.01	40.96	1633.70	10.72	1066.38	735.69	3722.05
2053	7.18	0.40	226.14	41.56	1634.81	10.72	1065.63	735.71	3722.15
2054	7.10	0.39	226.45	43.40	1628.38	10.72	1065.90	730.91	3713.24
2055	7.18	0.40	227.60	43.03	1633.54	10.72	1066.89	735.98	3725.33
2056	7.16	0.40	225.53	40.87	1633.54	10.72	1065.11	735.55	3718.88
2057	7.05	0.39	221.62	41.79	1624.83	10.71	1061.72	727.62	3695.74
2058	6.99	0.38	220.38	42.32	1619.26	10.70	1060.62	723.40	3684.04
2059	6.97	0.38	219.82	43.78	1615.77	10.70	1060.13	722.25	3679.81
2060	7.01	0.38	221.88	44.56	1618.02	10.70	1061.96	724.51	3689.03
2061	7.07	0.39	224.03	44.60	1622.64	10.71	1063.84	728.98	3702.26
2062	7.03	0.38	223.89	44.43	1619.46	10.71	1063.72	726.27	3695.88
2063	7.05	0.37	224.41	46.61	1618.09	10.70	1064.18	726.82	3698.23
2064	7.10	0.38	225.09	46.37	1622.29	10.71	1064.76	730.59	3707.29

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	7.09	0.38	222.05	45.00	1621.71	10.71	1062.13	729.53	3698.59
2066	7.13	0.38	225.19	46.41	1626.10	10.71	1064.88	732.56	3713.38
2067	7.12	0.39	222.61	44.00	1627.53	10.72	1062.64	732.44	3707.44
2068	7.12	0.39	223.51	46.18	1626.96	10.71	1063.43	732.54	3710.84
2069	7.06	0.39	220.24	44.01	1625.83	10.71	1060.57	729.53	3698.34
2070	7.11	0.40	221.45	42.75	1631.38	10.72	1061.64	733.63	3709.08
2071	7.14	0.41	221.11	42.11	1635.73	10.72	1061.34	735.83	3714.39
2072	7.27	0.42	223.88	42.64	1644.92	10.73	1063.78	744.24	3737.88
2073	7.24	0.41	223.92	43.67	1641.16	10.72	1063.82	741.98	3732.93
2074	7.25	0.41	224.68	44.39	1640.54	10.72	1064.48	742.55	3735.03
2075	7.12	0.40	220.39	43.29	1633.36	10.71	1060.75	734.27	3710.29

Table G4: Scenario 7 RCP 2.6, business as usual, crown-of-thorns starfish control; low enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.57	0.24	171.76	26.80	1535.98	10.58	1012.82	623.62	3387.36
2018	5.54	0.24	171.76	26.46	1535.06	10.58	1012.82	621.58	3384.04
2019	5.50	0.25	169.01	24.47	1535.47	10.58	1009.87	620.30	3375.45
2020	5.47	0.24	168.20	25.56	1529.36	10.57	1008.99	617.68	3366.08
2021	5.45	0.25	168.00	26.73	1528.57	10.57	1008.78	616.94	3365.28
2022	5.43	0.25	168.24	28.26	1528.58	10.57	1009.04	616.69	3367.05
2023	5.45	0.25	168.59	28.89	1531.46	10.57	1009.43	617.99	3372.63
2024	5.54	0.26	171.47	29.28	1536.68	10.58	1012.55	623.95	3390.31
2025	5.41	0.25	167.07	28.55	1525.57	10.56	1007.84	615.33	3360.59
2026	5.39	0.25	167.06	29.59	1522.54	10.56	1007.83	613.00	3356.22
2027	5.44	0.25	169.18	29.82	1527.89	10.57	1010.15	617.03	3370.34
2028	5.53	0.25	170.65	30.39	1533.98	10.57	1011.73	623.10	3386.20
2029	5.60	0.25	171.00	30.18	1539.78	10.58	1012.11	628.22	3397.71
2030	5.62	0.26	172.06	30.86	1541.90	10.58	1013.26	630.17	3404.71
2031	5.83	0.27	179.72	33.54	1556.12	10.60	1021.46	644.03	3451.56
2032	5.99	0.27	185.04	33.20	1565.22	10.61	1026.96	654.48	3481.77
2033	6.21	0.28	192.86	35.01	1580.33	10.63	1034.87	669.36	3529.54
2034	6.36	0.28	199.40	37.30	1590.04	10.64	1041.28	678.87	3564.16
2035	6.51	0.29	204.29	37.68	1602.86	10.65	1045.94	690.00	3598.23
2036	6.68	0.30	210.71	39.67	1615.75	10.67	1051.96	701.14	3636.87
2037	6.86	0.31	216.64	40.80	1628.77	10.68	1057.39	713.05	3674.49
2038	7.00	0.31	221.14	41.30	1638.09	10.69	1061.42	721.69	3701.65
2039	7.14	0.32	226.51	43.04	1647.15	10.70	1066.15	731.18	3732.20
2040	7.24	0.32	229.60	44.31	1653.68	10.71	1068.83	737.13	3751.82
2041	7.40	0.33	235.52	46.69	1664.43	10.72	1073.90	747.50	3786.48
2042	7.49	0.34	238.02	47.37	1670.27	10.72	1075.99	753.09	3803.29
2043	7.51	0.34	239.26	47.59	1671.80	10.73	1077.03	754.57	3808.81
2044	7.51	0.34	238.15	45.93	1671.82	10.73	1076.11	754.71	3805.30
2045	7.54	0.34	241.02	46.41	1674.32	10.73	1078.50	756.90	3815.75
2046	7.64	0.34	244.94	47.72	1679.91	10.74	1081.73	762.91	3835.93
2047	7.71	0.34	247.26	47.49	1685.34	10.74	1083.61	767.66	3850.16
2048	7.82	0.35	252.40	48.09	1691.92	10.75	1087.77	775.10	3874.22
2049	7.86	0.35	253.61	47.14	1694.54	10.76	1088.74	777.47	3880.47
2050	7.85	0.36	254.89	46.70	1695.03	10.76	1089.75	777.54	3882.88
2051	7.77	0.35	252.22	45.97	1688.33	10.75	1087.64	771.98	3865.01
2052	7.73	0.35	253.03	46.53	1686.96	10.75	1088.28	769.76	3863.39
2053	7.83	0.36	255.53	46.48	1693.06	10.76	1090.27	775.61	3879.91
2054	7.86	0.36	256.91	47.55	1694.25	10.76	1091.36	777.50	3886.56
2055	7.83	0.37	254.97	46.47	1691.96	10.76	1089.84	776.03	3878.23
2056	7.86	0.37	256.32	46.91	1691.78	10.76	1090.91	778.11	3883.02
2057	8.00	0.37	260.16	47.58	1699.42	10.77	1093.92	786.33	3906.56
2058	8.07	0.38	262.56	48.44	1702.42	10.77	1095.79	790.58	3919.01
2059	8.07	0.38	260.84	48.13	1701.57	10.77	1094.46	790.28	3914.49
2060	8.09	0.38	260.51	47.78	1702.80	10.77	1094.20	791.73	3916.25
2061	8.03	0.37	259.07	48.40	1699.84	10.77	1093.08	788.59	3908.15
2062	7.98	0.37	258.73	49.60	1697.13	10.77	1092.82	785.93	3903.34
2063	7.98	0.38	256.71	49.41	1697.78	10.77	1091.24	785.75	3900.01
2064	7.88	0.38	252.76	48.11	1693.33	10.77	1088.14	780.36	3881.72

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	f.73	0.39	249.11	47.06	1688.95	10.76	1085.24	772.54	3861.78
2066	7.75	0.39	248.32	45.38	1690.83	10.76	1084.61	773.52	3861.56
2067	7.68	0.39	246.42	43.97	1687.31	10.76	1083.08	769.12	3848.73
2068	7.56	0.38	242.85	43.81	1678.58	10.75	1080.18	761.07	3825.18
2069	7.42	0.38	238.45	43.49	1671.44	10.74	1076.57	752.20	3800.68
2070	7.38	0.37	237.05	42.45	1671.03	10.74	1075.40	750.33	3794.75
2071	7.36	0.38	235.67	42.68	1670.55	10.74	1074.26	749.31	3790.95
2072	7.30	0.37	233.46	42.34	1666.80	10.74	1072.40	745.25	3778.65
2073	7.40	0.38	236.65	41.81	1673.94	10.74	1075.10	751.77	3797.79
2074	7.39	0.38	236.10	41.74	1674.89	10.75	1074.64	751.79	3797.67
2075	7.48	0.38	239.85	44.17	1680.47	10.75	1077.78	757.43	3818.30

Table G5: Scenario 10 RCP 2.6, BAU crown-of-thorns starfish control; high enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.69	0.25	175.54	27.12	1546.37	10.59	1016.83	632.34	3414.73
2018	5.71	0.26	174.88	26.89	1547.43	10.59	1016.14	634.20	3416.10
2019	5.79	0.26	177.25	27.50	1551.03	10.60	1018.64	639.56	3430.63
2020	5.82	0.26	177.49	26.70	1552.64	10.60	1018.89	641.25	3433.64
2021	5.82	0.27	179.87	28.07	1553.97	10.61	1021.38	642.82	3442.80
2022	5.83	0.27	181.70	29.27	1553.61	10.61	1023.28	643.31	3447.88
2023	5.87	0.27	181.58	28.08	1556.51	10.61	1023.15	645.77	3451.84
2024	5.89	0.27	182.14	27.56	1558.43	10.61	1023.72	646.81	3455.43
2025	5.90	0.27	182.98	28.87	1558.83	10.61	1024.59	647.54	3459.59
2026	5.95	0.27	185.45	28.80	1563.14	10.62	1027.11	651.35	3472.69
2027	5.89	0.27	184.89	29.90	1556.75	10.61	1026.54	646.50	3461.37
2028	5.86	0.27	183.30	29.56	1554.11	10.61	1024.93	644.58	3453.22
2029	5.83	0.27	181.26	27.47	1553.57	10.61	1022.85	643.44	3445.30
2030	5.78	0.27	178.37	25.41	1550.96	10.61	1019.88	640.57	3431.86
2031	5.96	0.28	184.91	27.51	1564.20	10.62	1026.68	653.22	3473.39
2032	6.18	0.28	192.81	29.31	1579.13	10.64	1034.68	667.80	3520.84
2033	6.27	0.29	197.44	31.91	1585.20	10.65	1039.22	674.95	3545.93
2034	6.57	0.30	208.09	34.26	1605.63	10.67	1049.47	694.54	3609.54
2035	6.76	0.31	213.39	36.20	1615.83	10.68	1054.36	707.03	3644.56
2036	6.91	0.31	218.64	38.04	1624.80	10.69	1059.12	716.60	3675.12
2037	7.07	0.32	224.48	39.58	1634.66	10.71	1064.31	727.41	3708.54
2038	7.24	0.33	231.13	41.43	1644.43	10.72	1070.10	738.18	3743.56
2039	7.46	0.33	238.33	41.54	1657.57	10.73	1076.24	751.91	3784.11
2040	7.58	0.33	242.73	42.63	1663.13	10.74	1079.90	758.98	3806.03
2041	7.82	0.34	252.24	45.14	1676.71	10.76	1087.69	773.70	3854.40
2042	7.72	0.34	251.20	45.65	1667.92	10.75	1086.87	766.82	3837.26
2043	7.82	0.34	255.19	47.46	1675.16	10.75	1090.05	773.13	3859.90
2044	7.88	0.34	258.06	48.25	1678.09	10.76	1092.32	775.96	3871.66
2045	7.95	0.35	259.69	49.72	1682.68	10.76	1093.59	780.57	3885.31
2046	7.94	0.35	261.12	50.53	1683.62	10.76	1094.71	780.39	3889.42
2047	8.00	0.35	262.48	50.96	1687.21	10.76	1095.76	783.94	3899.47
2048	8.06	0.35	265.28	51.75	1693.00	10.77	1097.92	787.88	3915.01
2049	8.07	0.36	265.31	53.41	1694.55	10.77	1097.95	788.65	3919.07
2050	8.03	0.36	262.08	52.02	1692.26	10.77	1095.47	786.42	3907.40
2051	7.95	0.36	259.25	51.82	1687.38	10.76	1093.29	781.90	3892.72
2052	7.98	0.36	259.34	51.33	1690.62	10.77	1093.36	784.30	3898.06
2053	7.94	0.36	257.83	51.54	1688.65	10.77	1092.18	781.77	3891.03
2054	7.80	0.36	253.52	52.59	1681.58	10.76	1088.80	773.46	3868.86
2055	7.76	0.36	251.40	52.26	1680.19	10.76	1087.12	772.09	3861.93
2056	7.76	0.36	251.76	52.10	1681.62	10.76	1087.41	772.04	3863.82
2057	7.67	0.36	248.56	51.30	1677.32	10.75	1084.86	766.71	3847.52
2058	7.55	0.35	244.93	50.96	1669.14	10.74	1081.94	759.07	3824.68
2059	7.44	0.36	241.26	50.44	1663.24	10.73	1078.94	752.66	3805.07
2060	7.39	0.35	239.25	49.31	1661.48	10.73	1077.29	750.03	3795.84
2061	7.37	0.35	240.40	50.71	1658.79	10.73	1078.25	748.60	3795.19
2062	7.32	0.34	236.84	47.93	1654.13	10.72	1075.30	745.01	3777.59
2063	7.43	0.34	240.61	46.34	1662.26	10.73	1078.46	752.55	3798.72
2064	7.41	0.35	241.15	46.39	1662.61	10.73	1078.90	751.57	3799.11

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	7.38	0.34	240.77	46.75	1660.41	10.73	1078.58	749.73	3794.69
2066	7.42	0.34	241.21	46.03	1663.15	10.73	1078.94	752.06	3799.89
2067	7.35	0.34	237.74	45.11	1659.34	10.73	1076.09	747.86	3784.56
2068	7.38	0.34	236.61	42.91	1662.32	10.73	1075.15	749.68	3785.11
2069	7.42	0.34	238.04	43.10	1666.80	10.74	1076.34	753.10	3795.88
2070	7.45	0.35	238.72	42.51	1670.20	10.74	1076.91	755.30	3802.19
2071	7.46	0.35	238.26	42.38	1672.25	10.74	1076.53	755.66	3803.64
2072	7.35	0.35	234.46	41.69	1667.10	10.74	1073.36	749.12	3784.16
2073	7.36	0.35	234.64	41.94	1667.95	10.74	1073.52	749.91	3786.41
2074	7.34	0.34	234.57	41.68	1667.11	10.73	1073.46	748.43	3783.65
2075	7.35	0.34	234.69	41.40	1668.16	10.74	1073.56	749.51	3785.75

Table G6: Scenario 34 RCP 2.6, Perfect crown-of-thorns starfish control; high enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.56	0.25	169.59	24.04	1535.33	10.58	1010.52	623.23	3379.08
2018	5.52	0.24	168.67	23.82	1531.50	10.57	1009.52	621.06	3370.91
2019	5.54	0.24	168.11	24.64	1532.07	10.57	1008.92	622.02	3372.12
2020	5.47	0.25	167.60	25.48	1526.70	10.57	1008.37	616.93	3361.35
2021	5.43	0.24	167.24	25.70	1523.07	10.57	1007.97	614.28	3354.51
2022	5.36	0.23	164.92	25.49	1514.20	10.56	1005.43	608.62	3334.82
2023	5.30	0.23	163.14	25.54	1508.24	10.56	1003.46	603.93	3320.39
2024	5.26	0.22	161.85	26.70	1500.14	10.55	1002.02	599.88	3306.63
2025	5.15	0.22	157.74	25.82	1489.98	10.54	997.41	593.16	3280.01
2026	5.12	0.22	156.63	26.07	1486.97	10.54	996.14	591.88	3273.56
2027	5.17	0.21	158.71	25.91	1490.38	10.54	998.53	595.45	3284.92
2028	5.19	0.22	159.83	25.47	1491.80	10.55	999.81	596.70	3289.56
2029	5.15	0.21	159.98	25.96	1486.44	10.55	999.98	592.88	3281.14
2030	5.12	0.21	157.96	27.24	1482.73	10.54	997.69	590.94	3272.45
2031	5.33	0.22	165.07	28.66	1499.17	10.56	1005.83	606.05	3320.89
2032	5.57	0.23	173.30	30.48	1515.95	10.59	1014.92	622.01	3373.05
2033	5.84	0.24	183.10	33.23	1534.87	10.62	1025.36	640.02	3433.27
2034	6.10	0.25	191.88	35.25	1552.78	10.64	1034.32	657.51	3488.72
2035	6.33	0.26	200.84	38.24	1568.15	10.67	1043.14	672.67	3540.30
2036	6.53	0.27	208.46	39.79	1582.75	10.68	1050.38	686.18	3585.04
2037	6.74	0.28	215.82	41.75	1597.39	10.70	1057.17	700.50	3630.35
2038	7.07	0.29	227.14	43.08	1618.46	10.73	1067.34	721.97	3696.08
2039	7.51	0.30	243.14	47.48	1644.63	10.77	1081.16	749.61	3784.60
2040	7.93	0.32	258.75	51.40	1669.31	10.80	1093.97	776.09	3868.58
2041	8.21	0.33	268.76	55.41	1683.55	10.82	1101.79	792.75	3921.61
2042	8.65	0.35	285.53	59.73	1706.77	10.85	1114.52	819.30	4005.71
2043	9.07	0.36	301.07	65.47	1727.47	10.88	1125.78	843.86	4083.96
2044	9.46	0.38	315.74	68.98	1747.40	10.91	1135.98	866.44	4155.27
2045	9.73	0.39	324.62	72.96	1759.87	10.92	1141.94	882.25	4202.67
2046	10.17	0.41	342.56	78.08	1782.29	10.95	1153.72	908.12	4286.29
2047	10.53	0.42	357.33	84.03	1798.97	10.97	1163.03	928.52	4353.79
2048	11.03	0.44	375.18	88.10	1821.90	11.00	1173.91	956.05	4437.61
2049	11.50	0.46	393.44	92.54	1843.84	11.02	1184.64	981.42	4518.86
2050	11.85	0.47	407.13	98.58	1858.84	11.04	1192.40	1000.34	4580.64
2051	12.33	0.49	424.64	104.20	1880.03	11.06	1202.07	1025.51	4660.34
2052	12.69	0.51	438.54	108.21	1896.76	11.08	1209.50	1044.60	4721.90
2053	13.07	0.53	453.93	110.98	1914.42	11.10	1217.52	1065.47	4787.03
2054	13.50	0.55	470.28	115.37	1932.26	11.12	1225.83	1087.38	4856.30
2055	13.81	0.57	482.49	120.91	1945.85	11.13	1231.86	1102.74	4909.38
2056	14.27	0.59	500.86	125.94	1965.71	11.15	1240.77	1125.76	4985.05
2057	14.66	0.62	514.48	130.49	1981.73	11.17	1247.19	1144.70	5045.02
2058	14.96	0.64	523.62	133.84	1994.71	11.18	1251.40	1158.90	5089.24
2059	15.37	0.65	540.74	137.40	2010.42	11.20	1259.20	1178.41	5153.38
2060	15.80	0.67	560.40	146.39	2026.20	11.21	1267.94	1198.29	5226.89
2061	16.04	0.68	568.28	146.93	2036.28	11.22	1271.34	1209.59	5260.36
2062	16.35	0.69	581.15	151.07	2047.73	11.23	1276.85	1223.81	5308.87
2063	16.71	0.70	599.51	157.15	2060.79	11.25	1284.57	1240.64	5371.33
2064	16.98	0.70	611.31	161.70	2070.83	11.26	1289.42	1252.59	5414.80

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	17.12	0.70	618.50	165.36	2075.19	11.27	1292.33	1258.33	5438.80
2066	17.41	0.71	629.61	165.36	2085.61	11.28	1296.79	1271.51	5478.27
2067	17.66	0.71	643.75	169.63	2093.92	11.29	1302.38	1283.30	5522.65
2068	17.91	0.71	654.97	173.57	2102.15	11.30	1306.75	1293.94	5561.29
2069	18.19	0.72	668.17	176.31	2111.38	11.31	1311.82	1306.56	5604.45
2070	18.20	0.72	667.99	175.97	2111.77	11.31	1311.75	1307.21	5604.91
2071	18.30	0.72	673.11	181.36	2114.40	11.31	1313.69	1310.69	5623.58
2072	18.34	0.73	672.77	180.98	2115.09	11.31	1313.56	1311.99	5624.77
2073	18.46	0.73	680.20	183.54	2119.03	11.32	1316.36	1317.52	5647.15
2074	18.59	0.73	687.79	186.99	2122.90	11.33	1319.18	1323.23	5670.73
2075	18.61	0.73	690.19	188.13	2124.00	11.33	1320.07	1324.52	5677.59

Table G7: Scenario 14 RCP 8.5 BAU crown-of-thorns starfish control; no other interventions - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.56	0.24	171.56	25.26	1534.06	10.59	1012.61	624.62	3384.49
2018	5.51	0.24	170.20	24.25	1530.01	10.57	1011.15	622.15	3374.07
2019	5.43	0.23	166.28	24.37	1524.32	10.57	1006.92	614.98	3353.09
2020	5.44	0.23	168.75	25.90	1523.26	10.56	1009.63	619.55	3363.31
2021	5.41	0.23	169.45	26.02	1519.37	10.55	1010.40	620.85	3362.27
2022	5.43	0.23	170.02	26.05	1519.82	10.55	1011.01	621.88	3364.99
2023	5.43	0.23	169.32	26.24	1515.83	10.55	1010.25	620.60	3358.43
2024	5.45	0.23	169.65	25.35	1515.60	10.56	1010.62	621.22	3358.67
2025	5.41	0.22	167.02	24.94	1511.76	10.55	1007.77	616.40	3344.06
2026	5.26	0.22	160.84	24.42	1499.57	10.52	1001.00	604.98	3306.82
2027	5.21	0.22	158.78	23.86	1494.83	10.53	998.67	601.11	3293.22
2028	5.27	0.22	161.18	25.59	1499.03	10.53	1001.41	605.66	3308.90
2029	5.23	0.21	160.67	26.92	1495.91	10.51	1000.84	604.71	3305.01
2030	5.26	0.21	161.41	26.84	1497.69	10.51	1001.67	606.10	3309.71
2031	5.23	0.21	162.09	29.05	1493.68	10.49	1002.44	607.38	3310.60
2032	5.06	0.20	155.22	28.89	1479.86	10.47	994.73	594.49	3269.03
2033	5.15	0.20	156.79	29.56	1489.21	10.48	996.56	597.51	3285.62
2034	5.05	0.20	150.95	28.98	1482.93	10.48	989.83	586.38	3255.01
2035	5.02	0.20	148.76	29.04	1482.14	10.49	987.23	582.12	3245.23
2036	5.01	0.20	149.84	30.28	1480.98	10.46	988.53	584.24	3249.86
2037	4.98	0.20	146.94	26.94	1477.06	10.48	985.07	578.58	3230.57
2038	4.85	0.20	139.89	27.10	1471.33	10.47	976.53	564.70	3195.43
2039	4.91	0.21	141.24	27.16	1474.63	10.49	978.23	567.42	3204.66
2040	5.01	0.21	144.41	25.64	1482.44	10.50	982.20	573.80	3224.60
2041	4.89	0.21	139.40	23.98	1474.29	10.49	976.04	563.84	3193.57
2042	4.79	0.21	134.66	23.08	1464.66	10.49	970.07	554.27	3162.66
2043	4.68	0.20	131.60	20.95	1453.94	10.49	966.10	547.97	3136.40
2044	4.60	0.20	128.12	19.20	1446.58	10.48	961.50	540.72	3111.90
2045	4.54	0.20	125.84	20.80	1442.65	10.46	958.42	535.90	3099.32
2046	4.33	0.20	116.31	21.01	1426.91	10.44	945.39	515.61	3040.75
2047	4.21	0.19	111.01	20.17	1418.75	10.43	937.68	503.86	3006.90
2048	4.17	0.19	111.40	21.07	1416.06	10.40	938.27	504.75	3006.95
2049	4.09	0.18	109.57	21.42	1406.93	10.39	935.51	500.60	2989.36
2050	4.11	0.18	110.35	19.42	1406.44	10.40	936.71	502.39	2990.69
2051	3.74	0.17	101.40	18.55	1372.64	10.30	923.13	482.00	2912.71
2052	3.77	0.17	103.45	19.25	1375.94	10.30	926.46	486.89	2927.00
2053	3.42	0.16	89.52	19.52	1344.00	10.25	904.22	454.10	2826.02
2054	3.39	0.15	88.43	20.27	1340.52	10.24	902.27	451.34	2817.47
2055	3.29	0.15	85.26	21.02	1328.24	10.21	896.54	443.25	2788.87
2056	3.13	0.15	80.78	18.92	1313.43	10.17	888.20	431.59	2747.30
2057	3.07	0.15	77.87	17.31	1303.39	10.19	882.55	423.82	2719.25
2058	2.81	0.13	70.98	17.86	1273.29	10.11	868.78	405.07	2650.02
2059	2.77	0.13	69.98	18.25	1267.15	10.08	866.64	402.24	2638.29
2060	2.59	0.12	64.18	17.49	1249.88	10.04	854.00	385.55	2584.92
2061	2.58	0.12	62.84	16.49	1247.87	10.07	850.90	381.54	2573.46
2062	2.48	0.12	60.65	17.43	1237.35	10.01	845.69	374.88	2549.72
2063	2.29	0.11	55.22	16.41	1213.19	9.95	832.48	358.11	2488.93
2064	2.26	0.11	54.85	16.19	1208.06	9.93	831.50	356.91	2481.04

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	2.19	0.11	52.82	16.34	1199.48	9.91	826.13	350.29	2458.50
2066	2.11	0.10	50.96	16.04	1187.58	9.89	821.09	344.15	2433.21
2067	2.06	0.10	47.64	13.08	1180.05	9.91	811.79	332.92	2398.80
2068	1.95	0.09	46.77	13.21	1163.37	9.82	809.21	329.88	2375.63
2069	1.90	0.09	45.83	14.34	1156.84	9.78	806.41	326.57	2363.14
2070	1.68	0.08	39.84	14.29	1121.32	9.68	788.17	305.23	2281.75
2071	1.54	0.08	35.93	12.42	1100.87	9.63	774.84	290.25	2227.09
2072	1.54	0.08	36.13	12.69	1095.55	9.64	775.57	291.05	2223.75
2073	1.50	0.08	35.33	11.64	1083.90	9.63	772.63	287.84	2204.08
2074	1.43	0.07	33.94	11.20	1066.66	9.60	767.43	282.19	2174.08
2075	1.43	0.07	34.58	11.96	1064.66	9.57	769.88	284.82	2178.56

Table G8: Scenario 14s Benefits highly sensitive to changes in coral condition RCP 8.5 BAU crown-of-thorns starfish control; no other interventions - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.56	0.24	171.56	25.26	1524.86	10.59	1011.77	622.86	3372.70
2018	5.51	0.24	170.20	24.25	1516.82	10.57	1009.85	619.40	3356.84
2019	5.43	0.23	166.28	24.37	1505.53	10.57	1004.26	609.41	3326.09
2020	5.44	0.23	168.75	25.90	1503.45	10.56	1007.84	615.75	3337.91
2021	5.41	0.23	169.45	26.02	1495.76	10.55	1008.85	617.55	3333.83
2022	5.43	0.23	170.02	26.05	1496.65	10.55	1009.66	619.00	3337.60
2023	5.43	0.23	169.32	26.24	1488.78	10.55	1008.66	617.21	3326.40
2024	5.45	0.23	169.65	25.35	1488.34	10.56	1009.14	618.07	3326.79
2025	5.41	0.22	167.02	24.94	1480.79	10.55	1005.38	611.36	3305.67
2026	5.26	0.22	160.84	24.42	1456.91	10.52	996.44	595.51	3250.12
2027	5.21	0.22	158.78	23.86	1447.71	10.53	993.38	590.17	3229.86
2028	5.27	0.22	161.18	25.59	1455.85	10.53	996.99	596.42	3252.05
2029	5.23	0.21	160.67	26.92	1449.78	10.51	996.24	595.11	3244.66
2030	5.26	0.21	161.41	26.84	1453.23	10.51	997.34	597.02	3251.83
2031	5.23	0.21	162.09	29.05	1445.45	10.49	998.35	598.79	3249.66
2032	5.06	0.20	155.22	28.89	1418.70	10.47	988.19	581.01	3187.73
2033	5.15	0.20	156.79	29.56	1436.63	10.48	990.59	585.13	3214.54
2034	5.05	0.20	150.95	28.98	1424.51	10.48	981.74	569.87	3171.79
2035	5.02	0.20	148.76	29.04	1422.98	10.49	978.33	564.08	3158.90
2036	5.01	0.20	149.84	30.28	1420.77	10.46	980.04	566.96	3163.57
2037	4.98	0.20	146.94	26.94	1413.24	10.48	975.49	559.27	3137.55
2038	4.85	0.20	139.89	27.10	1402.27	10.47	964.29	540.48	3089.55
2039	4.91	0.21	141.24	27.16	1408.56	10.49	966.51	544.13	3103.20
2040	5.01	0.21	144.41	25.64	1423.49	10.50	971.70	552.69	3133.66
2041	4.89	0.21	139.40	23.98	1407.84	10.49	963.64	539.27	3089.70
2042	4.79	0.21	134.66	23.08	1389.44	10.49	955.82	526.44	3044.93
2043	4.68	0.20	131.60	20.95	1369.10	10.49	950.63	518.07	3005.73
2044	4.60	0.20	128.12	19.20	1355.24	10.48	944.63	508.48	2970.96
2045	4.54	0.20	125.84	20.80	1347.89	10.46	940.61	502.12	2952.47
2046	4.33	0.20	116.31	21.01	1318.48	10.44	923.64	475.51	2869.91
2047	4.21	0.19	111.01	20.17	1303.40	10.43	913.63	460.34	2823.39
2048	4.17	0.19	111.40	21.07	1298.45	10.40	914.40	461.48	2821.56
2049	4.09	0.18	109.57	21.42	1281.69	10.39	910.83	456.17	2794.33
2050	4.11	0.18	110.35	19.42	1280.80	10.40	912.37	458.45	2796.09
2051	3.74	0.17	101.40	18.55	1219.25	10.30	894.79	432.41	2680.60
2052	3.77	0.17	103.45	19.25	1225.11	10.30	899.08	438.54	2699.67
2053	3.42	0.16	89.52	19.52	1168.23	10.25	870.37	397.19	2558.66
2054	3.39	0.15	88.43	20.27	1162.18	10.24	867.87	393.81	2546.35
2055	3.29	0.15	85.26	21.02	1140.89	10.21	860.53	383.94	2505.28
2056	3.13	0.15	80.78	18.92	1115.45	10.17	849.84	369.80	2448.24
2057	3.07	0.15	77.87	17.31	1098.39	10.19	842.63	360.48	2410.06
2058	2.81	0.13	70.98	17.86	1047.67	10.11	825.07	338.15	2312.78
2059	2.77	0.13	69.98	18.25	1037.55	10.08	822.36	334.84	2295.97
2060	2.59	0.12	64.18	17.49	1009.28	10.04	806.33	315.38	2225.41
2061	2.58	0.12	62.84	16.49	1006.03	10.07	802.40	310.80	2211.32
2062	2.48	0.12	60.65	17.43	989.07	10.01	795.84	303.20	2178.78
2063	2.29	0.11	55.22	16.41	950.44	9.95	779.18	284.22	2097.81
2064	2.26	0.11	54.85	16.19	942.41	9.93	777.96	282.88	2086.59

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	2.19	0.11	52.82	16.34	929.02	9.91	771.22	275.54	2057.14
2066	2.11	0.10	50.96	16.04	910.59	9.89	764.91	268.77	2023.38
2067	2.06	0.10	47.64	13.08	899.03	9.91	753.28	256.50	1981.60
2068	1.95	0.09	46.77	13.21	873.62	9.82	750.07	253.21	1948.74
2069	1.90	0.09	45.83	14.34	863.81	9.78	746.57	249.66	1931.98
2070	1.68	0.08	39.84	14.29	810.77	9.68	723.89	226.82	1827.05
2071	1.54	0.08	35.93	12.42	781.20	9.63	707.42	211.24	1759.46
2072	1.54	0.08	36.13	12.69	773.65	9.64	708.31	212.05	1754.08
2073	1.50	0.08	35.33	11.64	757.19	9.63	704.70	208.77	1728.83
2074	1.43	0.07	33.94	11.20	733.11	9.60	698.30	203.03	1690.69
2075	1.43	0.07	34.58	11.96	730.36	9.57	701.31	205.68	1694.96

Table G9: Scenario 15 RCP 8.5, Strong crown-of-thorns starfish control; no other interventions - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.55	0.25	170.46	24.89	1535.78	10.58	1011.44	622.79	3381.74
2018	5.59	0.26	171.45	25.61	1540.21	10.58	1012.51	626.18	3392.38
2019	5.53	0.25	169.50	24.68	1536.59	10.57	1010.42	622.09	3379.63
2020	5.53	0.25	168.54	25.70	1536.76	10.57	1009.38	622.41	3379.14
2021	5.40	0.25	162.33	23.42	1526.42	10.56	1002.63	613.66	3344.66
2022	5.33	0.25	158.71	22.72	1520.47	10.56	998.57	608.73	3325.34
2023	5.48	0.25	163.22	22.10	1533.01	10.58	1003.71	619.65	3358.00
2024	5.53	0.26	163.85	21.23	1534.61	10.60	1004.42	622.65	3363.15
2025	5.64	0.26	167.01	21.44	1542.86	10.62	1007.93	630.34	3386.11
2026	5.54	0.26	163.69	22.78	1535.96	10.59	1004.29	623.54	3366.66
2027	5.54	0.26	163.79	22.87	1533.64	10.59	1004.40	623.39	3364.49
2028	5.42	0.26	159.27	21.11	1523.57	10.58	999.37	614.86	3334.45
2029	5.48	0.26	162.64	22.53	1525.04	10.59	1003.20	619.01	3348.74
2030	5.42	0.26	161.49	23.00	1522.74	10.56	1001.91	616.16	3341.53
2031	5.35	0.25	161.20	23.24	1513.26	10.54	1001.60	610.25	3325.68
2032	5.40	0.26	160.41	22.78	1517.91	10.55	1000.71	614.40	3332.42
2033	5.42	0.26	160.14	20.96	1522.10	10.56	1000.40	615.95	3335.78
2034	5.40	0.26	158.64	22.19	1522.60	10.56	998.70	614.82	3333.16
2035	5.45	0.26	158.07	21.60	1527.50	10.58	998.05	617.94	3339.46
2036	5.24	0.26	150.31	21.18	1508.96	10.57	989.17	602.16	3287.84
2037	5.31	0.26	152.38	20.83	1514.38	10.58	991.64	606.75	3302.13
2038	5.15	0.25	148.76	21.04	1501.57	10.55	987.38	595.51	3270.20
2039	5.19	0.24	150.58	23.02	1504.08	10.54	989.55	598.74	3281.94
2040	5.20	0.25	148.84	25.81	1505.63	10.55	987.49	600.09	3283.86
2041	4.94	0.25	139.03	23.42	1487.44	10.52	975.73	581.59	3222.92
2042	4.86	0.24	136.57	22.29	1479.02	10.52	972.62	575.02	3201.13
2043	4.65	0.24	128.96	22.24	1464.74	10.48	962.85	559.94	3154.12
2044	4.55	0.23	126.56	21.99	1452.74	10.47	959.64	552.43	3128.61
2045	4.55	0.23	125.25	22.14	1454.71	10.47	957.85	552.15	3127.35
2046	4.39	0.23	119.25	22.78	1439.08	10.47	949.61	538.74	3084.56
2047	4.29	0.23	114.42	22.03	1430.40	10.46	942.73	530.83	3055.40
2048	4.16	0.22	110.65	21.11	1417.82	10.44	937.16	520.15	3021.71
2049	4.02	0.22	106.33	21.36	1405.81	10.41	930.63	509.82	2988.58
2050	3.91	0.22	102.73	20.19	1392.11	10.40	925.01	500.57	2955.14
2051	3.68	0.21	95.10	19.00	1370.70	10.37	912.77	482.46	2894.29
2052	3.72	0.21	96.05	19.95	1377.75	10.35	914.39	486.15	2908.56
2053	3.50	0.21	89.58	16.06	1356.60	10.31	903.44	469.36	2849.06
2054	3.41	0.20	88.41	15.90	1347.78	10.28	901.35	461.62	2828.95
2055	3.28	0.19	84.96	17.05	1331.51	10.25	895.12	450.26	2792.62
2056	3.06	0.18	79.21	15.87	1306.39	10.20	884.40	431.55	2730.86
2057	2.87	0.17	72.75	14.21	1287.90	10.17	871.68	415.45	2675.21
2058	2.64	0.16	66.92	14.53	1261.12	10.06	859.38	395.48	2610.30
2059	2.63	0.16	66.23	14.93	1260.01	10.07	857.84	394.59	2606.46
2060	2.62	0.16	66.04	15.83	1258.09	10.05	857.39	393.15	2603.34
2061	2.68	0.17	66.23	15.28	1266.07	10.09	857.83	398.74	2617.08
2062	2.46	0.15	61.64	13.46	1237.33	10.01	847.42	379.10	2551.57
2063	2.46	0.15	61.95	13.50	1236.37	9.98	848.16	379.14	2551.71
2064	2.49	0.15	62.47	14.92	1243.39	9.99	849.40	381.66	2564.45

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	2.26	0.12	57.27	13.22	1209.07	9.92	837.03	359.15	2488.06
2066	2.20	0.12	56.40	13.08	1203.09	9.88	834.81	353.47	2473.05
2067	2.08	0.12	50.12	11.71	1186.33	9.90	818.61	342.19	2421.07
2068	2.01	0.12	47.78	12.77	1178.69	9.88	811.99	334.03	2397.25
2069	1.98	0.11	48.26	13.13	1172.54	9.85	813.40	330.64	2389.94
2070	1.95	0.11	47.44	12.21	1165.21	9.85	811.00	327.49	2375.27
2071	1.91	0.11	46.11	12.06	1156.16	9.83	807.05	322.99	2356.22
2072	1.61	0.10	38.25	11.20	1108.79	9.72	783.23	290.98	2243.88
2073	1.66	0.10	39.82	11.59	1113.82	9.72	788.78	296.72	2262.22
2074	1.61	0.09	39.16	10.50	1101.81	9.64	786.54	291.86	2241.21
2075	1.49	0.09	36.17	10.39	1086.43	9.54	776.20	278.89	2199.22

Table G10: Scenario 16 RCP 8.5, Perfect crown-of-thorns starfish control; no other interventions - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.72	0.25	177.36	27.54	1548.19	10.59	1018.77	634.95	3423.37
2018	5.61	0.25	174.32	27.64	1540.86	10.57	1015.59	627.89	3402.72
2019	5.64	0.24	174.73	28.07	1542.66	10.58	1016.03	629.89	3407.82
2020	5.73	0.25	177.77	28.42	1548.06	10.58	1019.23	636.12	3426.12
2021	5.73	0.24	176.67	28.14	1548.39	10.58	1018.08	636.60	3424.40
2022	5.67	0.24	174.46	28.91	1543.76	10.57	1015.77	632.78	3412.13
2023	5.61	0.24	170.73	27.71	1539.02	10.57	1011.82	629.02	3394.70
2024	5.65	0.24	173.52	28.59	1539.99	10.56	1014.82	631.60	3404.95
2025	5.60	0.24	170.32	28.30	1535.86	10.56	1011.42	628.57	3390.86
2026	5.54	0.24	168.40	27.36	1529.58	10.56	1009.35	623.83	3374.84
2027	5.47	0.24	166.23	26.07	1526.28	10.54	1006.99	619.90	3361.72
2028	5.49	0.24	166.16	25.99	1527.43	10.54	1006.91	621.15	3363.90
2029	5.53	0.23	168.11	26.04	1529.08	10.54	1009.06	624.05	3372.64
2030	5.39	0.23	163.80	25.19	1515.88	10.51	1004.36	614.45	3339.83
2031	5.45	0.23	164.71	25.34	1518.90	10.53	1005.37	618.80	3349.33
2032	5.48	0.23	165.67	25.70	1519.29	10.54	1006.43	620.42	3353.80
2033	5.30	0.22	162.02	24.95	1503.11	10.50	1002.42	607.10	3315.76
2034	5.29	0.22	160.86	25.24	1501.35	10.51	1001.10	606.10	3310.85
2035	5.27	0.22	160.26	26.93	1500.61	10.50	1000.43	605.22	3309.67
2036	5.16	0.22	153.90	26.76	1490.07	10.50	993.24	597.26	3277.36
2037	5.19	0.22	154.31	25.38	1492.24	10.51	993.72	599.19	3281.06
2038	5.26	0.22	156.37	27.31	1496.77	10.52	996.12	603.31	3296.19
2039	5.26	0.23	152.86	27.39	1500.07	10.53	992.06	604.68	3293.41
2040	5.31	0.23	152.90	28.28	1505.48	10.53	992.12	607.85	3303.06
2041	5.24	0.22	151.73	27.44	1496.06	10.53	990.74	602.60	3284.95
2042	5.29	0.22	154.20	29.95	1498.33	10.53	993.66	606.18	3298.77
2043	5.39	0.22	158.47	30.89	1504.86	10.53	998.64	612.88	3322.30
2044	5.50	0.23	161.46	31.14	1511.26	10.56	1002.06	620.39	3343.00
2045	5.42	0.23	158.09	32.11	1506.00	10.55	998.26	614.47	3325.54
2046	5.06	0.22	144.56	33.45	1485.26	10.49	982.78	589.16	3251.49
2047	5.05	0.22	144.97	35.55	1484.36	10.48	983.29	588.09	3252.55
2048	4.92	0.23	138.50	35.45	1476.68	10.45	975.36	578.80	3220.98
2049	4.93	0.23	139.09	37.16	1478.50	10.45	976.12	579.54	3226.64
2050	4.94	0.23	138.90	37.66	1479.02	10.45	975.87	579.99	3227.71
2051	4.72	0.21	134.99	39.28	1460.06	10.39	970.92	563.25	3184.52
2052	4.68	0.21	133.75	40.49	1457.68	10.40	969.31	559.14	3176.33
2053	4.45	0.20	125.25	35.31	1441.98	10.36	958.22	543.53	3120.03
2054	4.45	0.20	126.56	35.68	1439.08	10.35	960.03	543.67	3120.77
2055	4.23	0.20	117.45	33.59	1426.63	10.30	947.62	527.71	3068.55
2056	4.17	0.19	116.70	33.28	1420.44	10.27	946.54	523.46	3055.89
2057	4.07	0.18	116.46	36.02	1410.33	10.21	946.18	514.76	3039.11
2058	3.78	0.18	105.62	36.05	1387.10	10.14	930.41	490.93	2965.18
2059	3.62	0.16	104.63	37.80	1366.28	10.05	928.86	476.48	2928.96
2060	3.32	0.14	96.18	36.52	1335.95	9.96	915.48	451.00	2849.70
2061	3.11	0.13	88.45	35.87	1316.98	9.91	902.40	431.41	2789.48
2062	3.05	0.13	87.29	35.15	1308.01	9.87	900.30	426.22	2771.27
2063	2.95	0.12	83.94	32.94	1299.45	9.82	894.19	418.04	2742.76
2064	2.92	0.12	82.65	34.81	1298.85	9.84	891.77	414.20	2736.50

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	2.93	0.12	84.84	37.47	1296.43	9.84	895.94	412.85	2741.72
2066	2.62	0.11	76.72	36.04	1256.32	9.75	880.77	382.84	2646.60
2067	2.69	0.11	76.81	34.43	1266.95	9.81	880.95	391.88	2664.98
2068	2.57	0.10	72.66	31.21	1244.49	9.82	872.56	381.74	2616.49
2069	2.56	0.10	73.46	31.88	1240.62	9.81	874.24	380.38	2614.40
2070	2.51	0.09	72.60	32.84	1235.34	9.78	872.46	374.31	2601.29
2071	2.54	0.10	72.38	31.52	1243.86	9.77	871.98	379.23	2612.75
2072	2.33	0.10	62.42	24.81	1223.63	9.71	850.86	362.92	2538.23
2073	2.28	0.10	62.81	26.07	1211.60	9.65	851.80	355.95	2521.78
2074	2.18	0.09	59.93	24.37	1197.10	9.64	844.96	346.93	2486.72
2075	2.22	0.09	60.08	23.46	1205.55	9.64	845.34	351.85	2499.75

Table G11: Scenario 17 RCP 8.5, BAU crown-of-thorns starfish control; low enhanced corals, low cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.62	0.24	173.36	25.83	1538.30	10.59	1014.52	626.49	3394.94
2018	5.60	0.24	171.25	25.32	1533.72	10.59	1012.27	623.20	3382.18
2019	5.60	0.24	170.90	25.87	1531.43	10.59	1011.91	622.76	3379.26
2020	5.63	0.24	172.50	25.08	1534.11	10.60	1013.62	626.26	3387.99
2021	5.63	0.24	172.98	24.55	1532.66	10.59	1014.13	626.74	3387.47
2022	5.65	0.24	174.07	24.86	1533.65	10.60	1015.29	629.77	3394.07
2023	5.61	0.24	172.27	26.26	1526.63	10.57	1013.38	625.18	3380.13
2024	5.59	0.24	170.30	25.58	1522.50	10.56	1011.29	622.57	3368.63
2025	5.60	0.25	171.64	26.02	1523.26	10.56	1012.73	624.06	3374.11
2026	5.62	0.25	172.94	27.01	1523.41	10.57	1014.12	626.20	3380.09
2027	5.58	0.25	169.82	25.71	1516.10	10.56	1010.79	619.91	3358.68
2028	5.64	0.25	173.91	26.17	1524.11	10.59	1015.22	628.21	3384.03
2029	5.59	0.24	171.27	25.48	1514.34	10.57	1012.41	621.53	3361.38
2030	5.57	0.24	170.50	26.21	1511.79	10.56	1011.59	619.08	3355.50
2031	5.62	0.24	172.20	24.99	1518.42	10.59	1013.42	625.42	3370.83
2032	5.67	0.24	176.55	26.34	1526.29	10.60	1018.07	633.15	3396.90
2033	5.74	0.24	179.36	26.08	1534.44	10.63	1021.02	641.13	3418.63
2034	5.75	0.24	180.53	25.97	1536.05	10.63	1022.23	643.28	3424.74
2035	5.75	0.24	181.98	25.62	1536.70	10.63	1023.73	643.12	3427.87
2036	5.76	0.25	181.58	26.45	1536.97	10.63	1023.31	644.83	3429.90
2037	5.82	0.25	184.34	26.96	1544.93	10.65	1026.15	653.45	3452.70
2038	5.79	0.26	181.70	26.55	1540.59	10.64	1023.47	649.86	3439.06
2039	5.80	0.26	182.94	26.01	1543.70	10.65	1024.75	651.94	3446.27
2040	5.80	0.26	185.28	28.80	1544.84	10.62	1027.14	653.17	3456.19
2041	5.80	0.26	184.13	28.33	1544.35	10.62	1025.98	652.34	3452.11
2042	5.73	0.26	180.02	29.40	1536.30	10.59	1021.80	643.09	3427.54
2043	5.72	0.26	179.03	28.98	1533.30	10.59	1020.78	641.99	3421.01
2044	5.73	0.26	178.78	29.40	1532.18	10.59	1020.52	642.42	3420.24
2045	5.62	0.25	170.79	29.23	1519.13	10.55	1012.21	628.04	3376.24
2046	5.68	0.25	177.62	30.04	1525.76	10.55	1019.57	635.96	3405.86
2047	5.63	0.24	174.94	29.79	1518.49	10.53	1016.77	628.46	3385.34
2048	5.59	0.25	171.09	29.47	1515.07	10.52	1012.70	624.55	3369.75
2049	5.58	0.25	167.11	30.44	1513.31	10.52	1008.42	622.54	3358.71
2050	5.44	0.24	159.59	31.22	1490.47	10.47	1000.18	601.97	3300.20
2051	5.38	0.23	156.96	28.22	1482.17	10.46	997.19	594.33	3275.55
2052	5.29	0.23	150.27	30.68	1468.64	10.42	989.49	582.32	3238.00
2053	5.23	0.23	144.66	32.00	1458.82	10.40	982.82	571.60	3206.44
2054	5.23	0.23	145.01	31.77	1457.66	10.40	983.25	571.96	3206.21
2055	5.18	0.23	140.83	30.72	1450.51	10.37	978.12	565.22	3181.93
2056	5.11	0.23	135.03	27.95	1442.08	10.36	970.87	556.14	3148.51
2057	5.05	0.21	131.85	27.37	1428.86	10.34	966.74	545.68	3116.86
2058	4.83	0.20	116.58	23.68	1396.01	10.27	946.61	514.16	3013.18
2059	4.74	0.20	109.04	23.41	1379.92	10.25	935.64	499.50	2963.58
2060	4.65	0.19	101.71	23.71	1363.05	10.23	924.41	484.04	2912.89
2061	4.67	0.19	105.07	23.54	1364.42	10.22	929.84	487.44	2926.31
2062	4.65	0.18	103.69	23.47	1359.11	10.19	927.67	483.70	2913.60
2063	4.51	0.17	95.86	21.84	1332.32	10.12	915.18	461.05	2842.07
2064	4.39	0.16	84.86	22.45	1310.74	10.08	896.52	439.65	2769.93

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	4.39	0.16	85.80	24.62	1313.74	10.06	898.28	439.39	2777.52
2066	4.33	0.16	82.10	23.92	1302.36	10.02	891.42	428.65	2744.10
2067	4.37	0.16	84.39	23.73	1308.07	10.05	895.81	435.69	2763.39
2068	4.32	0.16	80.53	23.71	1302.18	10.03	888.57	427.31	2737.92
2069	4.37	0.16	82.72	22.61	1311.76	10.06	892.84	437.14	2762.76
2070	4.25	0.16	75.49	20.71	1286.61	9.98	879.04	416.87	2694.28
2071	4.19	0.14	75.62	21.02	1265.42	9.94	879.31	405.43	2662.28
2072	4.14	0.13	72.27	19.27	1249.95	9.90	872.44	395.12	2624.46
2073	4.10	0.13	69.63	19.00	1241.63	9.88	866.83	388.25	2600.76
2074	4.09	0.13	68.83	17.56	1235.30	9.92	865.08	386.36	2588.50
2075	4.15	0.13	73.58	19.58	1247.06	9.93	875.56	397.09	2628.31

Table G12: Scenario 18 RCP 8.5, Strong crown-of-thorns starfish control; low enhanced corals, low cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.58	0.24	172.36	25.19	1539.00	10.58	1013.46	624.94	3391.35
2018	5.62	0.25	173.11	25.47	1541.50	10.59	1014.26	627.81	3398.59
2019	5.64	0.25	172.87	25.39	1540.75	10.61	1014.00	628.63	3398.09
2020	5.66	0.25	171.26	24.18	1541.66	10.62	1012.29	630.04	3395.86
2021	5.65	0.25	171.54	23.02	1541.83	10.61	1012.59	629.90	3395.32
2022	5.74	0.24	174.50	24.74	1547.72	10.61	1015.77	636.34	3415.59
2023	5.79	0.25	176.45	24.80	1550.48	10.62	1017.83	639.61	3425.75
2024	5.80	0.25	176.95	24.67	1550.97	10.62	1018.35	640.85	3428.38
2025	5.79	0.25	175.77	23.75	1551.69	10.61	1017.12	640.73	3425.63
2026	5.73	0.25	172.63	22.91	1547.93	10.58	1013.81	637.43	3411.22
2027	5.75	0.25	173.38	23.96	1547.53	10.59	1014.61	638.82	3414.83
2028	5.71	0.25	173.19	25.86	1544.22	10.58	1014.41	635.89	3410.05
2029	5.84	0.26	177.14	25.28	1555.57	10.60	1018.62	645.23	3438.47
2030	5.86	0.25	177.91	26.78	1554.65	10.60	1019.42	646.08	3441.49
2031	6.06	0.26	185.16	29.65	1567.15	10.62	1026.99	659.85	3485.64
2032	6.18	0.27	189.71	32.19	1574.18	10.63	1031.58	667.29	3511.98
2033	6.28	0.27	192.73	33.08	1580.57	10.65	1034.58	673.73	3531.88
2034	6.34	0.27	194.79	34.72	1584.29	10.65	1036.60	677.72	3545.42
2035	6.44	0.27	196.65	36.02	1589.65	10.67	1038.41	684.19	3562.36
2036	6.49	0.28	199.18	35.96	1594.24	10.67	1040.85	688.20	3575.96
2037	6.51	0.28	200.61	36.45	1594.51	10.66	1042.22	689.35	3580.71
2038	6.53	0.28	201.22	36.58	1596.88	10.67	1042.80	691.29	3586.42
2039	6.56	0.28	200.70	38.31	1598.05	10.67	1042.30	693.45	3590.52
2040	6.41	0.27	196.51	37.37	1585.26	10.65	1038.32	682.96	3557.99
2041	6.49	0.27	200.17	38.12	1590.29	10.65	1041.86	688.69	3576.82
2042	6.40	0.27	195.92	36.82	1586.76	10.64	1037.81	683.08	3558.00
2043	6.41	0.27	195.25	35.10	1588.53	10.64	1037.17	684.35	3558.04
2044	6.37	0.27	192.32	34.81	1585.56	10.64	1034.32	681.57	3546.18
2045	6.22	0.26	189.56	36.11	1573.34	10.62	1031.61	670.96	3519.03
2046	6.07	0.26	185.62	35.91	1562.92	10.60	1027.70	661.25	3490.72
2047	6.01	0.25	183.31	37.31	1554.97	10.59	1025.37	656.34	3474.58
2048	5.96	0.25	181.79	37.21	1551.86	10.58	1023.82	653.43	3465.36
2049	5.87	0.25	178.55	38.17	1547.21	10.56	1020.49	647.05	3448.66
2050	5.79	0.25	173.42	38.40	1545.36	10.55	1015.16	642.21	3431.69
2051	5.81	0.25	175.57	37.18	1542.91	10.55	1017.45	643.18	3433.44
2052	5.73	0.25	172.25	39.63	1538.45	10.54	1013.95	637.29	3418.62
2053	5.44	0.24	161.01	39.19	1518.28	10.50	1001.91	616.57	3353.72
2054	5.36	0.24	157.60	36.60	1510.71	10.49	998.07	611.12	3330.80
2055	5.33	0.24	157.81	37.51	1510.37	10.48	998.31	609.49	3330.17
2056	5.27	0.24	153.69	36.04	1505.29	10.48	993.59	605.13	3310.36
2057	5.07	0.24	147.76	37.66	1491.36	10.45	986.65	589.39	3269.22
2058	4.90	0.23	142.06	37.19	1480.11	10.42	979.77	577.35	3232.71
2059	4.85	0.23	138.86	35.88	1476.99	10.42	975.79	574.29	3218.03
2060	4.89	0.24	137.98	36.31	1481.80	10.43	974.68	576.81	3223.84
2061	4.53	0.22	126.63	35.35	1452.51	10.36	960.23	549.58	3140.20
2062	3.97	0.20	109.83	33.91	1408.99	10.25	937.35	506.72	3012.10
2063	3.82	0.20	104.56	30.75	1396.70	10.24	929.31	495.86	2972.33
2064	3.88	0.21	105.86	32.23	1405.58	10.23	931.37	500.62	2990.91

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	3.90	0.21	106.03	31.83	1408.89	10.23	931.64	502.02	2995.67
2066	3.73	0.19	101.14	31.08	1390.89	10.19	923.98	488.43	2950.62
2067	3.84	0.20	105.14	31.46	1397.94	10.21	930.49	497.38	2977.62
2068	3.50	0.19	92.17	28.59	1369.93	10.16	910.01	469.48	2885.02
2069	3.38	0.19	88.17	26.51	1357.59	10.12	903.00	460.31	2850.31
2070	3.20	0.18	82.84	26.24	1342.20	10.08	893.33	444.17	2803.31
2071	3.02	0.16	78.29	23.37	1315.89	10.05	884.66	429.48	2746.02
2072	2.91	0.16	76.24	22.21	1301.71	10.01	880.56	420.17	2715.10
2073	2.95	0.16	76.93	23.43	1305.17	10.01	881.98	423.48	2725.27
2074	2.93	0.15	76.00	22.74	1300.84	10.02	880.09	422.38	2716.29
2075	2.77	0.15	69.43	22.23	1279.94	10.01	866.67	406.11	2658.46

Table G13: Scenario 19 RCP 8.5, Perfect crown-of-thorns starfish control; low enhanced corals, low cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.64	0.24	174.23	27.43	1541.24	10.58	1015.44	628.28	3403.09
2018	5.63	0.24	174.65	28.52	1542.23	10.58	1015.89	628.15	3405.87
2019	5.59	0.24	173.33	27.28	1539.81	10.58	1014.50	624.75	3396.06
2020	5.57	0.24	171.77	26.97	1538.62	10.57	1012.83	623.87	3390.41
2021	5.52	0.23	170.21	25.98	1533.21	10.57	1011.16	619.83	3376.67
2022	5.48	0.23	169.46	26.23	1530.66	10.56	1010.35	617.63	3370.58
2023	5.47	0.23	168.11	25.26	1528.25	10.56	1008.89	617.01	3363.78
2024	5.49	0.23	169.27	25.31	1526.86	10.56	1010.16	617.62	3365.49
2025	5.44	0.23	166.18	25.46	1521.58	10.55	1006.80	614.63	3350.86
2026	5.47	0.23	167.49	26.49	1520.82	10.55	1008.25	616.15	3355.43
2027	5.45	0.22	166.95	25.56	1517.09	10.55	1007.66	614.16	3347.63
2028	5.44	0.22	166.48	25.65	1516.77	10.55	1007.14	613.96	3346.20
2029	5.49	0.23	167.78	26.70	1520.86	10.56	1008.56	618.65	3358.78
2030	5.49	0.23	167.18	26.63	1521.20	10.56	1007.92	618.80	3357.97
2031	5.62	0.23	170.28	26.64	1529.46	10.57	1011.30	627.97	3382.01
2032	5.63	0.23	169.76	27.95	1528.42	10.56	1010.74	628.34	3381.65
2033	5.58	0.23	168.89	28.59	1523.60	10.56	1009.81	625.00	3372.33
2034	5.66	0.22	172.42	30.32	1526.79	10.56	1013.63	630.20	3389.94
2035	5.78	0.23	175.57	31.45	1535.75	10.57	1017.01	638.57	3415.08
2036	5.82	0.23	176.76	32.00	1539.87	10.57	1018.26	641.39	3425.07
2037	5.86	0.23	176.92	30.35	1543.58	10.58	1018.43	644.70	3430.85
2038	5.83	0.23	174.47	30.47	1540.69	10.57	1015.85	641.87	3420.24
2039	5.88	0.23	177.00	31.48	1543.16	10.58	1018.54	645.28	3432.43
2040	5.80	0.23	173.44	30.16	1537.42	10.57	1014.81	640.60	3413.36
2041	5.80	0.23	173.23	30.89	1535.90	10.57	1014.59	640.84	3412.40
2042	5.81	0.23	173.57	32.51	1535.02	10.57	1014.95	641.07	3414.11
2043	5.72	0.23	171.56	34.14	1526.23	10.55	1012.81	634.55	3396.20
2044	5.67	0.23	169.26	32.97	1521.99	10.55	1010.34	630.77	3382.19
2045	5.53	0.22	167.79	34.11	1511.98	10.54	1008.75	621.97	3361.33
2046	5.33	0.21	163.58	35.11	1496.20	10.52	1004.15	607.36	3322.94
2047	5.24	0.22	160.71	35.02	1492.50	10.51	1000.96	601.96	3307.62
2048	4.93	0.20	153.06	33.35	1468.84	10.48	992.32	579.25	3242.98
2049	4.85	0.20	149.90	33.02	1462.55	10.47	988.62	573.65	3223.85
2050	4.80	0.20	144.94	31.46	1456.74	10.46	982.70	570.18	3202.12
2051	4.88	0.20	147.60	31.31	1461.51	10.47	985.95	575.68	3218.22
2052	4.78	0.20	143.40	30.49	1453.42	10.45	980.89	568.09	3192.35
2053	4.69	0.20	138.04	30.23	1443.51	10.43	974.27	560.62	3162.65
2054	4.73	0.20	136.99	31.15	1444.40	10.42	972.94	562.63	3164.14
2055	4.58	0.20	132.94	29.14	1432.11	10.41	967.76	551.57	3129.41
2056	4.50	0.19	131.04	27.17	1425.03	10.40	965.26	546.67	3110.96
2057	4.57	0.19	133.81	26.47	1428.64	10.41	968.93	552.43	3126.14
2058	4.30	0.18	122.30	26.45	1410.13	10.37	953.94	531.56	3059.97
2059	4.35	0.19	123.54	28.02	1413.36	10.37	955.67	534.58	3070.84
2060	4.21	0.18	118.91	27.66	1399.36	10.34	949.24	523.51	3034.19
2061	3.97	0.17	111.17	26.89	1382.57	10.31	938.17	505.66	2979.73
2062	3.87	0.17	108.56	27.13	1369.70	10.29	934.24	496.62	2951.41
2063	3.79	0.17	104.88	26.45	1360.95	10.27	928.58	490.71	2926.66
2064	3.49	0.15	96.00	26.89	1333.65	10.21	914.57	465.89	2851.82

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	3.36	0.15	91.92	24.78	1319.40	10.20	907.66	455.58	2813.99
2066	3.08	0.15	82.25	24.22	1295.47	10.14	890.72	431.73	2738.78
2067	3.17	0.15	84.64	25.00	1305.28	10.15	895.30	439.48	2764.19
2068	3.00	0.14	78.82	21.50	1286.89	10.13	884.41	425.84	2711.76
2069	2.82	0.14	73.87	20.66	1266.78	10.09	874.61	409.77	2659.81
2070	2.85	0.14	75.26	21.41	1264.66	10.09	877.49	411.13	2664.07
2071	2.86	0.14	74.38	22.69	1269.12	10.08	875.69	412.17	2668.20
2072	2.66	0.14	69.13	22.82	1252.61	10.04	864.80	394.29	2617.60
2073	2.66	0.14	70.49	21.89	1248.13	10.05	867.80	395.51	2617.80
2074	2.55	0.13	67.47	21.83	1232.23	10.02	861.27	383.54	2580.17
2075	2.51	0.12	68.39	22.11	1222.43	10.02	863.33	379.05	2569.09

Table G14: Scenario 20 RCP 8.5, BAU crown-of-thorns starfish control; low enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.55	0.25	171.51	26.96	1536.31	10.56	1012.56	623.19	3386.91
2018	5.49	0.25	168.38	28.30	1530.99	10.55	1009.20	619.25	3372.42
2019	5.44	0.26	167.75	28.48	1528.75	10.52	1008.51	616.80	3366.56
2020	5.46	0.26	166.82	27.14	1531.35	10.53	1007.50	618.64	3367.72
2021	5.42	0.27	165.38	26.67	1529.37	10.51	1005.92	616.05	3359.63
2022	5.40	0.26	163.77	25.73	1525.36	10.51	1004.15	614.17	3349.39
2023	5.42	0.26	164.52	26.59	1523.83	10.52	1004.98	615.67	3351.83
2024	5.45	0.26	166.46	27.14	1524.12	10.52	1007.12	617.27	3358.37
2025	5.41	0.26	164.64	26.58	1521.24	10.50	1005.13	614.98	3348.77
2026	5.39	0.26	163.39	27.88	1519.00	10.50	1003.74	613.67	3343.87
2027	5.37	0.26	160.60	26.87	1515.47	10.50	1000.63	612.40	3332.12
2028	5.44	0.26	163.55	27.01	1518.23	10.51	1003.97	617.10	3346.09
2029	5.47	0.27	164.02	26.22	1521.99	10.52	1004.49	619.58	3352.55
2030	5.39	0.26	161.57	26.62	1515.25	10.51	1001.76	613.80	3335.17
2031	5.53	0.27	167.70	28.03	1525.13	10.51	1008.65	623.34	3369.16
2032	5.71	0.28	174.89	30.18	1538.76	10.54	1016.51	636.34	3413.25
2033	5.95	0.28	183.71	33.05	1553.59	10.56	1025.83	651.93	3464.97
2034	6.10	0.28	187.93	33.29	1562.98	10.59	1030.13	662.20	3493.59
2035	6.22	0.29	191.52	33.55	1571.30	10.60	1033.72	670.49	3517.82
2036	6.37	0.30	197.27	35.76	1581.96	10.61	1039.38	680.96	3552.74
2037	6.56	0.30	204.98	36.52	1592.75	10.63	1046.81	693.60	3592.30
2038	6.58	0.30	204.78	35.62	1593.68	10.64	1046.62	694.77	3593.19
2039	6.66	0.30	207.29	36.16	1599.00	10.64	1048.98	700.20	3609.45
2040	6.74	0.31	209.47	36.25	1604.78	10.65	1050.99	706.04	3625.48
2041	6.63	0.31	204.09	34.35	1599.00	10.65	1046.04	698.79	3600.13
2042	6.74	0.31	209.51	35.69	1605.06	10.65	1051.13	705.54	3624.92
2043	6.70	0.30	209.36	36.19	1599.21	10.66	1050.99	701.97	3615.67
2044	6.70	0.30	209.85	37.82	1597.80	10.66	1051.44	701.75	3616.63
2045	6.56	0.30	205.98	35.46	1589.05	10.64	1047.89	693.16	3589.37
2046	6.41	0.30	201.29	36.07	1580.60	10.60	1043.53	683.84	3563.03
2047	6.28	0.29	196.10	36.45	1574.60	10.58	1038.60	676.34	3539.68
2048	6.23	0.29	193.93	36.85	1571.89	10.57	1036.50	672.69	3529.41
2049	6.17	0.29	189.20	35.09	1569.55	10.58	1031.88	668.42	3511.67
2050	6.15	0.30	186.06	34.96	1570.23	10.58	1028.76	667.06	3504.60
2051	5.93	0.30	177.11	34.27	1558.49	10.55	1019.73	652.70	3459.62
2052	5.63	0.29	167.34	32.26	1540.24	10.51	1009.50	632.90	3399.23
2053	5.34	0.28	157.40	32.95	1522.17	10.46	998.61	612.28	3340.13
2054	5.34	0.29	157.86	31.94	1526.63	10.45	999.14	613.51	3345.82
2055	5.30	0.29	156.46	32.67	1526.74	10.41	997.53	610.96	3341.07
2056	5.35	0.30	158.98	32.87	1531.55	10.40	1000.44	615.11	3355.70
2057	5.35	0.30	161.12	34.32	1524.75	10.41	1002.88	614.57	3354.39
2058	5.32	0.29	157.48	34.54	1522.13	10.42	998.78	611.62	3341.27
2059	5.01	0.28	148.43	35.33	1499.86	10.36	988.37	589.14	3277.53
2060	5.06	0.28	148.93	33.90	1502.47	10.39	988.97	593.28	3284.01
2061	4.84	0.27	142.36	31.45	1483.20	10.35	981.08	577.18	3231.51
2062	4.77	0.27	140.69	30.68	1479.81	10.32	979.01	572.01	3218.36
2063	4.55	0.26	132.72	30.59	1465.42	10.27	969.01	556.19	3169.87
2064	4.49	0.26	128.40	28.90	1461.99	10.28	963.34	552.07	3150.62

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	4.41	0.26	124.95	27.40	1456.79	10.26	958.68	546.48	3130.13
2066	4.38	0.25	123.09	28.52	1451.27	10.26	956.12	543.02	3117.84
2067	4.31	0.26	120.45	27.13	1447.68	10.25	952.45	538.62	3102.08
2068	4.25	0.25	119.72	27.95	1442.66	10.22	951.40	533.67	3091.06
2069	4.09	0.25	111.00	29.66	1431.03	10.22	938.98	519.62	3045.79
2070	3.80	0.23	103.87	31.54	1404.16	10.14	928.20	495.01	2977.95
2071	3.64	0.23	99.16	30.69	1388.36	10.11	920.70	482.05	2935.96
2072	3.50	0.22	94.59	29.23	1369.23	10.10	913.15	469.82	2890.88
2073	3.27	0.20	88.38	29.15	1346.09	10.05	902.49	449.70	2830.45
2074	3.10	0.19	85.13	29.42	1325.62	10.00	896.63	434.23	2785.48
2075	3.09	0.18	85.18	26.37	1323.34	10.01	896.71	435.08	2781.10

Table G15: Scenario 21 RCP 8.5, Strong crown-of-thorns starfish control; low enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.52	0.24	169.02	25.22	1535.16	10.57	1009.92	621.44	3377.11
2018	5.47	0.24	165.67	23.51	1533.55	10.56	1006.29	618.53	3363.83
2019	5.47	0.24	165.97	22.82	1535.11	10.55	1006.61	619.38	3366.17
2020	5.50	0.25	167.13	23.40	1539.25	10.54	1007.89	621.29	3375.25
2021	5.57	0.25	168.08	23.48	1544.33	10.55	1008.93	626.82	3388.01
2022	5.56	0.25	168.74	24.25	1543.28	10.54	1009.65	626.33	3388.60
2023	5.64	0.25	171.21	24.71	1548.86	10.55	1012.33	632.42	3405.97
2024	5.72	0.25	172.01	25.85	1552.22	10.56	1013.20	637.40	3417.19
2025	5.72	0.26	172.48	26.23	1552.75	10.55	1013.69	637.83	3419.50
2026	5.67	0.26	170.82	26.33	1548.27	10.54	1011.92	634.40	3408.21
2027	5.61	0.25	169.25	27.27	1538.49	10.53	1010.23	630.25	3391.90
2028	5.49	0.25	166.57	28.02	1527.07	10.52	1007.32	621.30	3366.55
2029	5.50	0.25	167.49	30.13	1527.93	10.51	1008.33	621.72	3371.86
2030	5.35	0.24	164.70	30.97	1517.25	10.47	1005.29	611.43	3345.76
2031	5.59	0.25	172.85	33.85	1534.17	10.50	1014.32	628.03	3399.57
2032	5.72	0.25	177.22	34.40	1544.39	10.52	1018.98	637.50	3429.04
2033	5.90	0.26	183.31	35.69	1558.66	10.54	1025.35	650.02	3469.83
2034	6.07	0.26	188.83	37.67	1570.31	10.57	1030.98	660.91	3505.72
2035	6.17	0.27	192.76	39.31	1577.09	10.58	1034.89	668.02	3529.23
2036	6.35	0.27	198.27	41.01	1590.04	10.60	1040.29	680.18	3567.16
2037	6.50	0.28	203.24	41.67	1600.10	10.62	1045.06	690.06	3597.70
2038	6.65	0.28	208.56	42.52	1611.38	10.63	1050.06	700.25	3630.54
2039	6.77	0.29	212.28	44.50	1619.28	10.64	1053.49	708.44	3655.91
2040	6.79	0.29	212.15	43.78	1622.02	10.64	1053.37	710.48	3659.77
2041	6.81	0.29	213.61	44.15	1623.85	10.64	1054.70	711.98	3666.31
2042	6.76	0.29	212.40	43.27	1620.58	10.63	1053.61	708.55	3656.39
2043	6.77	0.30	213.00	44.33	1619.76	10.63	1054.15	709.17	3658.43
2044	6.81	0.30	213.76	45.78	1621.66	10.64	1054.84	711.87	3665.99
2045	6.75	0.30	210.65	45.29	1618.00	10.63	1052.03	708.22	3652.22
2046	6.66	0.30	207.29	43.92	1612.03	10.62	1048.95	702.16	3632.31
2047	6.66	0.30	207.11	43.00	1610.87	10.63	1048.79	702.41	3630.16
2048	6.69	0.30	207.45	41.76	1613.89	10.63	1049.10	704.71	3634.92
2049	6.57	0.29	204.48	40.61	1603.41	10.61	1046.35	696.46	3609.24
2050	6.55	0.29	203.72	42.13	1600.38	10.62	1045.64	694.68	3604.48
2051	6.46	0.29	199.36	39.76	1593.52	10.62	1041.54	688.80	3580.82
2052	6.30	0.28	195.57	38.51	1581.72	10.60	1037.92	677.89	3549.27
2053	6.26	0.29	191.72	36.37	1579.48	10.61	1034.19	675.53	3534.94
2054	6.05	0.28	184.77	37.07	1566.43	10.57	1027.34	662.24	3495.30
2055	5.85	0.27	179.00	36.12	1551.70	10.54	1021.50	648.48	3454.04
2056	5.67	0.26	174.34	37.33	1538.58	10.50	1016.65	635.92	3419.86
2057	5.51	0.26	166.58	36.25	1528.23	10.48	1008.43	624.94	3381.31
2058	5.39	0.26	162.32	36.74	1519.06	10.45	1003.74	616.06	3354.68
2059	5.19	0.25	153.52	34.53	1503.38	10.45	993.87	601.95	3303.82
2060	4.87	0.24	139.75	32.54	1478.16	10.40	977.74	578.36	3222.79
2061	4.87	0.24	142.37	33.50	1475.23	10.39	981.05	578.10	3226.49
2062	4.88	0.24	142.60	31.32	1473.07	10.40	981.34	579.23	3223.80
2063	4.88	0.23	142.54	32.16	1471.28	10.40	981.26	578.98	3222.45
2064	4.71	0.22	137.78	34.75	1457.19	10.36	975.34	565.08	3186.24

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	4.58	0.22	131.40	33.84	1449.16	10.34	967.21	555.19	3152.75
2066	4.40	0.22	126.75	33.53	1435.61	10.30	961.05	542.02	3114.75
2067	4.31	0.21	124.60	32.94	1426.17	10.28	958.12	534.76	3092.28
2068	4.11	0.20	118.77	30.60	1406.42	10.27	950.07	519.41	3040.74
2069	4.05	0.20	116.71	27.07	1406.03	10.24	947.12	515.84	3028.19
2070	3.88	0.19	111.84	29.29	1393.85	10.18	940.04	502.35	2992.58
2071	3.70	0.18	104.87	26.85	1376.48	10.16	929.57	487.31	2940.11
2072	3.47	0.17	96.95	26.98	1355.51	10.11	917.05	468.31	2879.59
2073	3.26	0.16	88.28	27.68	1331.22	10.10	902.48	448.72	2812.97
2074	3.19	0.16	86.91	25.98	1322.63	10.06	899.99	443.20	2793.22
2075	3.11	0.16	84.40	25.04	1317.75	10.01	895.39	437.24	2774.26

Table G16: Scenario 22 RCP 8.5, BAU crown-of-thorns starfish control; high enhanced corals, low cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.58	0.25	172.60	27.96	1536.21	10.58	1013.71	624.52	3391.41
2018	5.55	0.24	172.45	28.59	1533.04	10.57	1013.56	622.19	3386.19
2019	5.47	0.24	169.36	27.58	1526.03	10.56	1010.26	616.40	3365.90
2020	5.48	0.23	169.30	26.67	1524.70	10.57	1010.19	616.26	3363.38
2021	5.44	0.23	167.57	25.56	1520.15	10.57	1008.32	612.78	3350.58
2022	5.41	0.23	165.88	25.60	1516.10	10.57	1006.47	610.40	3340.63
2023	5.47	0.22	169.16	27.03	1517.54	10.57	1010.08	614.06	3354.12
2024	5.50	0.22	168.65	25.82	1518.17	10.58	1009.52	616.43	3354.86
2025	5.51	0.22	168.92	27.24	1518.22	10.59	1009.82	616.51	3357.00
2026	5.52	0.23	170.45	28.20	1518.89	10.58	1011.48	617.91	3363.23
2027	5.51	0.23	170.28	28.59	1517.27	10.58	1011.30	616.80	3360.52
2028	5.46	0.23	168.59	27.28	1513.77	10.57	1009.48	614.17	3349.51
2029	5.51	0.23	171.79	27.33	1516.85	10.56	1012.96	618.42	3363.62
2030	5.43	0.23	168.43	27.61	1510.95	10.54	1009.35	613.20	3345.72
2031	5.55	0.23	173.34	28.49	1518.77	10.55	1014.70	622.23	3373.83
2032	5.68	0.24	179.58	30.56	1525.49	10.55	1021.34	631.13	3404.60
2033	5.81	0.24	183.68	31.00	1535.57	10.56	1025.58	640.66	3433.18
2034	5.86	0.24	183.76	31.43	1537.58	10.57	1025.67	644.06	3439.28
2035	6.00	0.25	187.82	31.06	1546.70	10.60	1029.79	653.67	3466.01
2036	6.04	0.26	188.99	31.60	1550.23	10.59	1030.97	656.64	3475.49
2037	6.03	0.26	188.88	32.15	1547.81	10.60	1030.86	655.55	3472.33
2038	6.07	0.26	190.70	33.24	1549.00	10.60	1032.66	658.45	3481.21
2039	6.06	0.26	191.26	34.35	1547.38	10.59	1033.22	657.25	3480.64
2040	5.97	0.26	189.23	34.04	1543.02	10.57	1031.22	651.86	3466.50
2041	6.07	0.27	191.38	34.36	1550.73	10.59	1033.36	659.24	3486.33
2042	5.87	0.27	185.48	34.16	1537.30	10.54	1027.54	646.84	3448.40
2043	5.86	0.27	183.15	33.56	1534.59	10.56	1025.19	645.01	3438.58
2044	5.80	0.26	182.58	35.03	1529.91	10.54	1024.61	641.06	3430.22
2045	5.64	0.26	176.56	36.89	1518.35	10.51	1018.45	629.79	3396.90
2046	5.51	0.26	170.19	36.06	1509.09	10.49	1011.77	620.62	3364.49
2047	5.49	0.26	169.31	36.57	1508.72	10.47	1010.81	620.12	3362.30
2048	5.45	0.27	166.07	35.10	1509.02	10.47	1007.30	618.23	3352.48
2049	5.29	0.26	159.04	35.10	1496.54	10.46	999.56	606.88	3313.74
2050	5.22	0.26	155.62	32.97	1492.27	10.44	995.67	602.38	3295.48
2051	5.23	0.25	157.34	33.16	1490.22	10.43	997.66	603.13	3298.07
2052	5.25	0.26	158.76	33.70	1491.76	10.42	999.29	604.93	3305.02
2053	5.28	0.26	157.65	33.69	1493.04	10.44	998.02	606.88	3305.91
2054	5.20	0.26	156.52	36.15	1486.89	10.40	996.73	601.23	3294.08
2055	5.10	0.25	151.95	36.29	1478.68	10.39	991.45	594.02	3268.86
2056	5.12	0.26	152.40	37.95	1483.48	10.39	991.99	595.19	3277.51
2057	5.07	0.26	148.19	38.83	1478.85	10.39	987.03	590.51	3259.84
2058	4.96	0.25	143.92	39.18	1471.62	10.38	981.89	582.37	3235.30
2059	4.86	0.26	140.08	38.32	1467.45	10.34	977.17	575.43	3214.69
2060	4.73	0.25	135.28	35.53	1459.20	10.32	971.13	566.69	3183.93
2061	4.64	0.25	130.00	31.71	1454.29	10.33	964.30	561.01	3157.34
2062	4.60	0.25	129.85	32.18	1451.94	10.31	964.10	558.02	3152.07
2063	4.37	0.25	120.50	31.59	1434.64	10.27	951.62	539.45	3093.53
2064	4.29	0.24	120.82	32.20	1428.19	10.22	952.07	534.06	3083.03

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	4.03	0.24	111.38	29.49	1409.46	10.17	938.74	514.31	3018.79
2066	3.76	0.22	102.78	26.05	1381.86	10.15	925.79	492.52	2944.14
2067	3.59	0.20	99.45	25.82	1362.32	10.12	920.44	478.50	2901.49
2068	3.62	0.21	99.35	26.56	1364.46	10.11	920.27	480.64	2906.26
2069	3.37	0.20	91.20	24.71	1339.91	10.05	906.84	459.88	2837.27
2070	3.25	0.19	86.99	24.19	1330.88	10.02	899.42	449.74	2805.80
2071	3.10	0.18	83.52	24.70	1313.56	9.97	893.06	435.69	2764.95
2072	2.97	0.17	77.41	22.14	1300.31	9.99	881.51	424.78	2720.44
2073	2.72	0.16	70.11	20.81	1277.10	9.89	866.86	403.05	2651.98
2074	2.77	0.17	69.65	19.66	1280.67	9.94	865.86	407.68	2657.62
2075	2.83	0.17	71.09	20.06	1281.22	9.98	869.00	413.39	2668.91

Table G17: Scenario 23 RCP 8.5, BAU crown-of-thorns starfish control; high enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.61	0.24	173.35	26.00	1538.93	10.59	1014.52	626.66	3395.90
2018	5.57	0.24	170.35	24.92	1536.29	10.59	1011.32	624.21	3383.47
2019	5.47	0.24	165.50	24.62	1530.98	10.57	1006.08	617.42	3360.87
2020	5.43	0.24	162.65	22.44	1528.60	10.57	1002.94	615.23	3348.08
2021	5.52	0.24	165.34	22.81	1535.85	10.58	1005.95	622.15	3368.42
2022	5.48	0.24	164.41	21.65	1528.53	10.59	1004.93	618.22	3354.01
2023	5.54	0.25	164.21	22.72	1531.69	10.60	1004.70	622.65	3362.31
2024	5.56	0.24	165.36	22.49	1533.63	10.60	1005.98	624.40	3368.21
2025	5.50	0.24	163.57	22.98	1527.48	10.59	1004.01	619.34	3353.65
2026	5.56	0.24	165.25	24.19	1532.43	10.60	1005.88	623.56	3367.65
2027	5.63	0.24	168.17	24.29	1535.49	10.60	1009.10	629.32	3382.77
2028	5.59	0.24	165.53	24.85	1534.06	10.59	1006.22	626.77	3373.80
2029	5.56	0.25	163.94	23.50	1534.30	10.57	1004.47	625.58	3368.11
2030	5.64	0.25	167.52	24.64	1538.13	10.57	1008.44	631.76	3386.90
2031	5.86	0.26	176.06	26.23	1551.68	10.60	1017.78	647.04	3435.42
2032	6.06	0.26	183.14	28.32	1563.11	10.62	1025.23	660.17	3476.86
2033	6.25	0.26	189.77	29.46	1575.75	10.65	1032.00	673.45	3517.58
2034	6.40	0.26	194.85	30.25	1583.19	10.67	1037.03	682.33	3545.01
2035	6.47	0.26	198.25	31.39	1588.18	10.67	1040.34	687.51	3563.11
2036	6.61	0.27	202.59	31.60	1598.03	10.69	1044.50	697.05	3591.40
2037	6.72	0.28	207.26	32.82	1607.63	10.69	1048.91	704.96	3619.37
2038	6.78	0.28	208.42	32.67	1612.86	10.69	1049.98	709.31	3631.13
2039	6.89	0.29	213.97	34.70	1618.35	10.69	1055.11	716.47	3656.65
2040	6.84	0.28	212.90	33.69	1614.60	10.69	1054.14	713.22	3646.57
2041	6.89	0.29	213.89	33.65	1619.66	10.69	1055.04	717.33	3657.68
2042	6.94	0.29	215.57	33.36	1623.13	10.70	1056.55	720.02	3666.79
2043	7.08	0.30	219.38	34.34	1631.99	10.71	1059.98	729.59	3693.60
2044	7.03	0.30	216.93	34.00	1629.33	10.70	1057.81	726.88	3683.24
2045	7.07	0.32	217.83	36.38	1633.38	10.69	1058.61	730.12	3694.67
2046	7.03	0.32	216.47	34.71	1631.38	10.68	1057.40	727.60	3685.90
2047	7.06	0.32	215.92	35.22	1635.25	10.68	1056.91	730.28	3691.98
2048	7.00	0.32	214.14	35.53	1631.25	10.67	1055.31	726.69	3681.28
2049	6.87	0.32	208.95	36.42	1620.67	10.66	1050.62	718.15	3653.07
2050	6.93	0.32	211.40	36.08	1626.53	10.66	1052.88	722.89	3668.14
2051	6.82	0.32	208.25	38.58	1620.80	10.63	1050.00	715.25	3651.10
2052	6.61	0.32	203.16	38.36	1610.07	10.59	1045.29	702.11	3616.99
2053	6.48	0.31	197.82	39.60	1601.73	10.57	1040.27	693.28	3590.59
2054	6.26	0.31	185.27	35.33	1589.85	10.57	1028.20	678.63	3534.97
2055	6.16	0.31	182.15	36.57	1583.66	10.54	1025.05	671.97	3516.99
2056	6.12	0.31	179.00	35.67	1582.10	10.54	1021.82	668.96	3505.07
2057	5.92	0.30	170.75	35.21	1571.86	10.52	1013.25	655.09	3463.49
2058	5.65	0.29	162.47	35.30	1550.26	10.47	1004.32	635.90	3405.28
2059	5.77	0.29	168.64	37.75	1557.27	10.48	1011.23	644.06	3436.14
2060	5.56	0.28	161.65	40.21	1543.02	10.45	1003.62	629.15	3394.61
2061	5.38	0.27	154.33	39.57	1531.22	10.44	995.38	615.58	3352.87
2062	5.21	0.27	149.06	37.78	1518.41	10.42	989.22	603.54	3314.62
2063	5.19	0.26	148.43	37.48	1515.60	10.41	988.46	602.10	3308.65
2064	5.29	0.27	151.36	37.27	1520.96	10.43	992.00	609.38	3327.68

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	4.97	0.25	139.97	36.38	1495.68	10.41	978.49	585.39	3252.27
2066	4.74	0.24	132.13	34.67	1474.68	10.40	968.61	567.73	3193.97
2067	4.63	0.23	129.83	34.62	1463.44	10.37	965.58	559.33	3168.84
2068	4.71	0.23	132.00	34.18	1469.71	10.40	968.48	565.30	3185.77
2069	4.50	0.22	123.30	31.51	1453.79	10.38	956.99	549.54	3131.03
2070	4.15	0.21	112.66	29.45	1425.45	10.31	942.17	523.17	3048.40
2071	4.16	0.22	113.39	28.58	1426.84	10.29	943.27	524.79	3052.40
2072	4.01	0.22	107.45	26.34	1415.16	10.26	934.42	513.28	3012.02
2073	3.88	0.21	103.23	25.71	1402.98	10.24	927.87	502.95	2978.01
2074	3.74	0.21	98.19	24.94	1392.93	10.21	919.79	491.58	2942.54
2075	3.67	0.21	95.38	25.32	1384.74	10.21	915.11	484.60	2920.18

Table G18: Scenario 23s Benefits highly sensitive to changes in coral condition Scenario 23 RCP 8.5, BAU crown-of-thorns starfish control; high enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.61	0.24	173.35	26.00	1534.61	10.59	1014.30	625.70	3390.41
2018	5.57	0.24	170.35	24.92	1529.33	10.57	1010.08	622.27	3373.34
2019	5.47	0.24	165.50	24.62	1518.77	10.57	1003.16	612.77	3341.10
2020	5.43	0.24	162.65	22.44	1514.05	10.56	999.02	609.79	3324.18
2021	5.52	0.24	165.34	22.81	1528.41	10.55	1002.98	619.44	3355.30
2022	5.48	0.24	164.41	21.65	1513.83	10.55	1001.63	613.89	3331.70
2023	5.54	0.25	164.21	22.72	1520.10	10.55	1001.33	620.05	3344.74
2024	5.56	0.24	165.36	22.49	1523.94	10.56	1003.02	622.48	3353.66
2025	5.50	0.24	163.57	22.98	1511.72	10.55	1000.41	615.33	3330.30
2026	5.56	0.24	165.25	24.19	1521.53	10.52	1002.88	621.20	3351.37
2027	5.63	0.24	168.17	24.29	1527.59	10.53	1007.13	629.24	3372.82
2028	5.59	0.24	165.53	24.85	1524.76	10.53	1003.33	625.74	3360.57
2029	5.56	0.25	163.94	23.50	1525.23	10.51	1001.02	624.16	3354.16
2030	5.64	0.25	167.52	24.64	1532.85	10.51	1006.26	632.77	3380.43
2031	5.86	0.26	176.06	26.23	1559.85	10.49	1018.58	654.16	3451.48
2032	6.06	0.26	183.14	28.32	1582.84	10.47	1028.43	672.72	3512.23
2033	6.25	0.26	189.77	29.46	1608.44	10.48	1037.40	691.71	3573.78
2034	6.40	0.26	194.85	30.25	1623.63	10.48	1044.08	704.43	3614.38
2035	6.47	0.26	198.25	31.39	1633.85	10.49	1048.47	711.90	3641.07
2036	6.61	0.27	202.59	31.60	1654.12	10.46	1054.01	725.82	3685.48
2037	6.72	0.28	207.26	32.82	1673.99	10.48	1059.87	737.40	3728.83
2038	6.78	0.28	208.42	32.67	1684.88	10.47	1061.30	743.94	3748.74
2039	6.89	0.29	213.97	34.70	1696.36	10.49	1068.13	754.36	3785.18
2040	6.84	0.28	212.90	33.69	1688.51	10.50	1066.84	749.42	3768.98
2041	6.89	0.29	213.89	33.65	1699.08	10.49	1068.04	755.66	3788.00
2042	6.94	0.29	215.57	33.36	1706.36	10.49	1070.06	759.59	3802.65
2043	7.08	0.30	219.38	34.34	1725.00	10.49	1074.63	773.96	3845.17
2044	7.03	0.30	216.93	34.00	1719.37	10.48	1071.73	770.15	3830.00
2045	7.07	0.32	217.83	36.38	1727.91	10.46	1072.81	775.45	3848.22
2046	7.03	0.32	216.47	34.71	1723.68	10.44	1071.19	771.57	3835.40
2047	7.06	0.32	215.92	35.22	1731.86	10.43	1070.53	776.15	3847.49
2048	7.00	0.32	214.14	35.53	1723.40	10.40	1068.39	770.90	3830.08
2049	6.87	0.32	208.95	36.42	1701.04	10.39	1062.14	758.34	3784.48
2050	6.93	0.32	211.40	36.08	1713.35	10.40	1065.15	765.68	3809.32
2051	6.82	0.32	208.25	38.58	1701.27	10.30	1061.31	754.74	3781.59
2052	6.61	0.32	203.16	38.36	1678.73	10.30	1055.04	735.17	3727.68
2053	6.48	0.31	197.82	39.60	1661.34	10.25	1048.36	722.76	3686.93
2054	6.26	0.31	185.27	35.33	1636.71	10.24	1032.31	701.50	3607.94
2055	6.16	0.31	182.15	36.57	1623.96	10.21	1028.13	692.56	3580.06
2056	6.12	0.31	179.00	35.67	1620.76	10.17	1023.85	688.40	3564.28
2057	5.92	0.30	170.75	35.21	1599.78	10.19	1012.50	669.21	3503.87
2058	5.65	0.29	162.47	35.30	1555.81	10.11	1000.71	641.89	3412.23
2059	5.77	0.29	168.64	37.75	1569.88	10.08	1009.82	653.05	3455.28
2060	5.56	0.28	161.65	40.21	1541.15	10.04	999.77	633.32	3391.99
2061	5.38	0.27	154.33	39.57	1517.58	10.07	988.91	614.37	3330.49
2062	5.21	0.27	149.06	37.78	1492.18	10.01	980.82	597.18	3272.50
2063	5.19	0.26	148.43	37.48	1486.66	9.95	979.82	595.11	3262.89

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2064	5.29	0.27	151.36	37.27	1497.17	9.93	984.46	604.75	3290.50
2065	4.97	0.25	139.97	36.38	1447.40	9.91	966.71	571.48	3177.07
2066	4.74	0.24	132.13	34.67	1406.77	9.89	953.77	546.67	3088.87
2067	4.63	0.23	129.83	34.62	1385.33	9.91	949.82	535.02	3049.38
2068	4.71	0.23	132.00	34.18	1397.19	9.82	953.60	542.52	3074.26
2069	4.50	0.22	123.30	31.51	1366.93	9.78	938.60	521.51	2996.35
2070	4.15	0.21	112.66	29.45	1313.62	9.68	919.30	486.55	2875.63
2071	4.16	0.22	113.39	28.58	1316.19	9.63	920.73	488.38	2881.29
2072	4.01	0.22	107.45	26.34	1294.63	9.64	909.25	473.46	2825.00
2073	3.88	0.21	103.23	25.71	1272.36	9.63	900.78	460.26	2776.05
2074	3.74	0.21	98.19	24.94	1254.13	9.60	890.34	446.10	2727.24
2075	3.67	0.21	95.38	25.32	1239.39	9.57	884.31	437.57	2695.41

Table G19: Scenario 24 RCP 8.5, BAU crown-of-thorns starfish control; low enhanced corals, no cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.66	0.25	173.10	26.41	1543.62	10.59	1014.25	630.41	3404.27
2018	5.72	0.25	174.65	26.51	1549.14	10.61	1015.89	635.05	3417.77
2019	5.76	0.25	175.52	26.70	1551.30	10.61	1016.81	636.98	3423.87
2020	5.67	0.25	172.74	25.14	1545.38	10.60	1013.89	631.21	3404.82
2021	5.77	0.25	175.55	24.04	1553.85	10.61	1016.88	638.48	3425.36
2022	5.86	0.25	179.19	25.05	1561.37	10.62	1020.72	644.85	3447.83
2023	5.78	0.25	175.57	23.93	1556.13	10.61	1016.97	639.34	3428.51
2024	5.71	0.25	174.52	24.07	1550.06	10.60	1015.86	634.23	3415.26
2025	5.73	0.25	175.70	24.55	1550.94	10.59	1017.11	635.51	3420.34
2026	5.86	0.26	178.32	25.11	1559.31	10.62	1019.87	643.83	3443.09
2027	5.78	0.26	177.09	24.46	1554.36	10.60	1018.58	639.35	3430.41
2028	5.83	0.27	176.90	25.37	1557.21	10.61	1018.39	642.96	3437.46
2029	5.94	0.27	180.51	26.90	1563.48	10.63	1022.17	650.35	3460.14
2030	5.89	0.27	177.95	26.52	1560.99	10.61	1019.53	646.94	3448.62
2031	5.86	0.27	175.50	26.47	1558.30	10.61	1016.98	645.45	3439.35
2032	5.86	0.27	174.80	24.78	1556.84	10.63	1016.23	644.73	3434.09
2033	5.81	0.27	172.44	23.46	1554.66	10.63	1013.74	641.34	3422.36
2034	5.79	0.27	172.35	24.04	1551.07	10.62	1013.65	639.63	3417.47
2035	5.82	0.27	172.96	24.58	1552.17	10.63	1014.30	641.72	3422.54
2036	5.62	0.26	166.16	25.76	1538.96	10.59	1007.05	629.49	3384.06
2037	5.62	0.26	166.79	26.98	1537.13	10.59	1007.75	628.66	3383.98
2038	5.65	0.26	166.75	26.52	1539.05	10.59	1007.69	631.29	3388.05
2039	5.39	0.25	156.71	23.93	1520.23	10.57	996.69	612.52	3326.59
2040	5.12	0.25	145.72	23.21	1501.50	10.54	984.03	594.20	3264.93
2041	5.16	0.24	149.89	25.67	1500.21	10.53	989.11	596.54	3277.74
2042	5.38	0.25	155.13	25.94	1517.32	10.57	995.36	611.83	3322.13
2043	5.40	0.25	157.50	27.10	1516.11	10.57	998.12	613.22	3328.65
2044	5.23	0.24	151.13	26.85	1503.27	10.55	990.81	601.49	3290.00
2045	4.91	0.23	141.55	25.67	1478.85	10.49	979.44	578.88	3220.50
2046	4.76	0.22	136.51	24.84	1465.43	10.49	973.15	566.54	3182.45
2047	4.73	0.21	137.20	25.00	1460.32	10.48	974.04	564.13	3176.64
2048	4.67	0.21	132.15	24.08	1457.78	10.47	967.58	560.14	3157.64
2049	4.61	0.21	131.31	25.10	1453.66	10.46	966.48	555.95	3148.37
2050	4.55	0.21	127.70	25.95	1449.66	10.45	961.70	550.79	3131.65
2051	4.45	0.21	123.55	24.15	1443.21	10.43	956.07	544.25	3106.96
2052	4.44	0.21	121.51	24.59	1445.41	10.44	953.24	543.58	3104.06
2053	4.24	0.21	116.02	21.94	1428.66	10.40	945.53	529.40	3057.09
2054	4.26	0.21	115.00	21.54	1431.04	10.41	944.04	530.57	3057.75
2055	4.03	0.19	106.28	20.50	1409.97	10.37	931.23	512.74	2996.04
2056	4.03	0.20	106.81	19.06	1412.89	10.35	932.05	514.70	3000.84
2057	4.10	0.20	110.20	20.38	1415.92	10.36	937.33	519.15	3018.38
2058	3.93	0.20	103.49	19.96	1402.82	10.34	927.14	506.46	2975.10
2059	3.64	0.19	94.37	19.91	1378.47	10.28	912.57	483.22	2903.50
2060	3.60	0.19	92.39	19.84	1374.49	10.28	909.17	479.08	2889.88
2061	3.38	0.18	85.23	20.03	1354.66	10.25	896.67	459.95	2831.23
2062	3.21	0.18	80.15	19.69	1337.23	10.20	887.22	445.51	2784.31
2063	2.94	0.17	73.01	17.41	1305.58	10.13	873.26	423.24	2706.74
2064	2.83	0.17	70.64	16.95	1294.11	10.07	868.28	414.17	2678.32

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	2.83	0.16	72.44	17.65	1292.96	10.03	872.16	414.78	2684.13
2066	2.73	0.15	69.33	17.96	1277.15	9.99	865.56	404.36	2648.40
2067	2.59	0.15	65.79	18.67	1261.53	9.93	857.81	391.12	2608.82
2068	2.53	0.15	62.89	18.52	1256.19	9.94	851.17	385.25	2587.86
2069	2.49	0.15	61.80	18.51	1252.06	9.90	848.60	380.93	2575.70
2070	2.36	0.13	59.75	18.45	1225.34	9.88	843.68	368.27	2529.12
2071	2.25	0.12	56.27	18.33	1209.27	9.87	835.09	356.37	2488.84
2072	2.13	0.11	52.47	17.47	1192.30	9.82	825.27	344.51	2445.43
2073	2.06	0.10	52.10	17.39	1177.14	9.78	824.24	336.77	2420.96
2074	1.91	0.09	47.94	15.12	1153.92	9.75	812.81	321.67	2364.63
2075	1.88	0.09	47.25	14.41	1152.15	9.73	810.78	319.33	2357.06

Table G20: Scenario 25 RCP 8.5, BAU crown-of-thorns starfish control; high enhanced corals, low cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.54	0.25	170.49	25.65	1536.56	10.57	1011.48	622.58	3383.13
2018	5.49	0.25	169.45	24.69	1532.48	10.56	1010.35	619.42	3372.70
2019	5.43	0.25	168.01	24.16	1526.25	10.54	1008.79	615.02	3358.46
2020	5.41	0.25	166.39	22.55	1523.29	10.55	1007.03	613.30	3348.75
2021	5.26	0.23	161.56	21.90	1509.43	10.53	1001.73	602.70	3313.36
2022	5.26	0.24	161.09	22.11	1506.41	10.53	1001.20	602.34	3309.18
2023	5.29	0.23	161.67	21.79	1506.95	10.55	1001.85	603.79	3312.12
2024	5.28	0.23	161.00	21.74	1504.26	10.54	1001.10	602.90	3307.06
2025	5.32	0.23	162.60	22.77	1505.17	10.55	1002.89	605.82	3315.34
2026	5.27	0.23	161.53	22.85	1500.91	10.53	1001.70	602.18	3305.21
2027	5.30	0.23	162.46	22.15	1501.62	10.54	1002.74	604.78	3309.82
2028	5.32	0.23	164.08	22.76	1502.89	10.54	1004.56	605.66	3316.03
2029	5.23	0.23	159.98	22.32	1493.83	10.53	1000.01	599.50	3291.61
2030	5.14	0.23	154.33	22.14	1484.23	10.53	993.61	593.76	3263.96
2031	5.09	0.23	151.31	21.51	1479.37	10.53	990.09	589.72	3247.85
2032	5.09	0.24	151.11	21.82	1480.22	10.52	989.85	590.34	3249.25
2033	5.14	0.24	153.66	22.71	1484.66	10.52	992.87	594.36	3264.29
2034	5.09	0.24	152.36	23.24	1479.03	10.50	991.35	590.90	3252.90
2035	4.99	0.24	148.37	22.27	1470.38	10.49	986.66	584.02	3227.66
2036	4.89	0.24	143.98	22.34	1460.28	10.48	981.38	576.30	3200.15
2037	4.81	0.23	142.41	22.30	1453.26	10.45	979.45	571.11	3184.38
2038	4.76	0.24	142.14	22.74	1451.70	10.42	979.11	568.03	3179.55
2039	4.77	0.24	140.81	22.12	1451.69	10.43	977.47	568.56	3176.53
2040	4.73	0.23	139.65	21.33	1447.53	10.43	976.01	565.08	3165.45
2041	4.80	0.23	141.30	22.49	1451.94	10.46	978.09	570.36	3180.13
2042	4.78	0.24	136.56	21.32	1450.03	10.48	972.17	568.04	3164.06
2043	4.80	0.24	139.53	22.52	1452.52	10.46	975.98	570.79	3177.33
2044	4.79	0.24	141.02	23.74	1451.89	10.42	977.86	571.48	3181.98
2045	4.55	0.23	131.52	23.76	1433.27	10.38	965.98	553.01	3123.28
2046	4.49	0.23	129.57	23.25	1424.88	10.38	963.40	548.40	3105.21
2047	4.38	0.23	125.07	22.89	1418.42	10.35	957.39	540.75	3080.16
2048	4.24	0.23	117.24	20.67	1406.13	10.35	946.63	530.02	3036.19
2049	4.23	0.23	116.89	20.81	1406.73	10.33	946.13	530.18	3036.25
2050	4.29	0.24	118.02	20.54	1414.19	10.33	947.76	534.86	3050.99
2051	4.10	0.23	110.40	18.09	1398.99	10.30	936.80	520.43	3000.12
2052	3.91	0.23	102.78	17.50	1386.29	10.29	925.24	505.31	2952.34
2053	3.71	0.22	97.88	17.67	1369.69	10.24	917.39	489.72	2907.37
2054	3.66	0.21	97.39	18.00	1361.25	10.21	916.58	485.36	2893.55
2055	3.42	0.20	87.12	17.52	1339.48	10.18	899.39	464.72	2822.97
2056	3.11	0.19	78.55	15.62	1311.25	10.09	883.71	439.54	2743.07
2057	3.13	0.18	81.37	15.36	1308.13	10.09	889.31	441.53	2750.11
2058	3.12	0.18	79.00	14.69	1308.73	10.11	884.74	440.56	2742.14
2059	2.91	0.16	73.48	14.93	1284.16	10.07	873.84	421.30	2681.91
2060	2.92	0.16	74.81	15.23	1282.80	10.08	876.61	421.60	2685.24
2061	2.90	0.16	73.32	14.87	1278.57	10.09	873.54	419.88	2674.37
2062	2.82	0.16	70.72	15.56	1269.79	10.04	868.09	412.72	2650.98
2063	2.65	0.15	67.37	15.72	1249.28	9.95	860.86	397.52	2604.68
2064	2.60	0.15	65.76	15.60	1247.17	9.93	857.25	393.73	2593.42

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	2.49	0.15	61.39	16.94	1236.14	9.89	847.26	382.30	2557.82
2066	2.43	0.14	60.11	17.45	1225.18	9.87	844.18	375.44	2536.09
2067	2.41	0.15	59.08	17.97	1230.18	9.85	841.66	373.89	2536.51
2068	2.53	0.15	61.63	19.49	1249.18	9.89	848.00	384.03	2576.18
2069	2.44	0.16	58.78	18.32	1244.93	9.83	841.14	376.41	2553.35
2070	2.31	0.15	57.40	18.53	1223.77	9.75	837.68	363.50	2514.47
2071	2.26	0.14	56.11	17.92	1215.93	9.75	834.41	359.52	2497.44
2072	2.19	0.14	54.62	18.56	1204.52	9.71	830.54	351.08	2472.80
2073	2.17	0.14	51.64	17.12	1204.01	9.77	822.66	350.01	2458.93
2074	2.00	0.13	47.78	16.40	1174.74	9.70	811.97	332.22	2396.40
2075	1.77	0.11	42.68	15.83	1140.35	9.56	796.94	306.87	2315.70

Table G21: Scenario 26 RCP 8.5, BAU crown-of-thorns starfish control; no enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.62	0.25	173.09	26.48	1538.86	10.59	1014.23	627.39	3396.49
2018	5.65	0.24	175.44	28.54	1537.04	10.59	1016.74	629.30	3403.53
2019	5.66	0.24	174.59	27.83	1538.32	10.59	1015.84	630.01	3403.06
2020	5.61	0.24	172.51	27.71	1533.99	10.59	1013.64	626.70	3390.95
2021	5.59	0.24	171.83	25.82	1534.39	10.59	1012.92	624.97	3386.31
2022	5.58	0.24	172.92	27.85	1533.46	10.58	1014.08	624.85	3389.53
2023	5.56	0.24	171.88	27.81	1529.19	10.59	1012.98	622.36	3380.57
2024	5.47	0.24	167.32	28.44	1520.85	10.57	1008.09	616.73	3357.69
2025	5.41	0.24	166.21	27.15	1516.37	10.55	1006.88	612.99	3345.79
2026	5.41	0.24	165.61	27.90	1515.00	10.55	1006.21	613.66	3344.57
2027	5.38	0.24	161.92	23.76	1514.95	10.56	1002.14	612.52	3331.45
2028	5.40	0.24	162.68	24.20	1515.75	10.56	1003.00	613.55	3335.35
2029	5.35	0.24	160.89	25.92	1512.47	10.54	1001.00	610.54	3326.93
2030	5.40	0.24	161.21	24.15	1517.56	10.54	1001.36	615.25	3335.69
2031	5.60	0.24	169.54	27.04	1529.79	10.56	1010.74	628.46	3381.92
2032	5.83	0.25	178.73	30.28	1544.71	10.59	1020.69	644.28	3435.33
2033	5.94	0.25	184.45	31.98	1550.79	10.61	1026.64	651.04	3461.72
2034	6.18	0.26	193.88	35.15	1568.77	10.63	1036.20	667.56	3518.68
2035	6.34	0.26	200.34	37.71	1579.23	10.64	1042.51	677.99	3555.11
2036	6.39	0.26	201.30	39.18	1583.22	10.64	1043.43	681.81	3566.35
2037	6.57	0.26	207.49	41.47	1593.50	10.66	1049.29	693.47	3602.85
2038	6.65	0.26	212.11	43.56	1599.03	10.66	1053.57	699.09	3625.12
2039	6.78	0.27	217.67	45.26	1606.34	10.66	1058.64	707.16	3652.99
2040	6.79	0.27	216.78	45.53	1605.39	10.67	1057.85	707.40	3650.88
2041	6.86	0.27	220.36	46.61	1608.16	10.68	1061.04	711.84	3666.05
2042	6.86	0.27	219.31	44.64	1611.09	10.68	1060.12	713.08	3666.31
2043	6.83	0.27	219.30	44.28	1609.30	10.67	1060.11	710.97	3662.00
2044	6.89	0.27	220.89	44.48	1612.27	10.68	1061.52	714.73	3672.02
2045	6.73	0.26	216.24	44.07	1600.58	10.67	1057.42	703.66	3639.93
2046	6.79	0.26	219.40	47.33	1601.96	10.68	1060.25	706.53	3653.52
2047	6.71	0.25	215.95	47.86	1595.52	10.67	1057.19	701.23	3635.74
2048	6.63	0.25	215.08	49.12	1589.10	10.66	1056.41	695.67	3623.30
2049	6.50	0.25	210.70	46.21	1582.07	10.64	1052.46	687.44	3596.69
2050	6.37	0.24	206.72	43.36	1574.22	10.63	1048.82	678.64	3569.47
2051	6.27	0.24	202.11	44.30	1567.10	10.62	1044.54	672.38	3548.03
2052	6.17	0.24	198.44	45.66	1557.71	10.60	1041.06	665.49	3525.85
2053	6.05	0.24	192.80	43.72	1549.96	10.59	1035.66	657.63	3497.14
2054	5.95	0.24	188.95	42.65	1542.24	10.58	1031.88	650.71	3473.72
2055	5.56	0.24	173.99	42.44	1517.88	10.51	1016.97	624.84	3393.03
2056	5.36	0.23	166.14	37.43	1503.15	10.49	1008.62	611.56	3343.59
2057	5.19	0.22	157.30	36.13	1492.35	10.48	998.89	599.55	3300.73
2058	5.06	0.22	153.67	31.92	1480.85	10.47	994.70	590.20	3267.72
2059	4.71	0.20	138.89	28.02	1452.90	10.44	977.39	563.93	3177.17
2060	4.68	0.20	137.14	27.30	1450.31	10.45	975.17	561.84	3167.76
2061	4.58	0.19	137.40	28.65	1437.62	10.41	975.51	553.54	3148.62
2062	4.41	0.18	132.86	29.95	1422.89	10.38	969.70	539.47	3110.60
2063	4.22	0.18	127.04	28.11	1411.44	10.33	962.05	526.48	3070.64
2064	4.14	0.18	124.32	29.04	1402.39	10.31	958.35	519.56	3049.13

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	4.05	0.17	121.64	31.09	1390.77	10.28	954.64	511.17	3024.66
2066	3.88	0.16	116.33	31.63	1376.55	10.24	947.16	497.53	2984.41
2067	3.66	0.15	107.61	29.05	1354.25	10.21	934.45	479.86	2920.19
2068	3.72	0.15	111.43	30.68	1354.42	10.21	940.38	483.91	2935.84
2069	3.63	0.14	108.22	30.71	1344.86	10.18	935.54	476.72	2910.98
2070	3.60	0.13	106.35	30.96	1342.10	10.20	932.65	473.58	2900.53
2071	3.31	0.12	96.51	31.66	1313.90	10.12	917.25	449.16	2823.08
2072	3.34	0.13	97.26	32.07	1317.64	10.13	918.52	451.03	2831.15
2073	3.26	0.12	95.49	32.13	1310.67	10.09	915.55	443.93	2812.33
2074	3.14	0.12	89.31	29.95	1299.86	10.10	905.00	434.43	2772.96
2075	3.03	0.12	86.56	28.74	1287.24	10.07	900.08	425.17	2742.10

Table G22: Scenario 44 RCP 8.5, Perfect crown-of-thorns starfish control; high enhanced corals, high cloud brightening - Projected benefits 2016-2075 ($M per annum).

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2016	5.64	0.25	174.00	26.44	1543.25	10.59	1015.20	629.04	3404.41
2017	5.62	0.25	174.03	28.08	1540.43	10.58	1015.23	629.04	3403.26
2018	5.61	0.25	174.86	28.78	1539.36	10.57	1016.11	648.49	3424.04
2019	5.63	0.25	175.87	30.09	1539.15	10.57	1017.18	656.55	3435.31
2020	5.63	0.24	176.80	30.21	1536.98	10.57	1018.16	671.55	3450.14
2021	5.65	0.25	177.32	29.74	1537.83	10.58	1018.71	672.89	3452.97
2022	5.54	0.24	173.76	31.09	1527.28	10.55	1014.98	667.68	3431.12
2023	5.47	0.24	170.27	30.06	1521.64	10.55	1011.27	682.83	3432.33
2024	5.47	0.24	170.42	29.82	1521.21	10.53	1011.44	671.47	3420.60
2025	5.47	0.25	170.13	29.32	1520.80	10.52	1011.12	668.80	3416.40
2026	5.48	0.25	171.76	29.76	1520.65	10.51	1012.88	663.21	3414.50
2027	5.49	0.25	172.15	30.88	1519.97	10.50	1013.30	668.21	3420.76
2028	5.48	0.25	172.48	30.77	1518.94	10.50	1013.66	680.76	3432.84
2029	5.56	0.25	174.76	31.48	1523.10	10.50	1016.10	679.51	3441.27
2030	5.59	0.25	174.97	30.82	1525.84	10.51	1016.32	687.35	3451.66
2031	5.77	0.26	180.51	32.21	1538.56	10.54	1022.17	680.12	3470.14
2032	5.95	0.27	185.93	34.06	1551.47	10.57	1027.75	695.49	3511.49
2033	6.15	0.28	192.79	36.08	1565.99	10.59	1034.67	715.46	3562.02
2034	6.23	0.29	196.01	38.06	1570.38	10.59	1037.83	736.71	3596.10
2035	6.33	0.28	199.16	39.21	1576.75	10.61	1040.87	756.91	3630.13
2036	6.31	0.28	199.32	40.35	1573.56	10.60	1041.02	768.32	3639.76
2037	6.44	0.28	203.92	42.14	1579.98	10.62	1045.41	779.53	3668.32
2038	6.80	0.30	215.84	44.93	1604.18	10.66	1056.60	796.82	3736.14
2039	7.06	0.31	225.37	47.65	1621.94	10.68	1065.16	823.21	3801.38
2040	7.26	0.32	230.98	49.37	1633.50	10.70	1070.03	848.08	3850.24
2041	7.64	0.33	244.40	54.20	1655.26	10.74	1081.47	863.40	3917.44
2042	7.88	0.34	252.14	57.12	1669.01	10.77	1087.78	905.66	3990.70
2043	8.12	0.35	261.83	60.40	1684.77	10.78	1095.51	930.03	4051.80
2044	8.35	0.37	265.67	59.72	1698.68	10.80	1098.48	956.77	4098.85
2045	8.46	0.38	271.52	62.90	1706.08	10.79	1102.95	951.39	4114.48
2046	8.71	0.40	281.18	65.58	1720.50	10.79	1110.22	976.70	4174.08
2047	8.87	0.41	282.59	62.38	1732.02	10.80	1111.25	997.54	4205.86
2048	8.96	0.42	287.76	64.22	1736.16	10.80	1115.02	973.20	4196.53
2049	9.21	0.43	297.97	68.23	1749.34	10.81	1122.36	987.50	4245.85
2050	9.33	0.44	298.85	66.67	1755.45	10.82	1122.99	1018.38	4282.93
2051	9.55	0.45	306.70	68.64	1767.72	10.82	1128.47	1006.70	4299.05
2052	9.75	0.46	313.05	67.59	1777.67	10.83	1132.82	1021.61	4333.76
2053	9.82	0.46	318.19	72.22	1780.66	10.82	1136.28	1013.75	4342.20
2054	10.08	0.48	327.22	75.03	1793.15	10.84	1142.29	1048.53	4407.61
2055	10.28	0.49	335.38	81.29	1802.58	10.84	1147.61	1068.88	4457.34
2056	9.82	0.49	314.80	77.74	1783.77	10.79	1134.45	1113.46	4445.33
2057	10.18	0.50	329.15	82.60	1798.70	10.83	1144.09	1089.20	4465.25
2058	10.19	0.49	334.90	86.99	1796.48	10.83	1147.83	1123.24	4510.95
2059	9.82	0.48	322.58	90.94	1782.16	10.78	1139.93	1153.09	4509.77
2060	9.92	0.49	327.80	95.02	1788.53	10.78	1143.38	1179.24	4555.16
2061	9.97	0.49	325.44	89.43	1791.81	10.79	1141.84	1205.71	4575.48
2062	9.79	0.49	318.23	89.66	1782.21	10.77	1137.12	1170.20	4518.46
2063	9.24	0.49	291.86	90.24	1762.48	10.72	1119.55	1171.76	4456.33
2064	8.64	0.46	271.07	87.60	1732.55	10.67	1104.73	1175.54	4391.25

Year	Commercial Fishing	Coral Harvesting	Option (Medicinal)	Storm surge	Tourism	Recreational fishing	Non-Use	Indigenous	Total
2065	8.67	0.46	269.84	83.95	1736.35	10.66	1103.80	1158.32	4372.04
2066	8.72	0.46	273.36	86.83	1737.75	10.67	1106.47	1134.19	4358.44
2067	9.06	0.47	283.25	86.73	1753.96	10.72	1113.89	1153.66	4411.75
2068	8.70	0.44	272.90	83.74	1731.70	10.69	1106.33	1153.01	4367.50
2069	8.37	0.42	261.06	77.81	1712.72	10.69	1097.43	1133.10	4301.60
2070	7.32	0.38	223.17	70.64	1657.29	10.58	1067.98	1093.00	4130.37
2071	7.53	0.39	228.42	69.77	1669.09	10.61	1072.59	1042.63	4101.02
2072	7.36	0.38	220.25	65.25	1663.17	10.60	1065.53	1036.22	4068.76
2073	7.12	0.37	215.89	66.24	1646.47	10.55	1061.66	1002.68	4010.97
2074	7.34	0.38	225.22	70.90	1659.18	10.55	1070.08	1010.24	4053.90
2075	7.15	0.37	221.23	72.80	1649.36	10.49	1066.59	1045.80	4073.78

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