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Final Report

Designing an Aesthetics Long-Term Monitoring Program (ALTMP) for the Great Barrier Reef

Matt Curnock, Petina Pert, Adam Smith, Gemma Molinaro and Nathan Cook

CSIRO

Designing an Aesthetics Long-Term Monitoring Program (ALTMP) for the Great Barrier Reef

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ACRONYMS

AI/ML ..... Artificial Intelligence / Machine Learning
AIMS..... Australian Institute of Marine Science
AMPTO…….. . Association of Marine Park Tourism Operators
CSIRO …….. .. Commonwealth Scientific and Industrial Research Organisation
DAWE..... Department of Agriculture, Water and the Environment [Commonwealth]
GBR..... Great Barrier Reef
GBRF..... Great Barrier Reef Foundation
GBRMPA ….. .. Great Barrier Reef Marine Park Authority
GBRWHA ….. . Great Barrier Reef World Heritage Area
ICOMOS..... International Council on Monuments and Sites
IUCN..... International Union for Conservation of Nature
JCU..... James Cook University
LTMP..... Long-Term Monitoring Program for the GBR (led by AIMS)
MOUA..... Museum of Underwater Art
NESP..... National Environmental Science Program
NRM..... Natural Resource Management
OGBR …… .. Office of the Great Barrier Reef [Queensland Government]
OUV …… ..... Outstanding Universal Value (definition provided on p.2)
QLD …… ..... Queensland
QPWS …….. Queensland Parks and Wildlife Service
QTIC …… .... Queensland Tourism Industry Council
RIMReP..... Reef 2050 Integrated Monitoring and Reporting Program
RRRC ..... Reef and Rainforest Research Centre Limited
RTP..... Reef Trust Partnership (between the GBRF and Australian Government)
RSoOUV..... Retrospective Statement of Outstanding Universal Value (2012; cf. page 2)
SELTMP..... Social and Economic Long-Term Monitoring Program for the GBR
SoE..... State of the Environment (reporting)
TA..... Tourism Australia
TEQ ..... Tourism and Events Queensland
TWQ ..... Tropical Water Quality
UNESCO ..... United Nations Educational, Scientific and Cultural Organisation
WHA ..... World Heritage Area

EXECUTIVE SUMMARY

The Great Barrier Reef's (GBR's) aesthetic values form an important part of its World Heritage listing criteria, and contribute to a range of social and economic benefits. To date, however, there has been no systematic monitoring of aesthetic values in the GBR, and assessments of these values for World Heritage and Outlook reporting have been inferred from the condition of natural heritage values.

Aesthetic value is derived from people's *aesthetic responses* to an environmental setting, which is influenced by both *environmental* and *experiential characteristics* at the time of an observation or experience. While the environmental characteristics in a setting can be objectively quantified (e.g. the habitat type, ecosystem state, faunal presence), the experiential characteristics that affect aesthetic responses are individually variable and subjective (e.g. expectations, viewpoint, activity, social and cultural factors). Aesthetic responses are therefore not representative of a 'true value' that can be measured with accuracy. However, a degree of precision around a relative or indicative value can be derived, based on the closeness of agreement between multiple observers, and this value will vary between settings and be responsive to environmental changes. For example, research by Marshall et al. (2017) found significant correlations between non-expert ratings of beauty, and expert assessments of the ecological health of coral reef scenes, as well as correlations with particular environmental attributes (water clarity, fish abundance and coral topography).

In this report we present outcomes of the NESP TWQ Hub Project 5.6: "Designing an Aesthetics Long-Term Monitoring Program (ALTMP) for the Great Barrier Reef" (project duration from March 2019 to June 2020). These outcomes include:

1. A statement of the objectives and operational requirements for an ALTMP;
2. A summary review of existing programs that assess and/or monitor characteristics or attributes relevant to aesthetic values of the GBR;
3. Identification of a standard metric for measuring aesthetic responses;
4. An assessment of statistical design requirements and confidence parameters to guide the analysis and interpretation of aesthetic response monitoring data;
5. Standard protocols for the collection of monitoring data, and identification of potential implementation opportunities; and
6. Generic and site-specific monitoring protocols and tools designed for specific end-user needs (e.g. social acceptability monitoring of coral restoration sites, underwater art installations). *NB. We note that field testing of these monitoring tools in early 2020 was impacted by the COVID-19 pandemic, and we instead provide survey tools and protocols to facilitate their implementation at a later date*.

Monitoring objectives and program requirements were identified through a collaborative research process with input from c.46 end users and key stakeholders (Section 3). The program requirements encompass a range of potential management uses for aesthetics monitoring information, as well as requirements for Reef 2050 monitoring and reporting (via RIMReP). We further outline community engagement and stewardship benefits that could arise from the implementation of aesthetics monitoring. However, we note sensitivities associated with public reporting and framing of negative trends, as well as concerns raised about the potential for results to be used in competitive marketing by tourism operators or regions.

From our review of relevant assessment approaches and monitoring programs (Section 4), we identify features of different programs that are relevant to the assessment and monitoring of GBR aesthetic values, and opportunities for existing programs to contribute to aesthetic value assessments. It is notable that the monitoring of environmental characteristics by numerous programs represents the potential for a wide range of existing data to contribute to aesthetic assessments; however, the collection of accompanying aesthetic response and experiential data is rare. Several monitoring programs have accumulated historical data and archives of geo-tagged imagery over several decades (e.g. AIMS LTMP, ReefCheck Australia, Eye on the Reef), representing a potentially valuable resource for post hoc image assessments and trend analyses (e.g. using computer assessment tools developed by Becken et al. for NESP TWQ Project 5.5).

Following this review, we focus on the use of non-expert aesthetic response ratings of 'beauty' as a standard monitoring metric, and examine statistical design requirements and confidence parameters, based on re-analysis of survey data collected under NESP TWQ Project 3.2.4. Key findings (from Pert et al., 2020, and summarised in Section 5) included modelled 95% confidence intervals at different sample sizes, showing an error of ±0.8 on the 1-10 rating scale at n=100 (which may represent a reasonable balance between cost and precision), and an error of ±0.43 at n=300, with diminishing reductions in standard error for larger samples. An examination of observer biases showed that approximately 5% of respondents consistently provided "extreme" ratings (i.e. systematically scored ≥2.9 points above or below the mean score), and these respondents were more likely to be >65 years of age, visit the GBR more frequently, and self-identify as having a higher level of interest and experience with coral reefs. For respondents with these characteristics, the direction of bias (i.e. positive or negative) could not be predicted. These findings provide valuable guidance on the use and interpretation of non-expert aesthetic response ratings for monitoring, now that caveats associated with different sample sizes and observer biases are better understood.

Based on the identified program objectives and requirements we outline protocols and recommendations for monitoring data collection and curation of: (i) in-situ aesthetic response data (including by non-expert and expert observers), and (ii) digital imagery for post hoc human and/or computer assessment (Section 6). For digital imagery that can accompany in-situ aesthetic response data and/or contribute to post hoc assessments, we provide recommendations on image capture, on accounting for the effects of different camera equipment, and on metadata requirements to optimise aesthetic assessments. We then suggest implementation opportunities, identifying five example programs and potential ways by which an aesthetics component could be incorporated in their ongoing monitoring. We note, however, that consultation with the respective program managers must precede the co-development and/or adoption of any new protocols within their program(s).

Several bespoke monitoring instruments and protocols are provided (Section 7) to assist GBR managers and proponents in addressing social monitoring for works and installations (e.g. coral restoration sites, underwater art installations), which is required under certain Marine Parks permissions, but for which no previous guidelines exist. We outline recommendations for future deployment of these instruments at specific GBR sites, enabling evaluation and monitoring of aesthetic values, educational and other social benefits, and for identifying attributes that contribute to the social acceptability of such works.

1. INTRODUCTION

Aesthetic appreciation is one of the fundamental ways by which people relate to and derive benefits from natural environments (Shafer & Meitz 1969; Rossman & Ulehla 1977; Cooper et al., 2016; Marshall et al., 2017). Among a range of cultural ecosystem services, the aesthetic attributes of natural places contribute to human wellbeing by stimulating positive emotional responses and reducing stress (Ulrich 1979; Berto 2014; Cooper et al., 2016). Aesthetic values of natural places are also a strong driver of tourist and recreational visitation (Valentine 1992; Othman et al., 2015).

World Heritage properties are recognised globally for their 'Outstanding Universal Value'[1] (OUV). One of the ten criteria for OUV is criterion (vii), which requires a property to "*contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance*" (UNESCO 2019, p.26). Of the 213 natural and 39 mixed (i.e. listed for both natural and cultural values) World Heritage properties listed globally in May 2020, 146 have met criterion (vii), including Australia's Great Barrier Reef (GBR) (UNESCO 2020). However, limited guidance on the assessment and application of criterion (vii) has been widely recognised, contributing to concerns about the rigour and consistency of the varied assessment methods applied across properties, including the GBR (Lucas et al. 1997; Mitchell et al., 2013).

Addressing these concerns for the Great Barrier Reef World Heritage Area (GBRWHA), and in response to the 2012 monitoring mission to the GBRWHA by representatives of the World Heritage Centre and IUCN (Douvere & Badman 2012), the Australian Government commissioned a report to identify, define and assess the aesthetic values of the GBR and determine their sensitivity to a range of potential impacts (Context Pty Ltd., 2013). The authors of the report (the "Context Report") reviewed and drew from a range of assessment methodologies to: (a) identify key components of GBR aesthetic values, (b) define typologies for framing and evaluating environmental and experiential attributes, (c) evaluate a range of historic and contemporary data sources, (d) compile a list of places recognised for their strong aesthetic values, and (e) present and analyse the evidence of values in relation to the GBR's (retrospective) Statement of Outstanding Universal Value (RSoOUV) against the World Heritage criterion (Context Pty Ltd., 2013). The RSoOUV (written in 2012 using information from the 1981 listing, to address updates to the World Heritage criteria) states:

> "The GBR is of superlative natural beauty above and below the water, and provides some of the most spectacular scenery on earth. It is one of a few living structures visible from space, appearing as a complex string of reefal structures along Australia's northeast coast. From the air, the vast mosaic patterns of reefs, islands and coral cays produce an unparalleled aerial panorama of seascapes comprising diverse shapes and sizes. The Whitsunday Islands provide a magnificent vista of green vegetated islands and spectacular sandy beaches spread over azure waters. This contrasts with the vast mangrove forests in Hinchinbrook Channel, and the rugged vegetated mountains and lush rainforest gullies that

[1] "Outstanding Universal Value means cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole" (UNESCO 2019, p.20).

> are periodically cloud-covered on Hinchinbrook Island. On many of the cays there are spectacular and globally important breeding colonies of seabirds and marine turtles, and Raine Island is the world's largest green turtle breeding area. On some continental islands, large aggregations of over-wintering butterflies periodically occur. Beneath the ocean surface, there is an abundance and diversity of shapes, sizes and colours; for example, spectacular coral assemblages of hard and soft corals, and thousands of species of reef fish provide a myriad of brilliant colours, shapes and sizes. The internationally renowned Cod Hole near Lizard Island is one of many significant tourist attractions. Other superlative natural phenomena include the annual coral spawning, migrating whales, nesting turtles, and significant spawning aggregations of many fish species" (UNESCO 2012).

Since the completion of the Context Report, two Great Barrier Reef Outlook Reports (GBRMPA 2014; 2019) have reported on the condition and changes to aesthetic heritage values and natural beauty in the GBRWHA. The 2014 Outlook Report, informed by the 2013 Context assessment, assigned grades of 'good' for both *aesthetic heritage values* (noting limited evidence and consensus), and *natural beauty and natural phenomena* (noting adequate evidence and high consensus level; GBRMPA 2014). The 2019 Outlook Report's approach to assessing the *aesthetic heritage values* was similar to that in 2014; however, was not underpinned by a repeat of the comprehensive assessment process performed by Context Pty Ltd in 2013. For Outlook 2019, evidence on the condition of such values was "inferred from the condition of the Reef's natural heritage values" as assessed in the Report's preceding chapters (GBRMPA 2019, p.101). The 2019 grade for *aesthetic heritage values* was 'good' (with limited evidence/consensus in the grade) but was noted to have deteriorated from 2014 (inferred/with very limited evidence for confidence in the trend), while the grade for *natural beauty and natural phenomena* was 'good borderline poor' and had also deteriorated from 2014 (with limited evidence/consensus for confidence in the grade and trend; GBRMPA 2019). A notable event impacting on these values was the mass coral bleaching in concurrent summers over 2016 and 2017, which was reported to have had widespread effects on local residents' and tourists' perceptions, values and emotional responses to the GBR's health and vulnerability (GBRMPA 2019; Marshall et al., 2019a; Curnock et al., 2019).

To date, there has been no systematic monitoring of aesthetic values in the GBR. The Context Report provided a detailed *assessment* of the GBR's aesthetic values in relation to the GBR's eligibility under World Heritage criterion (vii), and established a replicable methodology to conduct future assessments at scales ranging from local sites to the entire property. However, the efficacy of repeat assessments relies on the availability of evidence and appropriate data to underpin them. Due to the spatial and temporal variability of source material (including the provision of expert knowledge), the ability to make comparable assessments for many places over time is likely to be limited. Addressing this problem, as identified and recommended by several authors (e.g. Lucas et al., 1997; Mitchell et al., 2013; Context Pty Ltd., 2013), requires the establishment of systematic monitoring that encompasses the environmental and experiential attributes and characteristics that contribute to human aesthetic responses in the varied natural settings.

Recent efforts to quantify coral reef aesthetic attributes and develop cost-effective monitoring methods have involved assessments of underwater photographs, to correlate and identify attributes that contribute to perceptions of beauty and aesthetic value (e.g. Tribot et al. 2019; Marshall et al., 2019b). Innovative technologies, such as eye tracking and Deep Learning Convolutional Neural Networks (also referred to as 'Machine Learning' and Artificial

Intelligence') have also been applied to aesthetic assessment of coral reef imagery (e.g. Haas et al., 2015; Becken et al., 2018; Le et al., 2019; Scott et al., 2019), and such approaches offer the potential to evaluate large quantities of digital images, including from social media platforms, some of which may be geo-tagged. A limitation common to these and other recent approaches, however, is the reduction of aesthetic value to only visual aspects; omitting the other sensory experiences (e.g. auditory, olfactory, haptic) that contribute to human aesthetic responses in natural environments (Pocock 2002; Brady 2016). Operationalising such approaches in a systematic monitoring program also requires a critical evaluation of their suitability (i.e. reliability of indicators and sensitivity to detect change), biases and limitations, so that resource managers and other end-users can interpret the results confidently, and weigh such data appropriately against other available evidence.

1.1 Defining aesthetic values

Defining the concept ("aesthetic values") is a critical first step in the identification of appropriate attributes[2] and indicators for assessment and monitoring. From their review of the relevant literature, Context Pty Ltd (2013) provided an operational definition for aesthetic values and aesthetic response in a natural setting, as it relates to "areas of exceptional natural beauty and aesthetic importance" from the World Heritage criterion (vii):

> "…we will define aesthetic value or significance as the response (the aesthetic response) derived from the experience of an environment or parts of an environment. Human senses - sight, touch, smell, sound, movement – are important in how humans experience an environment. And culture, knowledge, expectations and past experience mediate sensory perceptions. Aesthetic response can therefore be said to be linked to:
>
> - the characteristics of an environment
> - culturally or personally derived preferences.
>
> Aesthetic value or aesthetic significance is therefore defined in this project as including sensory, experiential and emotional response to place." (p.33)

While many of the characteristics[3] of an environmental setting (*environmental characteristics*) can be objectively quantified, and are to a large extent assessed and monitored visually, the human sensory experience and the 'culturally or personally derived preferences' (i.e. the *experiential characteristics*) are individually variable (i.e. subjective) and involve a holistic sensory and perceptual experience (Pocock 2002; Brady 2016).

Environmental characteristics

Some of the environmental characteristics contributing to aesthetic responses in natural settings within the GBR can be identified in the RSoOUV (cf. p.2). Lucas et al. (1997) provided a more detailed description of GBR natural attributes that contribute to the OUV, encompassing

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[2] In this context, we define ***attributes*** as the specific features and conditions present within a discrete environmental setting. For example, attributes of a particular reef site may include its coral colonies, the clear surrounding water, and its assemblages of resident and transient fishes and other taxa.

[3] We define ***characteristics*** in this context as the broader categories that can be used to describe sets of attributes that may be present across multiple settings. Environmental characteristics, for example, include the geomorphology, spatial dimensions and visibility (through air and water), habitat type, ecosystem state/health, faunal and human presence, etc. (see Fig 1, p.8).

(but not delineating) aesthetic heritage values, which included geological and geomorphological aspects, the diverse habitats (above and below water) and taxa representing the GBR's wealth of biodiversity, significant natural phenomena such as breeding aggregations, and specific sites and regions that exemplify 'exceptional natural beauty'. In addition, they noted that while inadequately defined, the aesthetic importance associated with GBR values was likely to be correlated with community perceptions of an undisturbed, natural state, with a low level of human presence.

Studies of tourists' and recreational users' stated preferences for coral reef settings, including the GBR, have identified a range of environmental attributes that are highly valued and which contribute to aesthetic responses, including: clear water; 'healthy' corals and reefs; colourful and diverse corals; complex coral topography; the presence, diversity and abundance of reef fishes and other taxa; and the absence of anthropogenic debris or rubbish (Miller 2005; Stoeckl et al., 2013; Marshall et al., 2017; Marshall et al., 2019b; Tribot et al., 2019). The presence of iconic marine megafauna (e.g. turtles, sharks and rays, large fishes, marine mammals) have also been shown to elicit strong effects on GBR visitors' responses and satisfaction, and some taxa (and even some individual animals) are valued highly for their economic contribution to GBR tourism (e.g. potato cod, Maori wrasse, turtles, sharks and rays; Miller 2005; Stoeckl et al. 2010). Some species have even become a primary attraction for specialist visitors to the GBR (e.g. dwarf minke whales; Curnock 2010). The effects of good and bad weather on visitor experiences in the GBR are also well known, with overcast and rainy conditions contributing to reduced satisfaction and affecting perceptions of the Reef's colour and vibrancy (Coghlan & Prideaux 2009).

For island settings, a study of visitor values associated with Whitehaven Beach on Whitsunday Island identified beach cleanliness, pure white sand, clear water and 'unspoilt' nature among the aesthetically important environmental characteristics (Ormsby & Shafer 2000). In other terrestrial settings (beyond the GBR), indicators of high and low value aesthetic attributes have been identified in a range of landscape types. For example, a study on the aesthetic value of mountain regions by Schirpke et al. (2016) found that landscapes with elevated viewpoints and long vistas of natural landscapes were valued highest, while shortened views in proximity to human infrastructure and disturbed/impacted forests were valued least.

Context Pty Ltd (2013) noted that built infrastructure and human-made objects (including historic shipwrecks) are not recognised as part of the GBR's OUV and World Heritage listing; however, the aesthetic effect of such objects and infrastructure situated within the GBRWHA remains an important consideration. While the aesthetic characteristics of natural and built environments are often perceived as dichotomous, practical considerations for human access, safety and the protection of environmental values often necessitates the placement of human-made parts into otherwise natural settings (Parsons 2008). Built facilities, vessels and objects need not detract from visitors' aesthetic experience, and due consideration of characteristics such as the design, materials, maintenance, placement and the relationship between human-made parts and the natural setting can facilitate positive aesthetic responses (Parsons 2008).

In response to recent acute environmental impacts and a broader trend of declining Reef health (GBRMPA 2019), initiatives to restore and improve the experiences of visitors to degraded/impacted Reef sites in the GBRWHA have included assisted coral propagation and replanting (i.e. 'coral restoration') and the placement of artistic installations in natural settings

(see www.moua.com.au for example). While such initiatives have become established practices in other coral reefs worldwide (Tallman 2006; Hein et al., 2019), their introduction to the GBR marks a new paradigm of intervention and assisted recovery for Reef management. Coral restoration activities and art installations can bring new social and economic benefits and opportunities (e.g. education, tourism, conservation), and can contribute to enhancing visitors' aesthetic responses (Tallman 2006; Hein et al., 2019). Similar to other human-made facilities, characteristics of art installations that are considered likely to influence aesthetic responses include their design, materials, placement and relationship to natural surroundings (Tallman 2006; Parsons 2008). For coral restoration sites, such characteristics are hypothesised to include mimicry of the natural conditions and surroundings (Tallman 2006); however, the aesthetic effects of associated attributes have not yet been established empirically. The passing of time and natural (re)establishment of corals and other organisms on restored sites and art installations is also assumed to enhance their aesthetic value (Tallman 2006).

An attempt is made in Appendix 1 to provide an indicative overview of the diverse settings (i.e. habitats and viewpoints) and levels of human use and human-made facilities throughout the GBRWHA. Based on the environmental characteristics described in the abovementioned literature, a short list is provided of attributes particular to each setting, which may contribute either positively or negatively to aesthetic responses. Note that Appendix 1 does not represent a comprehensive list of all GBR habitats, nor of all the potential environmental attributes that may contribute to aesthetic responses. It may, however, be a useful resource for identifying additional attributes of importance, and for future research that tests assumptions and the relative influence of such attributes.

Experiential characteristics

Echoing the findings from Context Pty Ltd (2013), the 2014 Outlook Report described experiential characteristics associated with GBR aesthetics, including naturalness, tranquillity, solitude, remoteness, discovery, inspiration and beauty, which can be experienced from a variety of perspectives including panoramic views, from elevated (or aerial) viewpoints, from water level and land level scenes, and below water via floating and immersed perspectives (GBRMPA 2014). Both sources also note the experiences facilitated by new technology, enabling people to access, experience and interact with parts of the GBR in increasingly novel ways, influencing people's perceptions, appreciation and understanding of the GBR's size and beauty.

In addition to the holistic sensory experience (i.e. visual, auditory, olfactory, haptic) that shapes aesthetic responses in natural settings, Brady (2016) describes the perceptual layers that also shape such responses, in which "thoughts, imaginings, knowledge and emotion may all become integrated into the [aesthetic] experience" (p.186). Aesthetic values and responses are further subject to the value orientations of the observer within a broader social and cultural context. People from different social and cultural groups can bring different expectations and respond differently to particular attributes (natural or human-made) in a setting (Pocock 2002). For example, the presence of a large crowd of people in a natural setting might not elicit a significant negative response from a Chinese tourist but may do so for an American or European (Jin & Pearce 2011; Inglis et al., 1999).

For Indigenous Australians and Traditional Owners of the Great Barrier Reef, the aesthetic characteristics and attributes of natural settings are likely to manifest themselves in different ways, and historically there has been little consideration given to Indigenous value systems in aesthetic heritage assessments, in Australia and internationally (Pocock 2002; Context Pty Ltd 2013; Cooper et al., 2016). Recent initiatives addressing this gap include a monitoring framework ("Strong Peoples – Strong Country") developed for Indigenous Heritage of the GBR, as part of the Reef 2050 Integrated Monitoring and Reporting Program (Jarvis et al., 2019). This 'biocultural' framework emphasises the connection of (i) Country health, (ii) people's health, (iii) heritage and knowledge, (iv) culture and community, (v) education, and (vi) empowerment and economics, as interrelated and inseparable system components. While aesthetic values are not identified explicitly within this framework, there are shared characteristics and attributes (both environmental and experiential) among those indicators proposed for monitoring (e.g. healthy habitats, clean water, emotional and cultural wellbeing; Jarvis et al., 2019).

Based on the literature reviewed above, Figure 1 (below) attempts to provide a summary overview of the environmental and experiential characteristics that contribute to human aesthetic responses, visitors' satisfaction and derived aesthetic value in natural settings. The list of items shown is not considered exhaustive, and other characteristics may have an influential role.

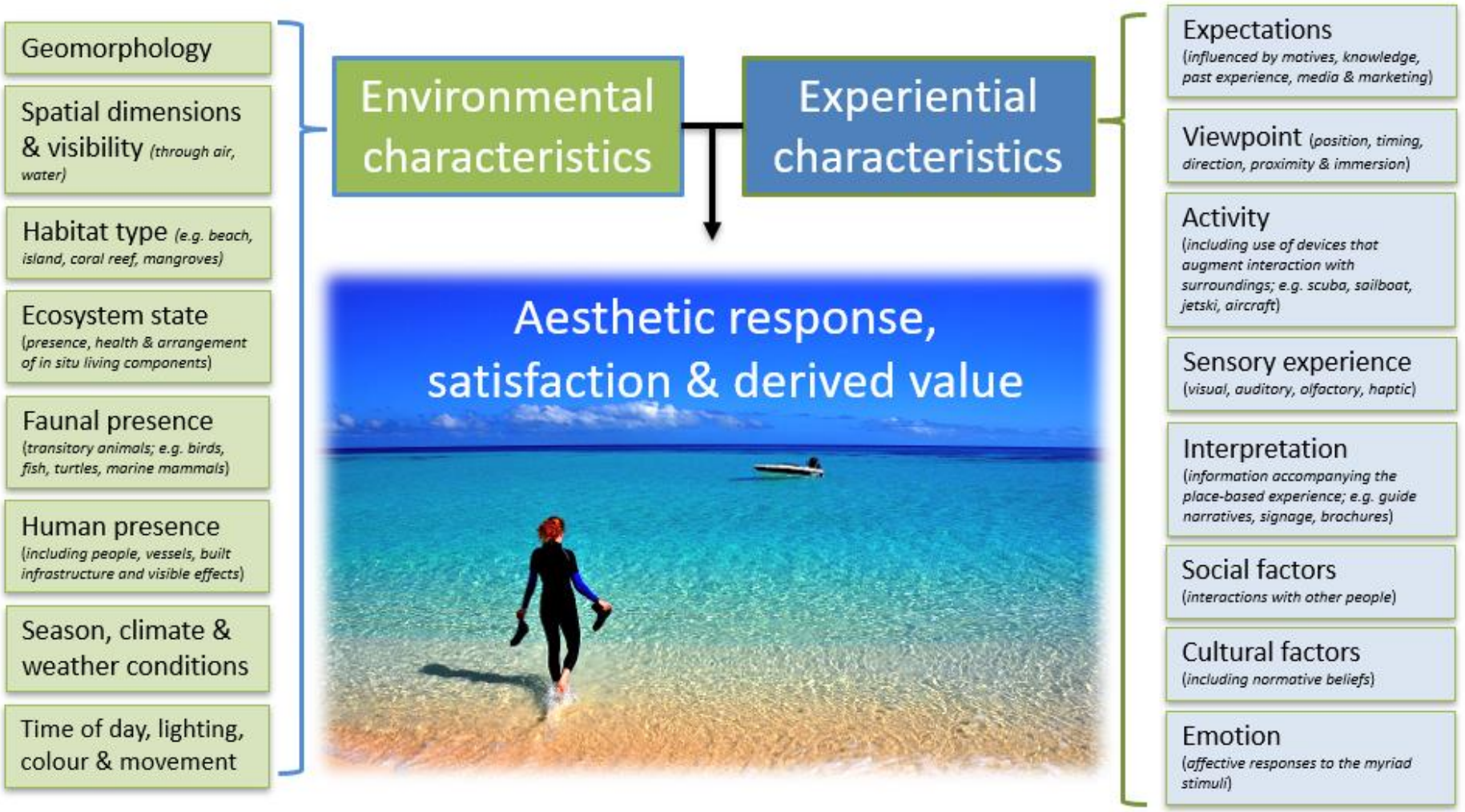

Figure 1: Environmental and experiential characteristics that contribute to aesthetic response, satisfaction and derived value in a natural setting.

Measuring aesthetic response

Aesthetic responses, preferences and judgements pervade the human experience, shaping our decision making and everyday life. Aesthetic responses feature both cognitive (reasoned understanding) and affective (emotional consequence) conscious and subconscious reactions to environmental stimuli, including objects, scenes and events (Palmer et al., 2013; Schindler et al., 2017). Aesthetic preferences and responses have been a topic of scientific psychological inquiry since at least the late 19th century (e.g. Fechner, 1876; cited in Palmer et al., 2013), and of philosophy for millennia (e.g. Plato, Aristotle). A central tenet of many studies, past and present, is the concept and sense of 'beauty' (e.g. in art, architecture, nature); however, aesthetic responses can encompass a range of negatively and/or positively valenced reactions including disgust and revulsion, as well as empathy, awe, joy, adoration and wonder (Wohlwill 1976; Stamatopoulou 2004; Palmer et al., 2013; Schindler et al., 2017).

Noting the inherent variability and subjectivity of individual aesthetic responses, the goal of empirical studies of aesthetic preferences and responses is not to measure an objective value, but to determine an average relative value among a particular population (Palmer et al., 2013). A range of empirical tools have been applied in studies of aesthetic preferences and responses, including rating scales, rank ordering, and forced choice comparisons, as well as physiological measurements (Wohlwill 1976; Palmer et al., 2013). Semantic differential and Likert-type scales are a popular tool in studies involving comparisons (ratings) of multiple scenes/objects by large groups of respondents (Osgood et al., 1957; Palmer et al., 2013).

Constructs used to assess different cognitive and affective dimensions of aesthetic responses are often presented on bipolar rating scales, and have included: *beauty* ('beautiful–ugly'), *interest* ('interesting–uninteresting'), *pleasantness* ('pleasant–unpleasant'), *originality* ('original–ordinary'), *uniqueness* ('unique–commonplace'), *naturalness* ('natural–artificial/unnatural'), *harmony* ('harmonious–discordant'), and *inspiration* ('inspiring–uninspiring') among others (Wohlwill 1976; Nadal et al., 2006; Sevenant & Antrop 2009; Kirillova & Lehto 2015; Goldberg et al., 2016; Schindler et al., 2017). Among these, *beauty* is the most widely used construct, and it has been suggested as the most representative general measure of the aesthetic experience (Eysenck 1940; Osgood et al., 1957; Nadal et al., 2006). The sense of beauty has been argued to extend beyond a mere feeling of pleasure or satisfaction, to further reflect the human desire for novelty and deeper meaning (Kant 1790/2000; Armstrong & Detweiler-Bedell, 2008).

In the context of the GBR, 'beautiful' is one of the most frequently recalled words in surveys of both local residents and tourists when they were asked "*what are the first words that come to mind when you think of the GBR*" (Marshall & Curnock 2019; Curnock et al., 2019). While other constructs can help to improve our understanding of intangible GBR values (e.g. inspiration; cf. Goldberg et al., 2016) and may have importance to particular settings (e.g. *naturalness* for coral restoration sites), for large scale monitoring purposes the use of a beauty rating scale (e.g. as applied by Marshall et al., 2019b) appears well-suited as a standard indicator of general aesthetic responses and relative aesthetic value across diverse GBR habitats and sites.

Related and relevant concepts

Scenic amenity

Scenic amenity is defined as "*a measure of the relative contribution of each place in the landscape to the collective appreciation of open space as viewed from places that are important to the public*" (Queensland Department of Natural Resources, 2001). Scenic amenity is an established and important concept in land use and marine park planning and management that guides decision making on appropriate scales and types of development, access and use levels, and activities that are permitted to occur in areas of significance and high value. The environmental characteristics and attributes of landscapes and other natural settings contribute to both scenic amenity and aesthetic value; however, many of the experiential characteristics (cf. Fig 1 above) are not considered among the components of scenic amenity. Methods for assessing scenic amenity typically include expert-led visual and photographic scoring and mapping of landscapes and component features, as well as surveys of public preferences (e.g. Queensland Government 2007). Such assessments, as utilised by local, state and Commonwealth government agencies, can therefore provide useful data to inform the broader assessment of aesthetic values, at locations where such assessments have been conducted.

Social acceptability

Defined in an ecosystem management context as an outcome resulting from "*a judgmental process by which individuals (1) compare the perceived reality with its known alternatives; and (2) decide whether the "real" condition is superior, or sufficiently similar, to the most favourable alternative condition*" (Brunson 1996, p.9), social acceptability is recognised increasingly among the key criteria for resource managers' decision making in natural and protected areas. Dimensions of social acceptability in a forest management setting, which are likely to be applicable in the GBR and elsewhere, include an awareness and sensitivity for diverse community values for the resource/setting; encompassing aesthetics, recreation, cultural, spiritual and other non-commodity values (Robertson 1991; Brunson 1996; Ford et al., 2009). Individual responses to changes in an environmental setting, caused by human intervention or a naturally occurring process, are often based on a preconceived natural state or 'scenic aesthetic', which if altered can elicit negative sentiment (Gobster 1996).

In the GBR, rapid ecological changes and extreme climatic events have been shown to elicit widespread emotional responses (grief and empathy), influencing perceptions of the GBR's aesthetic and other values, threat perceptions, and protective sentiment (Marshall et al., 2019a; Curnock et al., 2019). Within this context, management and community responses are transitioning to a new interventionist paradigm, in which the social acceptability of adaptation and restoration measures, as well as the introduction of new structures to the GBRWHA such as art works, are likely to be judged on their aesthetic effect, among other value ramifications. Monitoring that improves our understanding of underlying attribute parameters that influence aesthetic responses to different interventions should therefore help to better inform decision making about such interventions, and may contribute to an improved theoretical understanding of the role of aesthetics in social acceptability.

2. PROJECT OBJECTIVES, SCOPE AND METHODS

Objectives of this NESP TWQ Hub project[4], as addressed in this report, include:

1. Identify monitoring program objectives and reporting requirements based on end-user and stakeholder information needs (Section 3).
2. Review existing programs that monitor indicators of aesthetic values (i.e. particular characteristics and/or attributes) in the GBR, and identify appropriate method(s) for scalable monitoring (Section 4).
3. Assess statistical design requirements and describe confidence parameters for interpreting aesthetic response monitoring data (Section 5),
4. Develop monitoring tools and protocols that enable the integration of both human and computer aesthetic assessments, and identify implementation opportunities with existing programs (Section 6).
5. Pilot testing of monitoring tools and methods (*Reef Ecologic component*; Section 7).

This project builds upon work from an earlier NESP project[5] that (a) evaluated indicators (attributes) of coral reef aesthetics that could be used for monitoring and reporting purposes, (b) established linkages between coral reef health and aesthetic responses, and (c) explored opportunities for incorporating indicators of coral reef aesthetics into GBR monitoring and management processes (Marshall et al., 2017). Outcomes of the previous project are discussed in subsequent sections of this report as they relate to the present project outcomes.

Project timing (Figure 2) and available resources enabled the completion of four of the above five objectives, noting that global and Australian responses to the COVID-19 pandemic prevented field trials of pilot surveys planned over March-May 2020. Despite this setback, we have designed monitoring tools and other resources, incorporating feedback from end-users and stakeholders, enabling such tools to be implemented at a later date (Section 7).

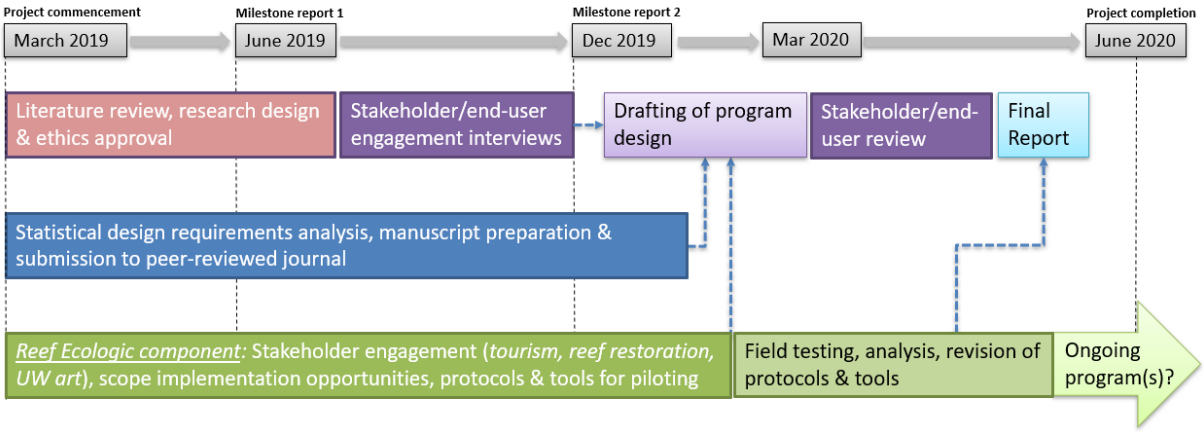

Figure 2: Project timeline, key activities and reporting milestones

[4]NESP TWQ Hub Project 5.6: Designing an Aesthetics Long-Term Monitoring Program (ALTMP) for the Great Barrier Reef. Details: https://nesptropical.edu.au/index.php/round-5-projects/project-5-6/
[5]NESP TWQ Hub Project 3.2.4: Defining, assessing and monitoring Great Barrier Reef aesthetics. Details: https://nesptropical.edu.au/index.php/round-3-projects/project-3-2-4/

2.1 Approach and methods

We adopted the broad epistemological approach of 'sustainability science' (cf. Kates et al., 2001; Clark 2007) in our research to address the abovementioned five project objectives, using a mixed methods approach to address the varied project objectives.

Identifying monitoring program objectives and reporting requirements

For Objective 1 (results/outcomes reported in Section 3 below), we applied principles from Participatory Action Research (cf. Argyris & Schön, 1989; Greenwood et al., 1993) in a collaborative research process where the lead researcher operated as a facilitator in engaging with stakeholders and end-users to identify information needs and gaps, defining emergent issues, objectives and opportunities, and in linking scientific understanding to the design outcomes. Steps in our research process included: (i) providing introductory seminars and facilitating workshop discussions with end-users and stakeholders (held at GBRMPA on 29/8/2019 and at JCU Townsville on 10/9/2019); (ii) conducting a series of semi-structured interviews and meetings (in person and via telephone; ranging in duration from 20 minutes to more than one hour) with staff from end user and stakeholder organisations, either as individuals or in small groups (total n=46 participants from 15 organisations, from August to December 2019) from which detailed notes were taken for subsequent qualitative content analysis (i.e. concepts from these discussions were typed up and sorted thematically using MS Excel, then addressed in the program design); and (iii) soliciting feedback from the same participants on a draft, leading to refinement of a final report (this report) featuring the monitoring program design.

Human research ethics approval was obtained from the CSIRO Social Science Human Research Ethics Committee (CSSHREC; ref. 092/19). Among the ethical conduct provisions adopted for this study, interviews were not audio recorded, and we undertook (intentionally from the outset) to not attribute any statements or quotations to individual respondents or their organisation, to allow respondents to more freely share ideas and views on their organisations' functional needs and uses for aesthetics monitoring. A participant information sheet was provided to all respondents prior to interviews (Appendix 2) and an interview template containing question prompts was used (Appendix 3), but loosely followed, with particular questions asked only when relevant to respondents.

Review of existing programs and methods

Information gathered for Objective 2 (reported in Section 4) was obtained from multiple lines of inquiry, including through the abovementioned key informant interviews, the literature review process, and via targeted web searches of relevant scientific, government and non-government organisations.

Criteria for identifying appropriate monitoring methods and tools for long-term and integrated monitoring in the GBR included SMART criteria (i.e. Simple, Measurable, Accurate, Responsive & Timely) as well as additional requirements identified during the research stakeholder engagement process. An additional and important consideration in the selection and application of monitoring methods was the requirement to integrate effectively with the proposed Reef 2050 Integrated Monitoring and Reporting Program (RIMReP), and the incorporation of relevant principles into the program design.

Assessment of statistical design requirements and confidence parameters

The focus of this objective was to evaluate the sensitivity, sampling requirements and inherent biases in the use of non-expert aesthetic ratings of coral reef images, as utilised in recent studies (e.g. Tribot et al. 2019; Marshall et al., 2019b) that propound the method as a cost effective and scalable monitoring tool for coral reef environments. To achieve this, we re-analysed data collected by Marshall et al. (2017)[6], which consists of online survey responses and image ratings from a sample of 1,417 Australians. The respondents gave ratings ranging from 1 = "very, very ugly" to 10 = "extremely beautiful" for 40 images each, selected from a pool of 181 images of coral reef scenes that contained a defined set of attributes. Each image was thus rated by at least 381 respondents (see Marshall et al., 2019b for further details).

The aims, methods and results of this study are summarised briefly in Section 5; and a complete manuscript detailing the aims, methods and results (along with introduction and discussion) were reviewed and published in a scientific journal (Pert et al., 2020).

Development of monitoring protocols & identification of implementation opportunities

Key design concepts and specific information requirements for monitoring tools and protocols (outlined in Section 6) were derived from the research process outlined above, drawing on advice received from key informants, from theoretical concepts and monitoring principles in the literature (e.g. from Wohlwill 1976; Gitzen et al., 2012; Bryman 2012), from examples used in other studies and monitoring programs (cf. Section 4), and from relevant practical experience and insights identified by the research team when considering regional and site-specific features and limitations (e.g. for bespoke in-situ survey instruments). Implementation opportunities were identified via much the same process, in particular from the review of existing programs and methods (Section 4) and from advice provided by end-users and stakeholders throughout the project.

Pilot testing of monitoring tools and methods

This component, led by Reef Ecologic research partners (A. Smith, N. Cook, G. Molinaro), involved design and testing of field survey instruments at selected sites that featured differing states of reef health (i.e. impacted + "pristine" sites) and with different human activities and installations, including coral restoration and underwater art. Specific protocols, pilot survey instruments and other relevant considerations are reported in Section 7. Additional tools (in development at the time of writing) are being co-designed with collaborators from NESP TWQ Project 5.5 and eAtlas, including an online image database to facilitate post hoc human and computer aesthetic assessments.

[6] This dataset is stored in a publicly available repository at: https://doi.org/10.25919/5cee318edd4bc

3. MONITORING OBJECTIVES AND PROGRAM REQUIREMENTS

3.1 Monitoring program purpose and objectives

Based on a broad range of advice and information gathered through the collaborative research process, and drawing on elements of the RIMReP purpose, vision and objectives (GBRMPA 2018), the purpose of an operational Aesthetics Long-Term Monitoring Program (ALTMP) should be:

> *To provide reliable metrics and representative data that informs assessments of the state and trend of GBRWHA aesthetic heritage values, and the pressures on those values for all habitat types, ranging from local sites, to regions, and scalable up to the World Heritage property, enabling: (i) timely and suitable responses by Reef managers and partners to emerging issues and risks, and (ii) benchmarking of relevant targets and objectives within the Reef 2050 Plan*.

Objectives of an operational ALTMP, again drawing on those from RIMReP, relevant literature (e.g. Addison et al., 2015), and from advice provided by key informants, should include:

i. Ability (i.e. sufficient sensitivity) to detect trends and changes in aesthetic values in a timely manner, via reliable metrics and robust data and indicators,
ii. Ability to establish environmental correlates with aesthetic responses across a range of habitats, to improve understanding and assist future assessment processes that may infer aesthetic value from the state of natural heritage values,
iii. Cost-efficient implementation and long-term operation,
iv. Clarity, logic and transparency in its operational processes and in the communication of results,
v. Adaptability to integrate new technologies and methods for data collection, analysis, communication and data integration as required by RIMReP,
vi. Accessibility of data to the wider community, enabling research that improves knowledge and understanding of GBR aesthetics, relationships with other social-ecological system components, and predictive models to assist decision making.

3.2 Operational requirements

Specific operational requirements were elicited though the key informant interviews and subsequent end-user and stakeholder feedback. These included:

- The ability to inform management decisions (cf. Table 1 below)
- Timely provision of data to managers, meeting RIMReP data requirements
- Timely communication of results to end-users and stakeholders
- Simple and replicable protocols to enable broad participation in data collection (e.g. by tourism operators, citizen scientists and scientific professionals alike)
- Use of scalable and comparable metric(s) across all habitat types (i.e. from individual sites, to reefs, to regions, to the WH property)
- Complementarity and integration capability with existing GBR monitoring programs
- Relevance to environmental condition/health/state
- Ability to account for observer biases.

3.3 Management uses

Potential management uses, derived from feedback from key informants and comparison with other monitoring program designs (e.g. Gooch et al., 2019), are categorised below (Table 1) within a hierarchical monitoring framework developed by Udy (2017).

Table 1: Potential management uses of aesthetics monitoring information (adapted from Udy, 2017).

	Category of management use				
	Tactical	**Operational**	**Strategic planning**	**Quantifying effectiveness**	**Reporting**
Relevant management tools and processes	Rapid impact assessment Marine Tourism Contingency Plan (assess alternate site suitability)	Permit assessments Proponent-led baseline assessment and site monitoring	-Plans of Management -Marine Tourism Contingency Plan (process updates) -Site Plans -Policy development -Resilience Network	Environmental assessment and permissions (EPBC and GBRMP Acts) Monitoring and benchmarking of permit conditions; decisions relating to mitigation & offsets	-Outlook Report -State Party reports to WHC (periodic and reactive) -Reef 2050 Plan Reporting -QLD SoE reporting -Regional Report Cards -Public & stakeholder engagement & media
Hierarchical monitoring:	**Example use/application of data by managers**				
Spatial extent: • Map high value sites and areas • Identify common and unique values across regions and habitats	Estimate extent of potential social and economic impacts from an incident. Identify areas that require remediation and other actions. Identify suitable alternative sites for tourism use.	Improve ability for permit assessments to balance conflicting values/activities Establish aesthetic value guidelines and monitoring requirements for development proposals	Ensure future planning, policy & assessments consider high value sites, appropriate use levels and activities. Better inform decision making on allocation of resources to protect or restore sites/ areas.	Improve cost benefit assessment of restoration, intervention and other actions by identifying high value areas/ regions.	Reporting to communicate the values, uses, management & community effort and achievements across different scales in the Marine Park and WHA.
Temporal trend: • Compare condition and values over time	Understand severity of an incident/impact & determine if intervention is required.	Provide guidance on appropriate management activity/ intervention for achieving desired outcome(s)	Focus use of planning/policy tools on problem areas/regions and issues Adaptive planning of resource allocation & effort distribution	Ensure protective and restorative efforts are achieving desired goals (benchmarking). Compare effectiveness of management actions over different timescales.	Track progress over long-term and report on attributes against desired state, changes over time
Process understanding: • Causal relationships • Predictive models	Identify probable outcome scenarios and the optimal management response	Assess social acceptability and site-suitability of development proposals and interventions. Understand likely impacts of a proposed activity;	Predict the likely trend in condition(s), potential pathways for recovery, and use planning/ policy tools to enhance resilience	Understand the multiple impacts of interventions/ developments and monitor to ensure strategy and actions are progressing towards intended outcomes. Evaluate/assess potentially shifting	Report on actions completed and outcomes achieved, supporting cause and effect understanding. Use improved understanding of aesthetic values to engage more effectively with

		linkages between human pressures and state of value(s).		baselines in aesthetic and related social values.	public and stakeholders

Key informant interviewees identified the potential for aesthetics monitoring data to inform several management decision making and planning processes, including assessments for: (i) Plans of Management, encompassing areas in which appropriate tourism use levels and activities are specified (e.g. the Cairns Area Plan of Management and the Whitsundays Plan of Management), (ii) contingency arrangements for permitted tourism operations under the Marine Tourism Contingency Plan, and (iii) the Marine Parks permission system.

As part of the permissions system, proponents and assessors are required to consider the potential impacts to social values (including aesthetic values), for which assessment guidelines are provided (Social Value Assessment Guidelines; GBRMPA 2017a). Within these guidelines, assessors are advised to consider the environmental and experiential characteristics that contribute to aesthetic values (based on Context Pty Ltd. 2013). Based on advice from key informants, such assessments are applied when required for specific assessments, and will rely on the availability of location-specific data or other evidence, some or all of which may be provided by the proponent. Once a permit is issued, permit holders are required to adhere to a range of permit conditions, among which may include monitoring of "social impacts including aesthetics and conflict of use"[7]. Currently no guidelines or templates exist to guide such monitoring. To address this gap, we have designed monitoring instruments and protocols for this purpose, which encompass visitor aesthetic responses, perceptions of social acceptability and related concepts (see Section 7).

3.4 RIMReP requirements

Monitoring of GBR aesthetic values was identified as a key gap and "critical" activity for Reef 2050 Plan monitoring by the RIMReP Human Dimensions Expert Theme Group (Gooch et al., 2019, p.42). To ensure that an ALTMP delivers effectively to RIMReP, a clear line of sight to relevant Reef 2050 Plan Objectives and Targets is needed, and there must be alignment with the appropriate thematic (cf. other human dimensions and GBR monitoring), logistical and data integration protocols, in addition to the abovementioned operational requirements.

Under the current Reef 2050 Plan (Commonwealth of Australia 2018)[8], an operational ALTMP will primarily inform progress towards:

Community Benefits:

- Target **CBT2** – "Community benefit values have been identified and are considered in decision making",

[7] Example: Environment Protection (Sea Dumping) Act 1981 – Sea Dumping Permit 19/04 for Museum of Underwater Art Limited. Available at: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0009/266166/SD19-04-Permit.pdf

[8] Noting that an updated Reef 2050 Plan with new targets is anticipated in mid-2020.

- Target **CBT4** - “Community benefit values for Great Barrier Reef coastal ecosystems are being monitored and show a positive trend”,
- Objective **CBO3** - “Community benefits provided by the Reef, including its superlative natural beauty and the sense of place, are maintained for current and future generations”, and
- Objective **CBO4** - “Local, regional and Reef-wide community benefits are understood and the community is actively engaged in managing Reef activities”.

Heritage:

- Target **HT2** - “Indigenous and non-Indigenous heritage values are identified, documented and protected in decision-making and planning processes”,
- Target **HT3** – “Partnerships between Traditional Owners and all stakeholders are increased to ensure key Reef heritage values are identified, documented, and monitored”, and
- Objective **HO2** – “Indigenous and non-Indigenous heritage including natural, aesthetic, historic, scientific, and social values are identified, conserved and managed in partnership with the community”.

Targets and Objectives that may be *indirectly* informed through the accumulation, analysis and synthesis of aesthetics monitoring data include:

Economic Benefits:

- Target **EBT5** - “The relationship between Reef health and the viability of Reef-dependent industries (e.g. tourism and fishing) is understood and considered in planning and development decisions”, and
- Objective **EBO3** - “Reef-associated industries are planned and managed in such a way as to protect the Reef’s Outstanding Universal Value and are sustainable, productive and profitable”.

DPSIR framework

The underlying framework for identifying appropriate indicators and system linkages within RIMReP is the Driver, Pressure, State, Impact and Response (DPSIR) model (Figure 3).

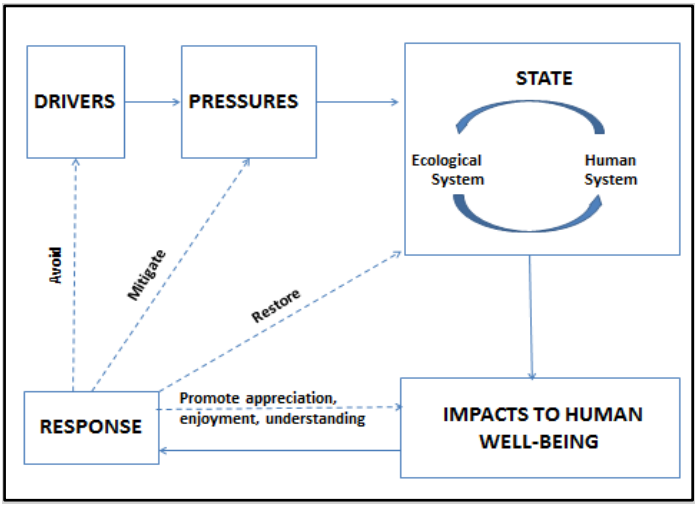

Figure 3: DPSIR Model/Framework (from DPSIR terminology guide; GBRMPA 2017b)

Aesthetic ***values*** of the GBR are represented in the ***state*** category as a function of both the ecological and human systems. Significant changes in the state of GBR aesthetic values (at regional and/or WHA property scales) are highly likely to contribute to ***impacts*** to human well-being, through affective social responses (e.g. "Reef Grief"; cf. Marshall et al., 2019) and through economic effects (e.g. a reduction in tourist visitation and expenditure). Affective responses associated with aesthetic perceptions and values for the GBR are further hypothesised to influence societal attitudes, a ***driver*** of change (e.g. potentially influencing protective sentiment for the GBR; cf. Curnock et al., 2019).

Alignment with GBR Human Dimension indicator framework

As part of the RIMReP program design process over 2017-2019, the Human Dimensions Expert Group report (Gooch et al., 2019) developed a comprehensive framework of GBR human dimension indicators sets, including "attributes" and "indicator clusters" to categorise and identify the monitoring required to assess progress towards the Reef 2050 Plan outcomes. Of the five major clusters, monitoring of GBR aesthetic values falls under *Culture and Heritage* (*CH1: World Heritage – underpinned by ecosystem health, biodiversity and water quality*), with the following key indicator sets identified:

- CH1.1 State of regional natural assets
- CH1.2 Perceptions of the Reef's aesthetic beauty
- CH1.3 Perceived impacts on the Reef's aesthetic beauty

Both CH1.2 and CH1.3 are identified as priority indicators (cf. Gooch et al., 2019, p.30), among those human dimension attributes not currently monitored. Other human dimension clusters and attributes that are hypothesised to be influenced by changes in the state of GBR aesthetic values include:

Aspirations, Capacity and Stewardship

- ACS1: Levels of community awareness and education about the Reef
- ACS2: Community capacity for stewardship

Community Vitality

- CV4: Community health/wellbeing/satisfaction associated with the Reef

Culture and Heritage

- CH2: Indigenous Heritage
- CH3: Contemporary culture

Economic Benefits

- EV3: Economic viability of Reef-dependent industries

Alignment with GBR Indigenous Heritage indicator framework

The *Strong Peoples – Strong Country* framework developed by the RIMReP Indigenous Heritage Expert Theme Group (Jarvis et al., 2019) provides a suite of Indigenous-driven indicators that were recommended for monitoring by Traditional Owner groups. Such monitoring would, through RIMReP, enable integration with thematically linked data from other monitoring programs. Explicit linkages between aesthetic values and indicators within this

framework should be made in collaboration with (and be led by) appropriate Traditional Owner representatives, and will require technical and management expert advice, at an appropriate time during the implementation process. Potential indicators from the *Strong Peoples – Strong Country* framework that relate to and/or encompass GBR aesthetic values may potentially include:

- Being on country
- Healthy coral
- Healthy other habitats
- Clean saltwater and clean freshwater
- Spirituality
- Cultural wellbeing

Logistical and data integration requirements

There are potential opportunities for a range of existing monitoring programs to contribute data that can assist with the assessment and monitoring of aesthetic values in different habitats and settings. Programs that include monitoring of environmental and/or experiential attributes can assist via: (i) proxy indicators of the state of particular environment attributes – where linkages to aesthetic responses are established and/or can be validated, and/or (ii) by providing imagery for post-hoc assessments of aesthetic responses. However, optimal opportunities for the integration of monitoring data from other programs will require:

(i) adequate description/quantification of the *environmental characteristics* and attributes present in the setting,
(ii) quantification of observers' *aesthetic response*(s) to the setting, and
(iii) sufficient descriptive information about the observer(s) to contextualise the aesthetic response (i.e. quantification of at least some of the *experiential characteristics*).

As we detail in Section 5, accounting for observer biases in aesthetic response ratings is an important consideration in the monitoring design and interpretation of data. Gooch et al. (2019) also noted that factors likely to influence attitudes and perceptions relating to the GBR include: interest, knowledge and experience with the GBR and its management, access to the GBR, activities and use levels, and demography. A key part of the data integration requirements is the inclusion of appropriate metadata. To enable effective assessment of aesthetic values in defined spatial areas, and monitoring of state and trend(s), aesthetic data must be accompanied by adequate spatial and temporal metrics. GPS coordinates (and polygons of the setting area if available) and date-time logging are fundamental to most biophysical monitoring protocols; however, these details are frequently not included with sufficient resolution in many social research and monitoring programs (e.g. SELTMP[9]). A review of current GBR monitoring programs that collect data relevant to aesthetic values is provided in Section 4, with logistical and data integration opportunities identified, including the integration of human and computer (AI/ML) assessments. Detailed metadata requirements for digital imagery and in-situ monitoring instruments are outlined in Section 6.

[9] SELTMP is the Social and Economic Long-Term Monitoring Program for the GBR. Background information and a list of publications and other outputs is available at: https://research.csiro.au/seltmp/

3.5 Reporting processes and outputs

Through our collaborative research process, a range of end-user information needs and reporting requirements were identified. Primary end-use reporting mechanisms included:

(i) the 5-yearly Outlook Report (particularly its assessment of the state and trend of aesthetic heritage values),
(ii) World Heritage State Party Periodic Reporting (c. 6-yearly cycle),
(iii) Benchmarking of relevant target(s) and objectives in the Reef 2050 Plan, via the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP),
(iv) Regional report cards, delivered by partnerships across major catchment (NRM) regions of the Great Barrier Reef coastal and inshore zone (e.g. Wet Tropics Healthy Waterways Partnership; Dry Tropics Partnership for Healthy Waters; Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership)

Secondary and ad hoc reporting and communication opportunities may include institutional and program annual reports (e.g. the Joint Field Management Program annual summary), newsletters and communiques (e.g. GBRMPA's "Reef in Brief", "From the Deck" and "Tracking Trends" newsletters), ministerial briefings, media releases, and social media posts.

Engagement and stewardship benefits

The ability to report aesthetic values as a simplified concept and relative measure along a beauty scale (cf. Section 1.1 above) makes the communication of monitoring results potentially accessible to diverse audiences. The experiential component of aesthetic values assessment and monitoring also enables broad participation in monitoring data collection (e.g. by tourism operators, tourists, citizen science groups). Facilitating wider community participation in GBR monitoring, and fostering wider community interest in the state and trend of GBR values is an important initiative that can help to build community support for management initiatives (e.g. those identified in the Reef Blueprint; GBRMPA 2017c). There may also be flow-on benefits for community participation in local-scale stewardship initiatives (e.g. community programs supported by the RTP[10]).

Sensitivities associated with public reporting

Several key informants suggested that there was likely to be a strong public interest in the reporting of GBR aesthetic values, including from local, national and international audiences. Future reporting of aesthetic values that shows positive trends (i.e. the improvement of aesthetic values) was considered to be welcomed by most stakeholders; however, concerns were expressed about sensitivities associated with messaging and framing of negative trends (i.e. deterioration of aesthetic values), and the need to avoid fomenting disempowerment of stakeholders and the wider community. Tourism industry stakeholders expressed a strong interest in the public reporting of aesthetic monitoring results, but some raised concerns about the potential for results to be used in competitive marketing by operators or tourism regions (e.g. "visit location A; it has higher aesthetic values than location B").

[10] Example programs funded under the Community Reef Protection component of the Reef Trust Partnership (RTP) are available at: https://www.barrierreef.org/what-we-do/reef-trust-partnership/community-reef-protection

4. RELEVANT ASSESSMENT APPROACHES, MONITORING PROGRAMS AND METHODS

4.1 Review of relevant assessment and monitoring approaches

This section presents a summary review of assessment approaches and monitoring programs (past, present and emerging) that deal with data relevant to GBR aesthetic values, and considers their potential to contribute to GBR aesthetics monitoring. These examples were identified by key informants, from literature and from a targeted search of relevant institutional websites, including universities, government management agencies (e.g. GBRMPA, QPWS), scientific institutions (AIMS, CSIRO), and citizen science and non-government organisations (e.g. Reef Check Australia, CoralWatch, Citizens of the GBR). Relevant aspects of these assessment approaches and monitoring programs are summarised in Table 2 (below), and a selection of examples are identified in Section 6 to outline potential ways by which these programs could contribute to monitoring of GBR aesthetic values.

Table 2: Comparison of assessment approaches and monitoring programs in the Great Barrier Reef that encompass aesthetic values and/or components

Monitoring / assessment activity	Description of approach / method	Periodicity; *scale(s)*	Relevance to aesthetics monitoring / assessment	Limitations for aesthetics monitoring / assessment
Great Barrier Reef Outlook Report	Expert assessment: grade and trend of Aesthetic Heritage Values of the GBRWHA; currently inferred from the condition of natural heritage values (Outlook 2019; section 4.5.2)	5-yearly (since 2014) *WH property scale*	Time series comparison Assessment requires updated evidence on 5-year timescale	No experiential component Low confidence levels in grade and trend due to limited availability of specific data on aesthetic values.
Context Report (2013)	Expert-led mixed method approach resulting in a holistic assessment, sensitivity analysis, and replicable method for potential future WHA-scale assessments.	One-off assessment (2012-2013); *WH property scale*	Comprehensive assessment process drawing on multiple lines of evidence Repeatable assessment method described	Relies on availability of up-to-date, spatially & temporally linked data. Does not encompass long-term monitoring requirements
GBRMPA Social Value Assessment Guidelines (based on Context 2013)	Describes aesthetic characteristics to be considered in environmental assessment and permissions processes	As required – for permit assessment and review processes *Site/proposal specific*	Social monitoring (unspecified) may be a permit requirement for successful proponents	A consistent process for applying the assessment & availability of evidence not specified.
QLD Department of Local Government and Planning Implementation Guideline No.8.	Guidelines for identifying and protecting scenic amenity values. Applied in QLD coastal planning processes.	Application in designated areas as required. *Limited number of coastal and inshore areas*	Process gathers useful evidence for aesthetic values assessment. (e.g. photographic scoring and mapping of landscapes and component features, surveys of public preferences)	Scenic amenity assessment excludes many experiential characteristics.

Monitoring / assessment activity	Description of approach / method	Periodicity; *scale(s)*	Relevance to aesthetics monitoring / assessment	Limitations for aesthetics monitoring / assessment
AIMS Long Term Monitoring Program	Expert administered in-water surveys provide topographical and habitat description of selected reefs, accompanied by digital images of different habitats (see link for example)	Long-term spatially stratified coral reef health monitoring across the WH property. *Sampled reefs representative of major regions of the GBR*	Enables long-term trend analyses of visible attributes Digital image historical archive with spatial and temporal metadata Multiple methods applied to quantify ecosystem state	No aesthetic response data or experiential characteristics
Social and Economic Long-Term Monitoring Program (SELTMP)	Single indicator used in surveys of GBR stakeholders (1-10 scale of agreement; "*The aesthetic beauty of the GBR is outstanding*")	4-yearly assessment (2013, 2017 so far) *WH property scale*	Non-expert aesthetic perception measure Large samples representative of GBR region residents, tourists and industries Enables correlation with other values and perceptions.	High-level indicator community perceptions Not linked to environmental attributes
Eye on the Reef - GBRMPA-led program that includes 4 survey types: - Sightings Network (SN) - Rapid Monitoring (RM) - Reef Health & Impact Survey (RHIS) - Tourism Weekly (TW)	SN is available to all GBR users; includes a smartphone app for reporting animal/ phenomenon observations. RM uses a non-expert in-water survey template. RHIS performed by trained personnel, using in-water survey template. TW uses trained personnel to survey select sites on weekly basis.	Ad hoc application for most methods. *RHIS has been used to conduct large scale impact assessments*. *TW at limited number of tourism sites*	TW includes time-series monitoring of tourism sites Observer consistency at TW monitoring sites Potential to correlate in situ aesthetic responses from visitors to Tourism Weekly sites. Time-series archive(s) of geotagged imagery	No aesthetic response data or experiential characteristics
GBR Health Monitoring and Training Project (Citizen Science collaboration between GBRF, GBRMPA Eye on the Reef, AIMS, ReefTeach, Citizens of the GBR)	New protocol developed by AIMS for GBRMPA's Eye on the Reef Tourism Weekly Program, utilising digital photos and AI/ML analysis of coral taxa.	Program currently in piloting stages *Limited number of tourism sites; 6 monthly sampling intervals*.	Focus on habitat health monitoring but potentially adaptable to include aesthetic values Tourism stewardship and education component Digital image indexed archive (in development)	Pilot testing phase Digital images are downward-facing for analysis of benthos only; does not include 'swimmer perspective' views of habitat.
Mangrove Watch	Monitors estuarine and coastal habitats including mangroves, saltmarsh and saltpans. Different groups conduct surveys in different regions of the GBR. Utilises GPS-linked video assessment method.	Different areas with ongoing annual monitoring for multiple years; region specific. *Several major coastal regions in WHA*	One of the few programs that surveys mangrove & other coastal habitats. Video footage archive amenable to post hoc assessment of aesthetic characteristics	No aesthetic response data or experiential characteristics included.

Monitoring / assessment activity	Description of approach / method	Periodicity; *scale(s)*	Relevance to aesthetics monitoring / assessment	Limitations for aesthetics monitoring / assessment
QPWS Health Checks for natural and visitor values	Part of QPWS Values-Based Management Framework. Includes check list of indicators for long-term monitoring linked to direct management actions.	Site-specific; risk-based approach to monitoring frequency, based on threats to values. *Island National Parks within WHA*	Potentially the only systematic monitoring of natural and visitor values for island National Parks. Natural values checks include relevant environmental attributes Visitor values checks include condition of infrastructure, access, visitor footprint, rubbish, etc.	No aesthetic response data and limited experiential characteristics
Seagrass Watch	International program for monitoring of seagrass sites, includes participation in 19 countries. Maps and monitors seagrasses, condition and resilience.	Multiple annual surveys at most sites since 2005 *29 sites in GBR adjacent to key catchment areas*	One of the few programs that surveys seagrass habitats.	No aesthetic response data or experiential characteristics included.
Tangaroa Blue	Community-based NGO dealing with marine debris. Clean-up events include monitoring of quantities and types of anthropogenic debris.	Multiple annual events *Beaches and islands, GBR-wide*.	Quantity & type of debris likely to correlate with aesthetic value (cf. Appendix 1)	No aesthetic response data or experiential characteristics included.
Great Reef Census (partnership between Citizens of the GBR, RRRC, GBRMPA, AIMS and UQ)	Large-scale citizen science initiative (proposal) to engage wider community in an annual census recording GBR values and health	Proposed annual GBR-wide census *Scale TBA*	Potential for broad community participation.	Program in development stages.
Virtual Reef Diver citizen science project (led by QUT)	Online repository of digital reef images, mapped to GPS locations, enabling citizen scientists to classify coral types.	Time series of imagery not specified. *Limited sites based on small number of photo contributors*	Potentially useful digital image archive	No aesthetic response data or experiential characteristics included
Assessing an ecosystem's beauty using VR (part of Virtual Reef Diver; led by QUT; cf. Vercelloni et al., 2018)	Research project using VR headsets and 360-degree coral reef image sets to elicit aesthetic responses.	Discrete research study *Scale N/A – study based on a small image set*.	Experimental method for evaluation of 360-degree image sets.	Aesthetic response limited to binary Y/N re: aesthetic appeal of settings. Visual assessment only Feasibility for scaled-up monitoring uncertain.
Reef Check Australia	Trained volunteers conduct transect-based surveys of fish and coral communities. Consistent & scientifically reviewed survey methods and long-term database.	Periodic surveys in GBR since 2001. *Numerous sites across GBR*	Includes anecdotal descriptive data of survey sites, as well as impacts, faunal presence and corals.	No aesthetic response data, limited experiential characteristics.

Monitoring / assessment activity	Description of approach / method	Periodicity; *scale(s)*	Relevance to aesthetics monitoring / assessment	Limitations for aesthetics monitoring / assessment
RIMReP Indigenous Heritage Expert Group: "Strong People, Strong Country" framework	Indigenous and Traditional Owner-driven holistic monitoring framework, encompassing range of country health indicators	Program currently in early implementation stages *Scale TBA*	Potential complementarity of some indicators for environmental and experiential characteristics.	Integration opportunities yet to be explored.
Coral Watch (led by University of QLD)	Non-expert, citizen science program based utilising flexible surveys protocols and an app for data entry. Focus on corals and coral health.	Ad hoc citizen-driven monitoring GBR sites since 2002. *Distributed sites across major regions of GBR*	Includes coral colour data and some environmental characteristics	Limited additional recording of environmental attributes. No aesthetic response data or experiential characteristics
Marine Monitoring Program – GBRMPA led program for inshore GBR areas.	Monitors condition and trend of inshore water quality, seagrass meadows and coral reefs. Synthesises data from other programs (e.g. Seagrass Watch, AIMS LTMP, RHIS).	Annual routine monitoring since 2005 *Multiple annual sampling of >28 sites adjacent to key catchments*.	Clear water is correlated with aesthetic responses (Marshall et al. 2019). One of the few programs that surveys seagrass habitats. Has an image archive from fixed monitoring sites.	No aesthetic response data or experiential characteristics included.
NESP TWQ Projects 3.2.3 and 5.5 (Becken et al.): Artificial Intelligence / Machine Learning image assessment	NESP Project developing an AI/ML tool for analysis of aesthetic values in digital images. Potential application in analysis of social media imagery; plus analyses of any indexed digital photo archives (e.g. AIMS LTMP)	Still in developmental phase *Scale TBA (adaptable to input data)*	Potential for AI to also identify and correlate environmental attributes with aesthetic ratings Enables benchmarking of human vs. computer assessments (for same images)	Development & training phase Visual assessment of images only No experiential component
NESP TWQ Project 3.2.4 (Marshall et al.): Non-expert "rapid" image assessment online survey.	Research project to evaluate suitability of non-expert aesthetic ratings of coral reef imagery. Identified significant correlations between aesthetics ratings and environmental attributes. Identified correlation between reef health and non-expert aesthetics ratings.	One-off research survey *Scale N/A.*	Non-expert rating method enables cost-effective, scalable monitoring. Enables benchmarking of human vs. computer assessments Includes some contextual information on respondents for bias analyses	Visual assessment of images only Limited number of attributes tested so far using this method

Inferring aesthetic value from environmental attributes

We note that while many of the programs and assessment processes identified in Table 2 (above) do not collect or use experiential or aesthetic response data, there is a potential for proxy metrics of relative aesthetic value to be derived from measurements of the state of environmental attributes (e.g. those hypothesised in Appendix 1), provided the relative contribution of those environmental attributes to aesthetic responses is known.

However, the use of a small set of proxy attributes to infer aesthetic value might not enable sufficient differentiation between sites/periods that otherwise have varying aesthetic appeal and value. For example, low water clarity is correlated with lower aesthetic response ratings (Marshall et al., 2019b) and is a common attribute among inshore reefs and islands. Thus the identification and validation of multiple aesthetically linked environmental attributes for different habitat types will be important for differentiating between such sites and for monitoring change over time. This can be achieved via further experimental studies in different settings, and/or through the accumulation of aesthetic responses and experiential data accompanying the monitoring of environmental attributes.

4.2 Identifying suitable metrics for aesthetic responses

Aesthetic response constructs

As outlined in our introduction (Section 1.1 “Measuring aesthetic response”), a range of scaled response constructs can be applied to study or monitor different dimensions of aesthetic value (e.g. beauty, uniqueness, pleasantness, inspiration, naturalness, harmony); however, the usefulness of particular constructs will vary between habitats and settings. For example a *‘natural–artificial/unnatural’* response scale may provide a useful metric for evaluating coral restoration/modified sites, but would be unlikely to yield useful comparisons of undeveloped/unmodified sites across most of the GBRWHA. The broad applicability and use of the *‘beautiful–ugly’* response scale in aesthetic studies spanning multiple decades (cf. Section 1.1) provides a sound theoretical basis for its use and importance as a key metric for long-term monitoring of GBR aesthetic values. Other constructs can (and should) be applied wherever applicable to enable an improved understanding of the effects of different environmental attributes; however, at minimum, the ‘beautiful–ugly’ construct can serve as a standard metric across all in-situ scenarios and post hoc analyses.

Scale length and labels

Choosing an appropriate scale length (i.e. number of response categories in a bipolar semantic differential scale) for social research and monitoring is an important decision that will ultimately influence characteristics of the data (Dawes 2002; Dawes 2008; Preston & Colman 2000). While five and seven-point Likert-type scales are among the most commonly used in social research, these scale lengths have been shown to be prone to cross-cultural and response style biases (Dolnicar et al., 2011). Odd-numbered scales provide a mid-point, which is often interpreted as a neutral option between opposite scale ends, while even-numbered scales feature no mid-point and present the respondent with a ‘forced-choice’ that is closer to one end or the other, thereby offering the opportunity for post hoc binary categorisation (e.g. for agreement-disagreement Likert-type scales) (Wohlwill 1976; Weijters et al., 2010). An empirical study on the pros and cons of different rating scale lengths found optimal levels of

test-retest reliability and discriminating power at scale lengths between seven and ten points, with respondent preferences being highest for the 10-point scale (Preston & Colman 2000). Rescaling of responses (e.g. extrapolating scores from a five-point to ten-point scale, or vice versa) can be performed for post hoc comparisons with other (comparable) datasets; however, this can result in small but potentially significant shifts in the counterfactual mean value and response distribution (Dawes 2002). An empirical study comparing the distributions of different scale lengths has also found that the 10-point scale format will usually produce slightly lower scores than corresponding 5-point and 7-point formats (Dawes 2008).

The style and wording of anchor labels for response options on rating scales can also have significant effects on the distribution of data and observer biases. For example, the use of fully labelled response options (i.e. each number on the scale is labelled) has been found to be associated with higher levels of *net acquiescence response style* (i.e. respondents' tendency to indicate agreement/positive responses), but lower levels of *extreme response style* (i.e. respondents' tendency to give ratings at the extreme scale ends; Weijters et al., 2010). The use of endpoint (only) anchor labels is a common approach for rating scales with more than five response options, and the numbered intervals are generally assumed to represent equal increments between the opposite scale ends. In such cases, strong anchor label wording (e.g. "*very* ugly", "*exceptionally* beautiful") is typically used to normalise the distribution of responses and improve discriminatory power; however, respondent interpretations of rating scales are always relative to the subject matter and survey context, and as such it is important to examine the resulting data to ensure its validity, and to evaluate potential response biases (Lam & Stevens 1994; Weijters et al., 2010; Picardi 2017).

We note that the above scale design issues were among the methodological considerations in the preceding study by Marshall et al. (2017; 2019b), which used a ten-point beauty rating scale (from 1="very very ugly", to 10="very very beautiful") to elicit aesthetic responses to coral reef images. While this construct and scale have a sound theoretical unpinning, its ability to detect change (i.e. precision and sensitivity) in long-term monitoring, the minimum sample requirements, and associated observer biases were important issues that required further examination to understand its efficacy and limitations. In the following section, we report on our investigation of the suitability of this aesthetic response metric for use in long-term monitoring and for informing decision making; encompassing statistical design and sampling requirements, and observer biases that may affect the reliability and interpretation of results.

5. STATISTICAL DESIGN REQUIREMENTS FOR USE OF NON-EXPERT AESTHETIC RATINGS IN MONITORING

This project component evaluated the suitability of non-expert ratings of aesthetic beauty for monitoring purposes. A manuscript providing a detailed description of the aims, methods, results and discussion points was published in a peer-reviewed scientific journal (Pert et al., 2020)[11]. A summary of the key outcomes and findings from this study is provided below.

Abstract

"Aesthetic values are a key driver of tourist and recreational visitation to natural areas and are listed among the selection criteria for World Heritage properties. However, assessment and monitoring of aesthetic values in natural areas, and coral reefs in particular, have proven to be challenging. In our study we explored the value and limitations of a rapid assessment approach involving non-expert ratings of aesthetic beauty as a potential tool for long-term monitoring of aesthetic values in the Great Barrier Reef World Heritage Area, Australia. We investigated the sensitivity of a rating scale for detecting change and sampling requirements for monitoring, as well as observer biases, using an online survey of 1417 Australians in which respondents rated the aesthetic beauty of 181 coral reef images on a ten-point scale. Our results show average aesthetic rating scores ranged from 4.35 to 8.34 on a scale from 1 (ugly) to 10 (beautiful), with potential to detect differences of statistical significance within one point, indicating sufficient sensitivity to change for monitoring purposes. We found that a sample size of c.100 ratings per image provided a reasonable balance between cost (i.e. sample size) and accuracy (i.e. error). Older respondents (>65 years) with higher levels of coral reef visitation, experience and interest were more likely to give extreme ratings, however, there was no apparent predictor for this bias to be positive or negative (high or low ratings). Based on these results we provide recommendations to assist coral reef managers in their use and interpretation of non-expert aesthetic ratings in coral reef monitoring." (Pert et al., 2020)

Background and aims

Previous research by Marshall et al. (2017; 2019b) utilised an online survey of 1,417 Australians, each of whom provided ratings of aesthetic beauty (i.e. their aesthetic response) for a selection of 40 coral reef images, drawn at random from a pool of 181 images depicting reef scenes with specific attributes shown to varying degrees. The researchers found significant positive correlations between non-expert aesthetic ratings and (i) water clarity, (ii) fish abundance, and (iii) coral topography, suggesting that these environmental attributes are useful indicators of relative aesthetic value, and that non-expert aesthetic response ratings are potentially useful for monitoring purposes.

In this study, we sought to answer the following questions:

1. Is the discrimination power of non-expert aesthetic beauty ratings sufficient for detecting changes in relative aesthetic value between coral reef settings?
2. What are the sampling requirements for this method to provide reliable information for management decision making purposes?
3. To what extent are the ratings subject to observer biases, and how can such biases be accounted for or treated?

[11]Available at: https://doi.org/10.1016/j.scitotenv.2020.139156

Methods

We re-analysed the data collected by Marshall et al. (2017)[12]. Analyses performed on this data set included, firstly, an examination of the rating scale sensitivity, as applied in this context, by examining the frequency distribution of mean aesthetic scores and 95% confidence intervals. Secondly, a power analysis was performed by systematically and repeatedly calculating the 95% confidence interval at varying sample sizes, from n=3 up to n=381 respondents in increments of two, in order to determine the median error for each image at each sample size. Thirdly, to investigate observer biases, we applied a linear mixed effect model to assess how image scores were related to descriptive covariables (e.g. demography, coral reef knowledge/familiarity, level of visitation) that were hypothesised to influence the aesthetic score.

Key findings and implications

1. The mean aesthetic rating score for all 181 images was 6.86 (mode = 7), ranging from 4.35 to 8.43 (n=381 respondents per image at minimum).

    - *Implication:* There was a slight positive skew in aesthetic response ratings for this image set. Other image sets may produce a different distribution of responses.

2. All images received ratings along the entire scale from 1 to 10 (i.e. even those images that received the highest and lowest mean ratings).

    - *Implication:* This result reinforces the notion that non-expert aesthetic responses are inherently subjective, and individual responses cannot be assumed to be representative of a larger cohort.

3. The 95% confidence interval (CI) at n=381 ratings per image was approximately ±0.4 on the 1-10 scale, allowing the detection of a statistically significant difference between two images rated at greater than 0.8 apart from each other on the same scale. Modelled 95% confidence intervals at different sample sizes from n=3 to n=381 produced an error (95% CI) of ≤0.8 at n=100, and an error (95% CI) of ≤0.43 at n=300. Samples larger than n=300 contributed diminishing reductions in the standard error.

    - *Implication:* The target sample size for non-expert observers/respondents contributing aesthetic response ratings is an important consideration in the monitoring program design. The ability of this method to detect a statistically significant difference/change of ~1.6 points on the 1-10 scale requires a sample of c.100 respondents. Smaller samples will provide less precision and sensitivity to detect significant change, while larger samples will provide incrementally smaller improvements in both precision and sensitivity.

[12] Data set availability and citation: Marshall, N., Marshall, P., Smith, A., Visperas, B., Pert, P. & Curnock, M. (2019): Great Barrier Reef Aesthetics Indicator Study 2017 Ratings. v1. CSIRO. Data Collection. Publicly available at https://doi.org/10.25919/5cee318edd4bc

4. Investigation of observer biases in aesthetic response ratings showed that approximately 5% of respondents consistently provided "extreme" ratings (i.e. systematically scored ≥2.9 points above or below the mean score). These respondents were more likely to: (i) be >65 years of age, (ii) visit the GBR more frequently, and (iii) self-identify as having a higher level of interest and experience with coral reefs (significant differences from the remaining cohort at $p<.05$). For respondents with these characteristics, the direction of bias (either positive or negative) could not be predicted.

    - *Implication:* This finding provides important context for analysis and evaluation of non-expert aesthetic response data. "Extreme response style" ratings given by such respondents will inflate the mean error. Those analysing or interpreting such data could consider different options, including treatment of the data (e.g. outlier removal, or log transformation for comparing skewed distributions), or deciding to use a 90% confidence interval (rather than 95% CI) for statistical tests.

Take home messages

1. The key findings and implications above provide important contextual information on the use of non-expert aesthetic response ratings for monitoring. These findings can provide guidance on sampling design, now that caveats associated with different sample sizes and inter-observer biases are better understood.

2. A key assumption is that the response characteristics and distribution of ratings from this survey data set (i.e. based on image assessments) will be more broadly applicable – including applicability to non-expert in-situ aesthetic responses (i.e. people's aesthetic responses in an environmental setting). This assumption can be tested, once sufficient in-situ data are collected, as long as adequate contextual metadata (e.g. observer/respondent characteristics) are recorded with the aesthetic responses.

3. Further comparisons and assumption testing will become possible if/when in-situ observer data is accompanied by digital imagery, collected from the same setting and time as the observer response(s), to enable post hoc human and/or computer assessment. Implementing such data collection does not seem logistically unfeasible and several monitoring programs already follow similar protocols (cf. Table 2 above).

Based on the above and preceding sections, recommended monitoring protocols are outlined, and implementation opportunities are identified in the next section.

6. MONITORING PROTOCOLS AND IMPLEMENTATION OPPORTUNITIES

This section provides recommended protocols for monitoring data collection, storage and curation of: (i) in-situ aesthetic response data (including by non-expert and expert observers), and (ii) digital imagery for post hoc human and/or computer assessment. For computer assessment of digital images, we refer to outcomes of NESP TWQ Project 5.5[13] (and a forthcoming report by Becken et al., in prep), and we note a collaborative effort between our two projects and staff from AIMS to develop an online image storage tool, to be hosted by eAtlas[14], to facilitate such post hoc assessments. We outline additional considerations relevant to data curation via a suggested (and simplified) relational database schema encompassing the variables described below, in Appendix 4.

Trial implementation phase

Due to the nascent stage of aesthetics monitoring, and a lack of in-situ data and field-tested protocols, it is considered prudent that the implementation of any routine monitoring be preceded by a phase of trial implementation with accompanying research and development. Such a phase would ideally include field trials across a range of candidate programs, to assess the suitability of in-situ protocols under different scenarios, and would include comparative analyses of data to inform the selection of appropriate and sustainable data collection methods, and the development of protocols for data curation and sharing to meet the requirements of RIMReP. Hypothesis testing of key assumptions (e.g. the contribution of environmental attributes to aesthetic responses in different habitats) during this phase would also enable the identification/confirmation of proxy indicators from other biophysical monitoring programs (cf. Table 2 above). Below we provide a range of recommended protocols that address the requirements identified through our literature review and research process, that aim to guide further research and development leading to the establishment of long-term routine monitoring.

6.1 In-situ aesthetic response data collection

Environmental characteristics

Sufficient information is needed to describe dominant attributes in the environmental setting that are likely to influence an observer's aesthetic response. Such attributes will differ between habitats and settings (cf. Appendix 1), and as such, bespoke data collection instruments will likely be required. Comparisons between different habitat types may still be possible, where common attributes exist.

[13] NESP TWQ Hub Project 5.5: Measuring aesthetic and experience values using Big Data approaches. Project webpage at https://nesptropical.edu.au/index.php/round-5-projects/project-5-5/

[14] eAtlas is a website and mapping system for presenting environmental research data for the GBR and other northern Australian regions. Details available at: https://eatlas.org.au/

Site description data/metadata should include the following fields:

1. Date & time of observation
2. Pinpoint observer location (GPS coordinates)
3. Define assessment area (e.g. polygon over map)
4. Classify habitat type (e.g. coral reef, sand cay, mangroves, continental island)
5. Classify observer viewpoint (e.g. underwater, surface level, elevated or aerial view)
6. Identify and classify human infrastructure and level of human presence within setting
7. Identify and classify dominant environmental attributes (cf. Appendix 1 and Figure 1)
8. Classify weather conditions and sea state

These items should also be included in metadata accompanying photographs if/when taken at the setting at the same (or similar) time as the observer's in-situ aesthetic response. Protocols for collection and collation of digital imagery are provided in Section 6.2.

Experiential characteristics

Numerous experiential characteristics will influence an observer's aesthetic response to a setting; however, not all of these characteristics are easily quantified (e.g. expectations, knowledge, emotional response, cultural background; cf. Figure 1), and a degree of variability between observers is an inherent characteristic in aesthetic responses. However, as noted in Section 5, the observers' demography and experience level (i.e. familiarity and understanding of coral reefs) are important and relatively easily quantified variables that have been shown to influence 'extreme' responses. We therefore recommend capturing the following data/metadata fields for the *minimum* descriptive information that can help to provide important context to the aesthetic responses:

1. Unique respondent ID (e.g. name, initials or assigned unique number)
2. Respondent age
3. Respondent gender
4. Respondent nationality (i.e. country of residence)
5. Classify level of self-rated 'coral reef experience' (e.g. see Figure 4 below).

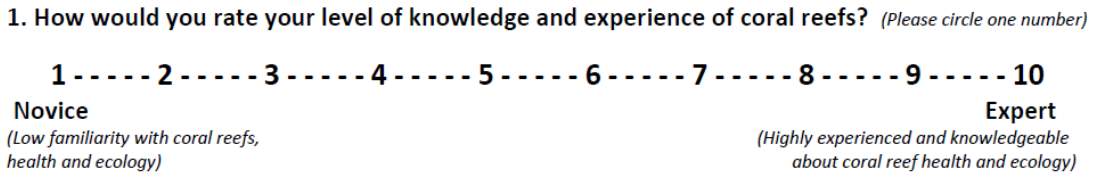

Figure 4: Coral reef experience rating scale (adapted from Marshall et al., 2017; 2019b)

Note that collection and storage of the above personal data from respondents must first be reviewed and approved by a human research ethics committee from an accredited institution and may be subject to conditions. It may also be appropriate to note on survey instruments that items 2-4 above are optional for respondents.

Aesthetic response metric

For reasons discussed in previous sections (cf. Section 1.1; Section 4.2; Section 5) we advocate the use of a ten-point *beauty* rating scale as a standard metric for observers' in-situ aesthetic responses and for post hoc aesthetic ratings of images. In Figure 5 (below) we have modified the anchor label wording from that used by Marshall et al. (2017; 2019b); whereby 1= "very very ugly" has been changed to 1="very ugly, unpleasant" and 10="very very beautiful" has been changed to 10="exceptionally beautiful". The addition of the *unpleasant* construct at the scale bottom reflects the notion that unmodified settings in the natural environment are seldom perceived as ugly (Tuan 1974; Carlson & Lintott 2007), and the intent of this weaker wording is to enable greater discriminatory power. At the top end of the scale, the replacement of "very very" with "exceptionally" removes redundancy, and the stronger wording is again intended to improve discriminatory power. However, further statistical analyses (cf. Pert el al., 2020) will be required to determine the effects of this wording on the response distribution.

Figure 5: Aesthetic response rating scale (adapted from Marshall et al., 2017; 2019b). Respondents would be asked: "*Please rate the aesthetic beauty of this place by choosing one number on the scale.*"

The use of additional constructs can and should be applied where relevant and/or pertinent to site-specific issues. For example, at coral restoration sites:

- "*Please rate the **naturalness** of this site by choosing one number on the scale: 1=very unnatural, artificial; 10=very natural*"

In some cases, Likert-type scales of *agreement* may provide more intuitive/accessible wording for some constructs in particular settings (e.g. harmony, interest, originality, uniqueness), and this approach enables multiple constructs to be assessed more efficiently by respondents, via use of the same scale anchor labels. For example, at underwater art sites:

- "*For the following statements, please rate your level of agreement or disagreement by choosing a number of the 10-point scale (where 1=very strongly disagree, and 10=very strongly agree):"*
    - *"The underwater art at this site is in **harmony** with the natural surroundings."*
    - *"The underwater art at this site is **original/unique***"

In addition, there is valuable contextual information that can be gained by following the aesthetic response rating(s) with an open-ended query, such as "What contributed most to this rating?" Short text responses can be categorised (e.g. into environmental and experiential characteristics/attributes) to enable subsequent quantitative and statistical analyses.

6.2 Image data considerations and metadata requirements

To enable comparative analyses and benchmarking of in-situ and image-based (post hoc) human and computer assessments, it will be necessary for digital images (photos or video) to be collected from those GBR sites at which observer aesthetic response ratings are simultaneously collected (i.e. from the same location at approximately the same time). While post hoc assessments of digital images will not account for the full range of experiential characteristics, correlations between human and computer rating scores, and the visible environmental attributes in images should be achievable when sufficient data are accumulated, as demonstrated by Marshall et al. (2017; 2019b).

Images not accompanied by in-situ assessments (e.g. from citizen science photo-monitoring, photo/video surveys, image archives, and social media posts) can still provide useful data for post hoc aesthetic assessments, and can contribute to trend analyses, provided they are accompanied by sufficient metadata. It is important to note, however, that online geo-tagged images, often shared across social media, disproportionately represent areas that are more highly valued for their aesthetic attributes (Casalegno et al., 2013).

Recommendations are made below on image data collection and metadata requirements to facilitate optimal image assessment outcomes.

Observer perspective

The viewpoint and perspective represented in a photograph is an important consideration for its use in a post hoc assessment of *environmental* attributes that contribute to an aesthetic response. Note that most of the contributing *experiential* characteristics cannot be inferred from the contents of an image, other than the observer's viewpoint, and in some cases the observer's activity (e.g. for underwater or aerial images; cf. Figure 1). Considering this, appropriate photographs and video footage should, as far as practicable, depict a viewpoint and perspective that an 'ordinary' human observer would likely experience in that setting. Extremely close-up images of small objects/animals in a small area (e.g. 'macro' images of a single coral colony) or of substrate only are less likely to be *representative of the setting* (and thus the aesthetic response evoked within the setting) than wide-angle images depicting a larger area/space.

Image quality

With the increasing availability and declining costs of high-quality consumer camera equipment, the general qualitative distinction between 'professional' and 'amateur/enthusiast' imagery has diminished (Mustard 2016). Nonetheless, differing levels of photographer experience and the type of equipment used (e.g. lens focal length and the use of artificial light) can impart different aesthetic characteristics to images, even if showing the same features taken from the same position at the same time. These effects are particularly pronounced in underwater settings, in which the visible spectrum of natural light from the surface is attenuated increasingly with depth, resulting in a loss of colour (see Figure 6 below, for example). For monitoring using digital imagery, the ability for assessments to draw on large quantities of images provides an opportunity for photographic artefacts to be accounted for in statistical comparisons, provided sufficient metadata accompanies each image.

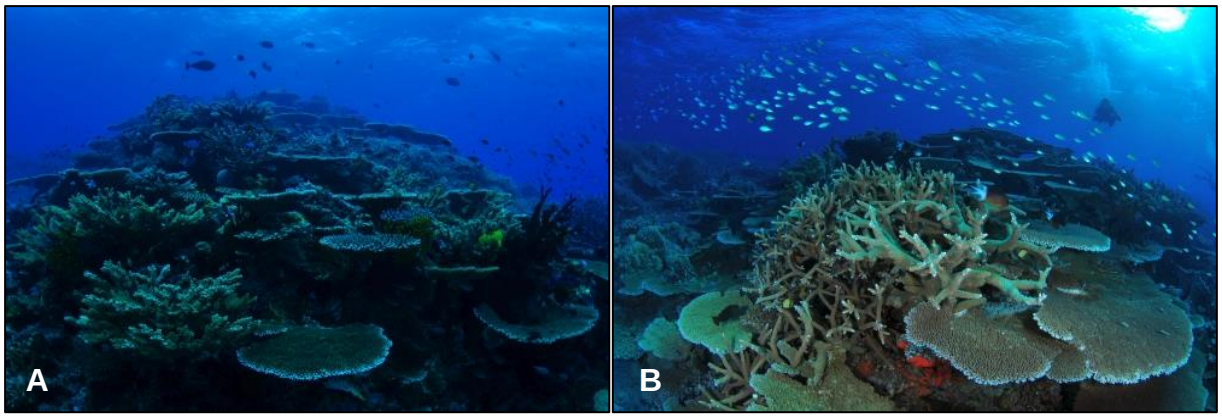

Figure 6: Comparison of underwater coral reef photographs, showing effects of artificial lighting on colours (and potential aesthetic appeal). Image A uses natural lighting from the surface only. Image B has artificial lighting added from underwater strobes. Images were taken at the same site at similar depth. Photos by Matt Curnock.

Image metadata requirements

Post hoc human and/or computer assessments of digital images will require the following basic metadata for both still and video imagery (categorised as either essential or desirable):

Essential:

1. Date and time of image capture
2. Location of image capture (NB. many camera devices have in-built GPS capability, however this function will generally not work underwater)

Desirable:

1. Contributor/photographer name
2. Contributor/photographer email address
3. Verify contributor is copyright owner (Y/N)
4. Agreement/consent to CC-BY licensing (Y/N; NB*. this agreement is required to facilitate post hoc analyses and potential publication of results*)
5. Number of images in batch
6. Use of artificial lighting (e.g. strobes) (Y/N)
7. An accompanying observer aesthetic assessment (i.e. the photographer/contributor gives a 1-10 rating in response to the question “Overall how would you rate the aesthetic beauty of this site at the time you took these images?”; cf. Figure 5 above)
8. Auto-assigned unique batch ID number for subsequent integration with other data)

To assist with computer image assessments, the following additional metadata is also desirable:

9. Image content and location descriptive tags:
    - Classify perspective (e.g. underwater, sea level (above surface), or elevated/aerial
    - Classify habitat type (e.g. coral reef, coral/sand cay, continental island, mangroves, beach, mainland coastal zone, seagrass, or other).
    - Classify any built infrastructure or artificial features (e.g. shipwreck, art installation, coral restoration, debris/rubbish, mooring, tourist pontoon, jetty, other).
10. Keywords describing dominant environmental attributes shown in images (e.g. animals, coral types, fish types, human infrastructure)

6.3 Sampling design considerations

Accuracy vs precision

In scientific applications, the term *accuracy* refers to the *"closeness of a measurement to the true value"* (International Standards Organisation, 1994). Considering that aesthetic responses are individually variable, there can be no 'true value' that represents an absolute aesthetic value of a setting. Instead, it is more useful to consider the *precision* of aesthetic response monitoring data. *Precision*, according to the International Standards Organisation (1994; ISO 5725-1) refers to the "*closeness of agreement between test results*".

When interpreting results of non-expert aesthetic response ratings, the mean standard error (±SE) represents the closeness of agreement (i.e. *precision*) around a relative value that will vary in response to changed environmental and experiential characteristics. This precision, and the measurement's sensitivity to change, improves as the ±SE decreases with larger samples (non-linearly with exponential decay as reported in Section 5; Pert et al., 2020). A target/minimum sample size for each setting and time period is therefore an important consideration when using data derived from non-expert observers who provide one-off aesthetic assessments (as addressed in Section 5).

Sampling involving 'experts'

For assessments provided by 'experts'[15], who participate in repeat surveys of a small number of sites/settings, a degree of *precision* can be inferred based on their familiarity with the site(s) and ability to detect changes in environmental attributes over time. While a study by Vercelloni et al. (2018) found no significant differences in the aesthetic perceptions of three groups of observers categorised as (i) marine scientists, (ii) experienced divers, and (iii) citizens, our research (Pert et al., 2020) indicates a higher propensity for extreme aesthetic response ratings among observers with higher levels of coral reef knowledge and experience. Thus, the potential for observer bias remains and as such, individual expert observers' aesthetic responses cannot be assumed to be representative of a wider cohort. The involvement of experts in aesthetics monitoring is also less likely to meet the sampling requirements for non-expert one-off observer assessments (i.e. with fewer observers), limiting opportunities for statistical comparison.

However, the ability for an expert observer to systematically monitor individual site(s) over time can provide a relative measure that can be sensitive to change. Such observers may also be able to collect standardised digital imagery with their assessments, providing further opportunities for post hoc assessments (e.g. computer assessment) that can be compared with their in-situ aesthetic responses.

[15] Experts, in this case, are considered to be those people with sufficient knowledge and first-hand experience of the setting(s) they assess, who are able to detect environmental changes that may influence aesthetic responses. Such experts may include experienced tourism industry personnel, management agency staff, scientists, and long-term/regular volunteers who participate in GBR research and monitoring programs.

Sampling protocols for different scenarios

Due to the relative simplicity of the data collection protocols outlined above (when compared with those from other biophysical monitoring programs), we consider that their uptake by existing programs with established sampling designs represents the most cost-effective means of implementation at any scale. For other implementation scenarios (e.g. new programs), we outline some basic sampling protocols below to assist with their collection of standardised monitoring data that can contribute to broader comparisons:

1. Tourism operators at tourism sites:
    - Involves long-term 'expert' crew member(s) with high degree of site familiarity and extensive GBR experience.
    - The spatial and temporal sampling will likely vary between operators, depending on their capacity to participate.
    - Survey involves collection of image batch (still photos and/or video) that can be considered "representative" of the site overall, and includes key features that can be identified and photographed in each subsequent sampling period.
    - Repeat surveys and images at sites should be collected under the same weather and lighting conditions (e.g. time of day, cloud cover and wind conditions, tidal level), with the same camera equipment for consistency.
    - Images are uploaded to online repository with appropriate metadata and the observer's overall aesthetic response rating for the site for each survey.
    - Observer descriptive data are captured, including at minimum (i) age, (ii) gender, (iii) nationality, and (iv) self-rated 'coral reef experience'. Additional data may be used for participants who contribute multiple surveys over time, enabling log-in to an online repository and retrieval of their multiple entries (e.g. a username, email address, organisation).
    - Due to the likelihood of low sampling frequency for some sites, statistical analyses of the observers' in situ aesthetic response rating may not be possible; however, the response rating remains useful as a benchmark for post-hoc image analyses (human and/or computer).

2. Tourists at tourism sites:
    - Involves non-expert tourists with varying levels of environmental knowledge and experience, and different cultural backgrounds.
    - Likely to be spatially representative of only a limited number of tourism sites, but repeated/periodic surveys can potentially enable detection of longer-term trends.
    - On departure from the site, tourists are asked to complete a short survey giving their appraisal of the site overall, e.g. via a mobile device application. Offering an incentive may help to increase the response rate.
    - Respondents provide a single aesthetic response rating (or 'site beauty rating') for the site overall, and up to five keywords for site attributes features that contributed to their response.
    - The minimum accompanying observer descriptive data recorded includes (i) age, (ii) gender, (iii) nationality, and (iv) self-rated 'coral reef experience' (as per Figure 4 above).
    - Tourists who have taken photos during their visit are encouraged to upload images to a repository with minimum image metadata recorded (cf. Section 6.2).
    - Recognising that different tourism operations have different passenger capacities and site visiting frequency; it is desirable to maximise the number of respondents (sample size) for each site within defined sampling periods (e.g. quarterly, six monthly) to minimise statistical error (cf. Section 5).

3. Citizen scientists at long-term monitoring sites:
    - Involves volunteers who have undergone training, but with varying levels of environmental knowledge and experience.
    - The spatial and temporal sampling design will vary between programs.
    - An aesthetic response rating is provided by surveyors for the defined survey area on completion of their monitoring survey.
    - Observer descriptive data are captured, including at minimum (i) age, (ii) gender, (iii) nationality, and (iv) self-rated 'coral reef experience'. Additional data may be used for participants who contribute multiple surveys over time, enabling log-in to an online repository and retrieval of their multiple entries (e.g. a username, email address, organisation).
    - Photos and/or video collected during the survey are uploaded to online repository with appropriate metadata and the observer's overall aesthetic response rating.

4. Professional scientists at long-term monitoring sites:
    - Involves scientists who have undergone training, with extensive environmental knowledge and experience.
    - The spatial and temporal sampling design will vary between programs.
    - An aesthetic response rating is provided by surveyors for the defined survey area on completion of their monitoring survey.
    - Observer descriptive data are captured, including at minimum (i) age, (ii) gender, (iii) nationality, and (iv) self-rated 'coral reef experience'. Additional data may be used for participants who contribute multiple surveys over time, enabling log-in to an online repository and retrieval of their multiple entries (e.g. a username, email address, organisation).
    - Photos and/or video collected during the survey are uploaded to online repository with appropriate metadata and the observer's overall aesthetic response rating.

5. Scientists/resource managers sampling ad hoc (e.g. impact surveys):
    - Involves scientists/managers who have undergone training, with extensive environmental knowledge and experience.
    - Sampling typically for site/region specific impact assessment and potentially benchmarking recovery.
    - An aesthetic response rating is provided by surveyors for the defined survey area on completion of their monitoring survey.
    - Observer descriptive data are captured, as per above.
    - Accompanying images and metadata are captured, as per above.

6. Fixed video/photo monitoring stations:
    - Involves image data collected repeatedly over time from a fixed position.
    - May be automated (e.g. from a scientific monitoring station/tool) or involve non-expert visitor contributions (e.g. tourists upload to online repository)
    - Aesthetic response ratings can be provided by photo contributors, along with minimum observer descriptive data; and/or derived from post hoc analyses.

7. Social media image monitoring:
    - Involves geo-tagged and time-stamped image data uploaded to social media platforms.
    - Aesthetic response ratings derived primarily from post-hoc computer analyses;
    - Automated recognition and coding of visible environmental attributes is desirable.

6.4 Implementation opportunities

Here we identify a selection of existing GBR monitoring programs as examples that could potentially incorporate an aesthetics monitoring component, based on a review of their existing protocols and preliminary discussions with respective program managers (Table 3 below). This list is not exhaustive (cf. Table 2 in Section 4), and in all cases consultation with the program managers must precede the co-development and/or adoption of any new protocols. Such protocols will need to be adapted to suit the unique characteristics of each program, whilst ensuring standardisation and comparability of data between programs.

Table 3: Example GBR monitoring programs that could potentially incorporate aesthetics monitoring

Program	Expert / non-expert involvement & description	Relevant monitoring protocol(s)	How aesthetics component could be incorporated / enhanced	Potential value added through contribution to aesthetics monitoring
Reef Check Australia	**Expert** *-Involves trained volunteers*	RCA Methods Manual *–Geolocated transect surveys of substrate, invertebrates, impacts and fishes.*	-Addition of in-situ aesthetic response rating by surveyors -Collection of geo-located images representative of transect area, linked with in-situ responses	-Time series data for regularly sampled sites -Consistency in method applied -Public engagement
Great Reef Census	**Non-expert** *-Proposed large-scale snapshot reporting by broad cross section of GBR users*	**Under development** *– will include an online portal for participant contributions*	-Addition of geo-located in-situ aesthetic response rating by participants -Collection of geo-located images linked with in-situ responses	-Potential broad spatial coverage for annual 'snapshots' -Public engagement
GBR Health Monitoring and Training Project (intended to become a routine feature of Eye on the Reef Tourism Weekly Surveys)	**Expert** *-Involves experienced tourism industry personnel who participate in the Tourism Weekly program*	**Pilot Standard Operational Procedure** (González-Rivero 2018) *- Geolocated benthic photo surveys of Tourism Weekly sites*	-Addition of in-situ aesthetic response rating by surveyors -Addition of geo-located wide-angle images representative of survey area, linked with in-situ responses	-Tourism industry engagement -Time series data of high value tourism sites -Consistency in method applied
Social and Economic Long-Term Monitoring Program (SELTMP)	**Non-expert** *-Tourists and GBR region residents; includes one indicator of overall GBR aesthetic perception*	SELTMP survey design and methods *-Large scale community surveys of Reef 2050 human dimension indicators*	-Addition of region-specific aesthetic perception indicator -Addition of site-specific aesthetic perception indicator	-Broad community perceptions -Potential time series comparison -Correlation with GBR sentiments /stewardship
AIMS Long Term Monitoring Program (LTMP)	**Expert** *-Involves professional scientists undertaking systematic surveys of representative reefs across GBR bioregions*	Topographical and habitat descriptions *-Summary data from manta tows from four main zones of each reef (AIMS 2015)*	-Addition of in-situ aesthetic response rating by surveyors -Linkage of geo-located images with in-situ response	-Time series data -Historical archive for post hoc comparisons -Correlation with other attributes & Reef health

The five examples shown above (Table 3) represent a cross-section of potentially suitable options for initiating time-series aesthetics monitoring at a broad spatial scale, providing valuable information for aesthetic assessments that contribute to statutory reporting and benchmarking (e.g. Outlook reporting, Reef 2050 reporting, regional report cards). Among these, we note that the AIMS LTMP represents the most established, spatially representative, and long-term sustainable option from which data informing the assessment of GBR aesthetic values can be either collected, or inferred from images and other data describing the presence and state of environmental attributes.

While the *Great Reef Census* is a new initiative under development (with no guarantee of widespread uptake or longevity) it nonetheless represents a potentially valuable opportunity for trial implementation and experimentation with data collection tools and protocols involving citizen scientists.

The use of broad-scale social surveys by SELTMP provides an additional opportunity to understand and compare community perceptions with the state and trend of in-situ metrics, and to better understand the relationship between such perceptions and other important values and attitudes associated with the GBR.

In the next section we outline bespoke tools and protocols for monitoring of specific sites for specific purposes; for example: *benchmarking the recovery of impacted sites* (including coral restoration sites), and *evaluating the social acceptability and aesthetic responses to human made installations* (e.g. underwater art). These bespoke monitoring tools are designed to address specific management needs (as outlined in Table 1), and can potentially address proponents' needs for 'social monitoring' of works/installations, where required within the Marine Parks permissions system.

7. PILOT TESTING OF ASSESSMENT AND MONITORING TOOLS[16]

Background

In a global response to declining coral cover, novel management strategies such as coral restoration are being used in an attempt to assist with reef recovery and conservation (Bayraktarov et al., 2019; Fidelman et al., 2019). Factors that contribute to the long-term success of coral restoration initiatives include a better understanding of environmental, economic, governance and sociocultural elements (Hein et al., 2017). While coral restoration activities have been ongoing in many parts of the world for more than a decade, such initiatives are new to the GBR. With declining coral cover from large scale impacts such as mass bleaching and cyclone damage, reef recovery responses on the GBR are becoming more prolific (Condie et al., 2018; Fidelman et al., 2019).

Additionally, the GBR has recently seen its first underwater art installations, which aim to raise public awareness to declines in coral cover and reef conservation issues, whilst providing new visitor experiences (Picken 2015; Beans 2018; Robidoux et al., 2018). For example, the *Whitsunday Reef Recovery and Public Art Project* was initiated in response to cyclone damage impacting tourism opportunities in the Whitsunday Island. For reefs that have been severely impacted by cyclones, art creates additional attractions for tourists to visit the marine environment while the reef recovers.

At John Brewer Reef, offshore from Townsville, the Museum of Underwater Art has created a large-scale art installation made up of a coral greenhouse with many diverse sculptures of people and trees. The project's aim is to increase environmental awareness and instigate social change. Engaging with people who visit art installations presents an opportunity to measure experiences and aesthetic appreciation of art in the marine environment.

Pilot monitoring design

Reef Ecologic have developed and implemented social surveys, encompassing aesthetic values, to collect knowledge and provide advice on marine park management in Vietnam and Kiribati since 2017 (Reef Ecologic 2017a, b). Prior to the commencement of a large-scale aesthetic value monitoring program in the GBR, we undertook to implement a pilot study of in-situ aesthetic monitoring and digital photo assessments, to test the suitability of survey instruments and compare data across a range of coral reef sites, including sites undergoing coral restoration and featuring underwater art installations. Planning for the pilot study involved:

(i) a review of candidate sites for suitable comparison, based on environmental characteristics, the presence of existing (and potentially complementary) biophysical monitoring, and the potential for survey collection,

(ii) engagement with relevant tourism operators to scope in-situ data collection opportunities,

[16] This section was contributed by A. Smith, N. Cook and G. Molinaro from Reef Ecologic (https://reefecologic.org/), a registered company that provides a range of marine and coral reef monitoring, training and consulting services.

(iii) field assessment and image collection of site features that were considered likely to influence visitor aesthetic responses, and
(iv) Pre-pilot testing of survey instruments and protocols on an opportunistic basis.

From July 2019 to late January 2020, opportunities were taken to test survey questions in different survey formats at a broader range of GBR sites between Cairns and the Whitsundays, involving colleagues and volunteers who were involved in other citizen science, coral restoration and educational projects. The purpose of these pre-pilot 'test surveys' was to refine the wording and format of particular questions and identify optimal protocols for survey administration. In total, during this phase we collected 166 social surveys that featured aesthetic response questions. While the data provided by these pre-pilot surveys was informative for our refinement of the survey instrument and protocols, we did not achieve a sufficiently large sample at any site that would be representative of a baseline for any particular site, nor be suitable for statistical comparisons.

Once our pilot survey instruments and protocols had been refined, we intended to initiate the pilot study across three GBR sites, selected on the basis of key features and tourist visitation, to enable useful comparisons of aesthetic responses to different environmental settings and types on visible human intervention. Among these sites, John Brewer Reef was considered a particularly important site to include, based on (i) the recent installation of underwater art, and (ii) an exceptionally high proportion of live coral cover and abundant marine life surrounding the art installation – which we hypothesised would elicit high to very high ratings on the aesthetic response scale, potentially representing a benchmark for other coral reef settings. Unfortunately, by the time our pilot study was to commence (scheduled from March to May 2020; coinciding with the official opening and launch of the MOUA 'Coral Greenhouse' at John Brewer Reef[17]), the GBR tourism industry had shut down in response to the COVID-19 pandemic.

Below we present an overview of our pilot monitoring plan, with descriptions of each site, accompanying protocols and survey instruments (pilot survey instruments included in Appendix 5). It is intended that these surveys and protocols be implemented at an appropriate time when tourism operators have resumed activities at these sites.

Target sample sizes for each site are n=100 (minimum) over a defined period; e.g. with data collection occurring on multiple trips, occurring over one week for high visitation tourist site, or several weeks for a low-visitation tourist site such as John Brewer Reef. We also acknowledge the limitation that our visitor surveys are in English language only, restricting our ability to provide insights on cross-cultural differences in visitor perceptions and aesthetic responses.

[17] Official launched of Coral Greenhouse MOUA installation delayed until further notice. Further details available at: https://www.moua.com.au/covid-19-delays-museum-of-underwater-art-launch/

Site selection, monitoring objectives and protocols

Our selected coral reef sites were in various states of reef health with diverse levels of anthropogenic influences, as well as diverse habitats and features, to enable testing of assumptions that distinct environmental attributes and human interventions contribute to specific aesthetic reactions. Conducting social and aesthetic monitoring at sites that possess active interventions such as coral gardening would also allow us to evaluate the public response and assess the social acceptability and visitor perceptions of these initiatives, providing additional metrics for evaluating intervention outcomes.

We selected three coral reef sites for the proposed pilot study on aesthetic monitoring in the Cairns, Townsville and Whitsunday regions: (i) John Brewer Reef (Townsville region), (ii) Manta Ray Bay (Whitsundays region), and (iii) Moore Reef (Cairns region). Two of the sites featured human interventions; coral gardening and underwater art, enabling comparisons and potential insights to the effects of these attributes (see Figure 7). All three sites are considered high-value tourism sites; however visitation numbers vary and the sampling protocols at each site differ slightly (outlined below).

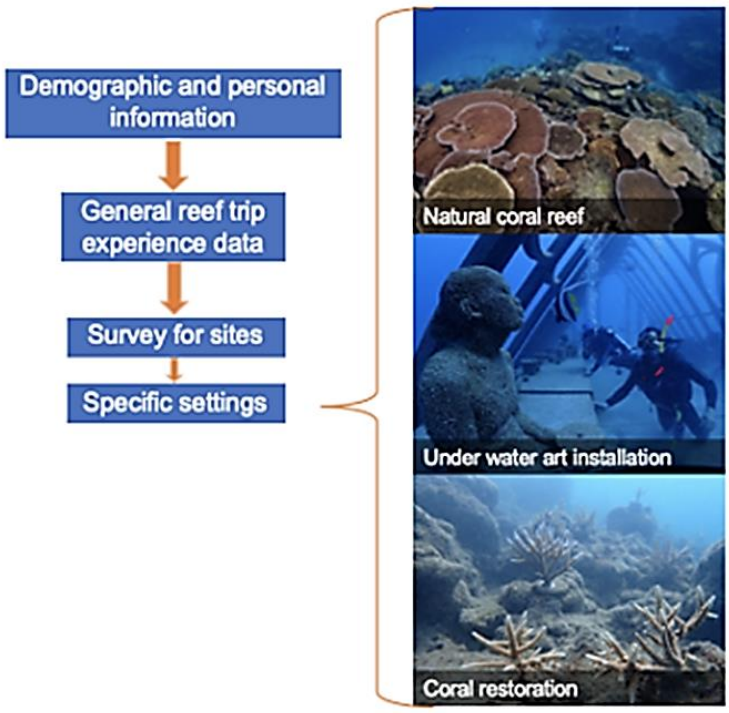

Figure 7: Overview of key attributes potentially influencing visitor aesthetic responses at the three GBR pilot study sites.

Common objectives for monitoring all three sites include standardised measure(s) of visitors' aesthetic response, demographic fields to account for minimum experiential characteristics, and categorisation of key environmental attributes that contribute to observers' aesthetic response, via open-ended survey question(s) and derived from compiled geo-located image data. Copies of the proposed pilot survey instruments are attached at Appendix 5 (a-d).

Site 1. John Brewer Reef (with MOUA art installation)

John Brewer Reef is situated 40nm offshore from Townsville and in late 2019 had a large underwater art museum installed on the northern area of the reef. The Museum of Underwater Art installation, “Coral Greenhouse” features a greenhouse building structure, surrounded by a number of smaller sculptures of people and a garden of trees (see Figures 8 and 9 below). John Brewer Reef is a large reef (14km^2) in a GBRMP Conservation Park Zone (Yellow), allowing a range of activities including recreational fishing and commercial extractive activities under permit. Despite being exposed to numerous pressures, including fishing and crown of thorns starfish predation, the coral surrounding the art installation remains in good health (as of May 2020).

Since the installation of moorings (suited for tourism operator use) in March-April 2020, local tourism operators are expected to bring snorkellers and scuba divers to explore this site and the surrounding reef, presenting a valuable opportunity to assess people's perceptions and engagement with the art and the reef. Trips to the site, however, are likely to be irregular and are subject to favourable weather conditions.

Key attributes at site:

- Underwater art installation
- Clear water, very high proportion of live coral cover and high fish abundance
- Low level of visitation and other infrastructure

Bespoke monitoring objectives (cf. Appendix 5a):

- Evaluate the relative contribution of underwater art to the visitor experience
- Assess visitor perceptions of artwork ‘harmony’ (i.e. relationship and ‘fit’ with natural surroundings) in-situ.
- Evaluate visitor perceptions and normative beliefs about the acceptability of artwork in the GBRMP
- Gauge visitor perceptions of the impacts of artwork in the GBRMP
- Assess potential benefits associated with the artwork in-situ (e.g. education, inspiration)
- Assess and correlate social acceptability of the artwork with aesthetic responses.

Sampling protocols:

- With the in-kind support of the tourism operator(s), vessel crew and passengers are briefed on the survey aims as part of the pre-departure briefing
- Self-administered (paper) surveys are distributed to passengers on board during the lunch break (after first dive/snorkel period) while the vessel is stationary (NB. there is likely to be insufficient time at the conclusion of in-water activities prior to vessel departure, and the variable sea surface conditions may make survey completion unfeasible).
- Crew member/researcher completes site visit overview survey form (see Appendix 5d), outlining weather conditions and visibility on the day. These metadata are subsequently merged with the visitor survey data.

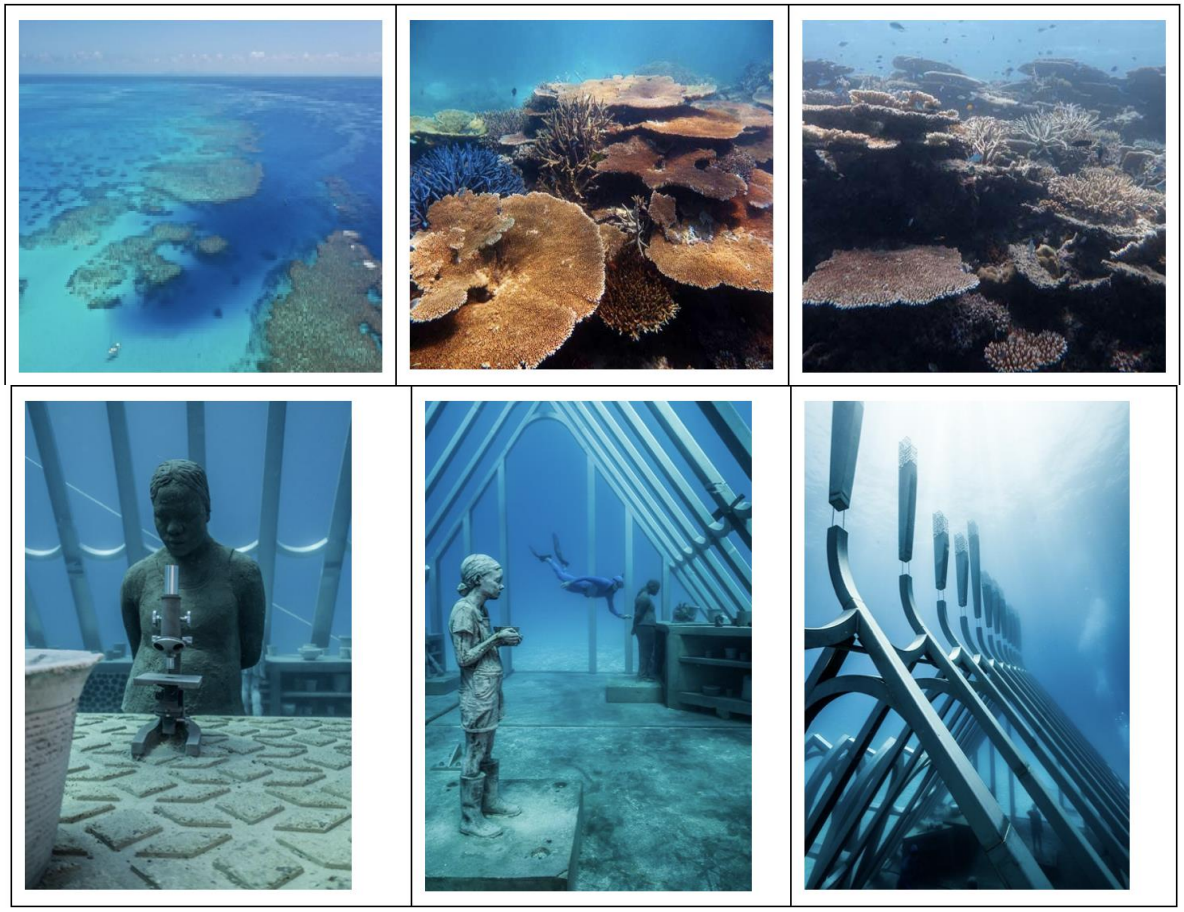

Figure 8: Images of John Brewer Reef and the MOUA Coral Greenhouse underwater art installation (photos by Reef Ecologic).

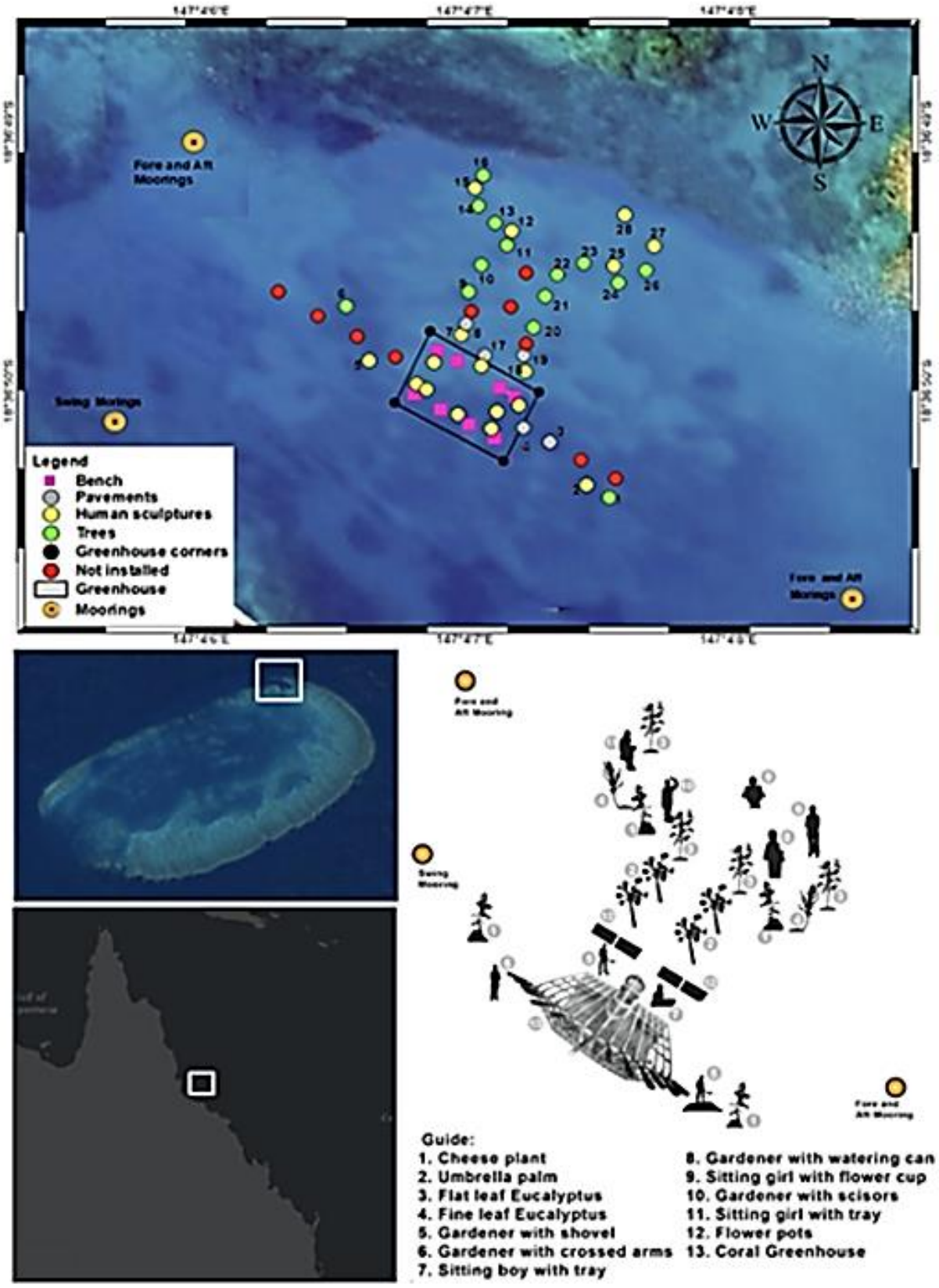

Figure 9: Location of John Brewer Reef and MOUA Coral Greenhouse underwater art installation features

Site 2. Manta Ray Bay, Hook Island

Manta Ray Bay is a fringing reef situated on the northern tip of Hook Island in the Whitsunday Islands (Figure 10 below). Manta Ray Bay is a popular tourism site in a GBRMP Marine National Park Zone (Green), that was heavily impacted by a Severe Tropical Cyclone Debbie in 2017, which reduced its coral cover extensively. Post-cyclone recovery projects to support the local tourism industry have included coral restoration activities to assist recovery of the fringing reef, as well as MOUA underwater art installations inspired by Indigenous stories of the islands (see Figure 11 below). Snorkelling is the predominant form of tourism in the bay, with visitors taking day trips around the island and viewing diverse reefs. Working with tourism operators, snorkelers will be surveyed to understand their perception of the underwater art, the coral nurseries and the general reef and marine life. As a recovering reef, data may be cross referenced with ecological data to investigate correlations with ecological interventions and changes in aesthetics ratings.

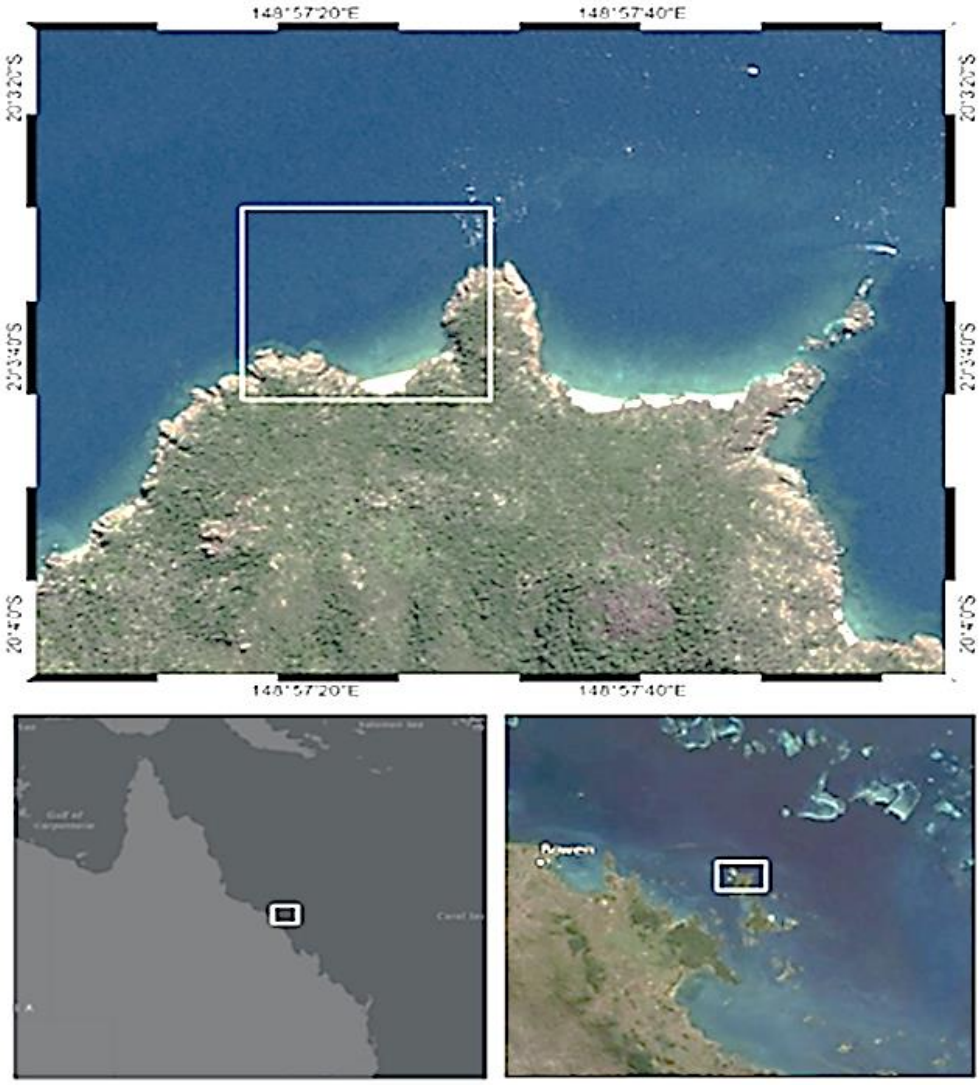

Figure 10: Location of Manta Ray Bay, Hook Island, Whitsundays

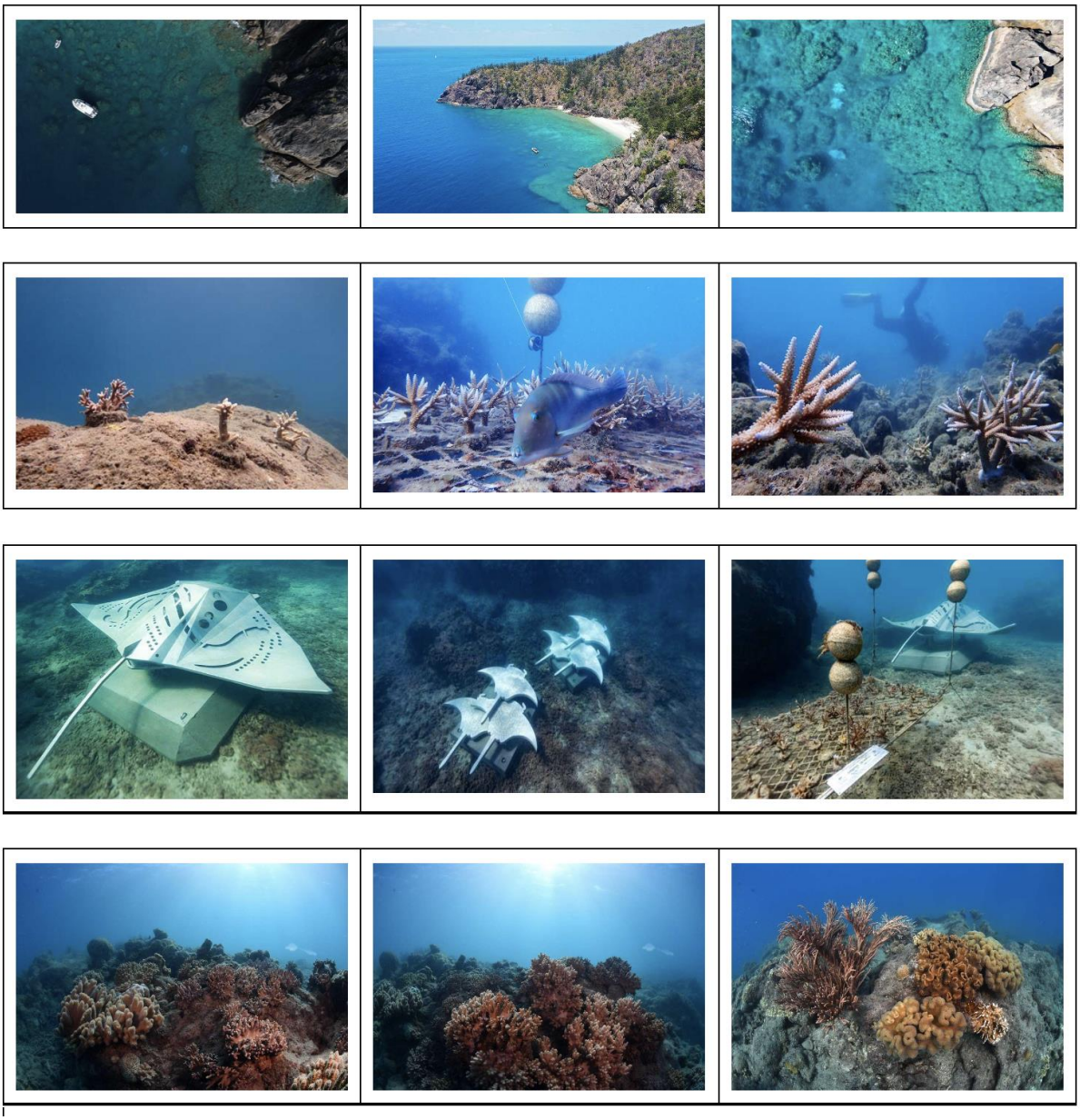

Figure 11: Images of Manta Ray Bay, including fringing reef, coral gardening works and underwater art installations (Photos by Reef Ecologic).

Key attributes at site:

- Coral gardening and restoration infrastructure present
- Underwater art installations
- Low to medium water clarity, low proportion of live coral cover, moderate fish abundance
- Moderate to high level of visitation and other infrastructure

Bespoke monitoring objectives (cf. Appendix 5b):

- Evaluate the relative contribution of underwater art to the visitor experience
- Evaluate the relative contribution of coral restoration to the visitor experience

- Assess visitor perceptions of artwork 'harmony' (i.e. relationship and 'fit' with natural surroundings) in-situ.
- Assess visitor perceptions of coral restoration 'naturalness' (i.e. mimicry and 'fit' with natural surroundings) in-situ.
- Evaluate visitor perceptions and normative beliefs about of the acceptability of artwork in the GBRMP
- Evaluate visitor perceptions and normative beliefs about coral restoration in the GBRMP
- Gauge visitor perceptions of the impacts of artwork and coral restoration in the GBRMP
- Assess potential benefits associated with the artwork and coral restoration in-situ (e.g. education, inspiration)
- Assess and correlate social acceptability of the artwork and coral restoration with aesthetic responses.

Sampling protocols:

- With the in-kind support of the tourism operator(s), vessel crew and passengers are briefed on the survey aims as part of the pre-departure briefing
- Self-administered (paper) surveys are distributed to passengers on board during the lunch break (after first dive/snorkel period) while the vessel is stationary (NB. there is likely to be insufficient time at the conclusion of in-water activities prior to vessel departure, and the variable sea surface conditions may make survey completion unfeasible).
- Crew member/researcher completes site visit overview survey form (see Appendix 5d), outlining weather conditions and visibility on the day. These metadata are subsequently merged with the visitor survey data.

Site 3. Moore Reef Pontoon (northern), Cairns.

Moore Reef is located 50kms east of the popular tourism city of Cairns (see Figure 12 below), in a GBRMP Marine National Park Zone (Green). Several large tourism operators undertake daily trips to this large reef, which also features several permanently moored tourist pontoons, at the northern and south-western ends of the reef. There is no underwater art or coral restoration present, and apart from the tourism infrastructure, the corals and marine life are presented in a natural state. This reef was impacted by coral bleaching events in 2016 and subsequent; however, some recovery of corals has occurred, and sites surrounding the pontoon(s) generally remain in good health (as at May 2020).

Key attributes at site:

- High visitation tourism site with pontoon, multiple vessels and associated infrastructure
- Clear water, moderate proportion of live coral cover, high fish abundance
- High number of tourists

Bespoke monitoring objectives (cf. Appendix 5c):

- "Control" site for comparison and benchmarking of aesthetic responses between sites.
- Assess effect of high level visitation and tourism infrastructure on aesthetic responses.
- Cross cultural aesthetic response comparison.

- Establish baseline for long-term monitoring of aesthetic response trends at site.

Sampling protocols:

- With the in-kind support of the tourism operator(s), passengers are briefed on the survey aims as part of the outgoing and return journey briefings, prior to survey distribution.
- Self-administered (paper) surveys are distributed to consenting passengers after site departure, on the return journey to Cairns (approx. 90-minute journey).
- An incentive (e.g. a free souvenir) may be offered to increase the response rate.
- Crew member/researcher completes site visit overview survey form (see Appendix 5d), outlining weather conditions and visibility on the day. These metadata are subsequently merged with the visitor survey data.

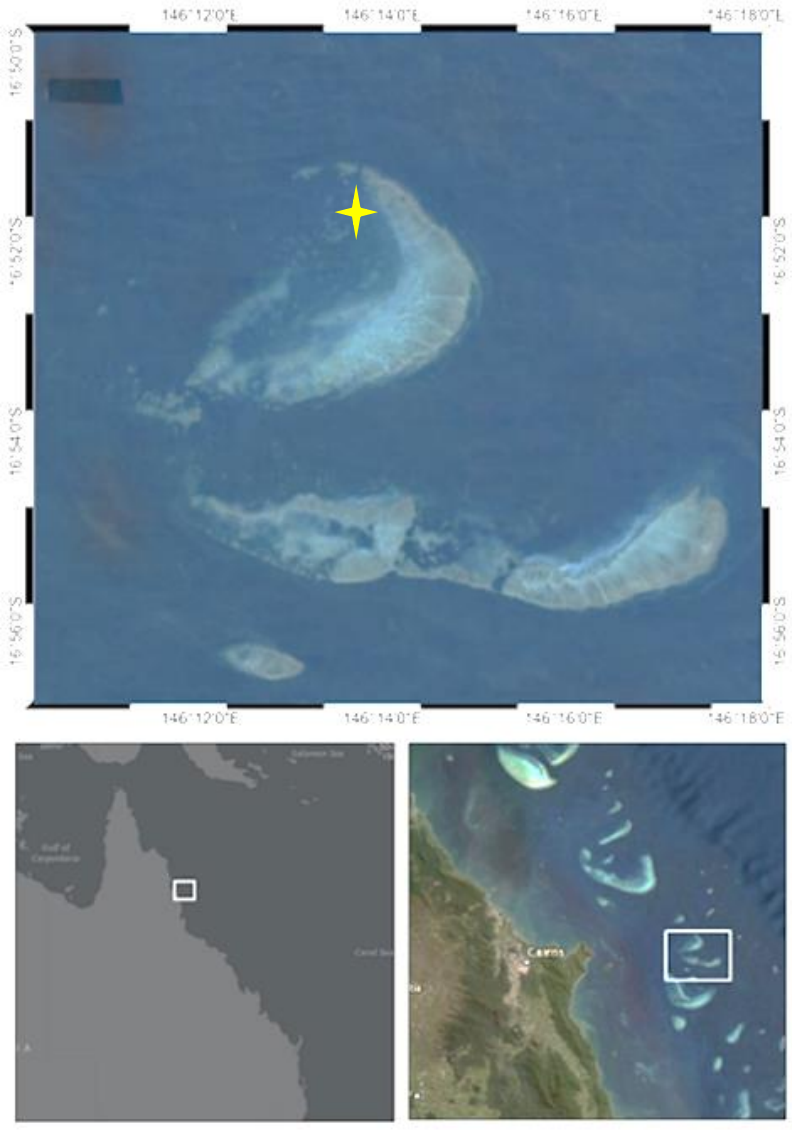

Figure 12: Location of Moore Reef and tourism pontoons

8. DISCUSSION AND CONCLUSIONS

Assessing the condition and trend of aesthetic heritage values for the GBRWHA is a substantial undertaking that requires a systematic and replicable process, and relies on the availability of standardised, representative time-series data. Context Pty Ltd developed and applied such a process in their 2013 assessment, and this report outlines the objectives, operational requirements, metrics and protocols for an Aesthetics Long-Term Monitoring Program (ALTMP) that can potentially contribute standardised, representative time series data to facilitate similar assessments in future. The implementation of an ALTMP, however, requires commitments from end-users, investors, stakeholders and monitoring data provider(s) within an agreed framework, matched with sufficient resources. While it was beyond the scope of this project to solicit such commitments, we note that strong in-principle support for the implementation of aesthetics monitoring in the GBR was widespread among stakeholders and end-users involved in our collaborative research process.

In addition to World Heritage, Outlook and Reef 2050 reporting, there are numerous other direct end-uses for aesthetics monitoring data (e.g. those identified in Section 3.3). We provide tools to address some of the present management information needs, including for benchmarking the recovery of sites undergoing restoration works, and for understanding the social acceptability of underwater art installations in the Marine Park (Section 7; Appendix 5). We note that bespoke monitoring instruments and protocols will likely be needed for different issues and other specific sites. By applying standardised protocols (e.g. as outlined in Section 6), such monitoring can potentially also contribute to aesthetic assessments at a broader scale.

Implementation recommendations

To achieve cost efficient monitoring with broad spatial coverage, the proposed protocols are adaptable and can be integrated in a range of existing monitoring programs. While engagement with leaders of some identified programs (e.g. those in Table 3, Section 6.4) occurred through this project, the capacity and willingness among existing programs to adopt new protocols has not been assessed. Further work and additional resources may also be needed to facilitate the integration of an aesthetics monitoring component in such programs.

However, more immediate ‘low-hanging fruit’ of particular value to aesthetic assessments are archives of geo-tagged digital images, which can potentially be made available for post hoc aesthetic assessments. While post hoc *human* assessments of large image sets might not be feasible or cost-effective, the potential for AI/ML assessment tools (e.g. that developed by Becken et al. for NESP TWQ Project 5.5) to rapidly process and evaluate image data streams from such archives is promising. To facilitate the collection, storage and retrieval of new images from other sources, we have been collaborating with colleagues from Project 5.5 and eAtlas to co-design an online portal and repository, which is in a developmental stage at the time of writing, but currently without specifically allocated resourcing to implement beyond a pilot/trial implementation.

As discussed in Section 6, we recommend that the commencement of routine, long-term monitoring be preceded by a trial implementation phase with accompanying research and development, that includes:

- Field assessment and refinement of in-situ monitoring protocols and instruments across candidate programs in different environmental settings,
- Statistical testing of hypothesised correlations between aesthetic responses and environmental attributes in different settings (e.g. those shown in Appendix 1; for the purpose of identifying/confirming proxy indicators that can help with the assessment of aesthetic value when inferred from the status of natural heritage values),
- Comparisons and benchmarking of in-situ aesthetic response ratings with post hoc ratings of images from the same setting(s),
- Comparisons and benchmarking of human aesthetic ratings of images with those generated by computer assessment(s), and
- Co-development of reporting and communication protocols with end-users, encompassing framing of negative trends (cf. Section 3.5), aggregation of scores for spatial regions, and rescaling of metrics for reporting in the Outlook Report, Regional Report Cards, etc.

The accumulation of aesthetics monitoring data over time should provide opportunities to test additional hypotheses and assumptions (i.e. 'process understanding'; cf. Table 1, Section 3.3) about (for example):

(i) the influence of educational content and delivery (e.g. by tourism guides) on in-situ aesthetic responses;
(ii) the influence of media representations on aesthetic responses and perceptions;
(iii) the influence of aesthetic perceptions on the social acceptability of GBR interventions; and
(iv) the influence of aesthetic perceptions of the GBR more broadly on community aspirations and environmental stewardship.

Embedding the above concepts and comparable variables in monitoring surveys (where relevant and possible) to enable hypothesis testing should be considered an important objective of both pilot studies and long-term monitoring, to help improve in our understanding of causal relationships between aesthetic values and other components of the GBR social-ecological system.

Future assessments of aesthetic heritage values for periodic Outlook and World Heritage State Party reporting will require comparisons of the current state of such values against historical benchmarks, including from the 1981 World Heritage listing (Context Pty Ltd. 2013; Tarte & Day 2019). A problem associated with such comparisons is that human perceptions of a natural ecological baseline will change over time, thus a perceived "healthy" setting may in fact be in a degraded state when compared objectively with its longer-term history. Such shifting baselines present a risk to the protection of heritage, as progressive environmental degradation goes unrecognised (Soga & Gaston 2018; GBRMPA 2019). Recommendations to address the problem of "shifting baseline syndrome" have included (i) calls for improved educational opportunities that increase people's (especially children's) familiarity with the natural environment, (ii) increasing opportunities and promotion of positive nature-based experiences and interactions, (iii) increased restoration and 'rewilding' of degraded environments, and (iv) increased effort and public engagement in environmental monitoring (e.g. via citizen science; Soga & Gaston 2018). The establishment of an ALTMP represents an opportunity to address some of these calls for action, and offers the potential to accumulate

and analyse large data sets of archival imagery (e.g. via AI/ML) that may assist with longer-term benchmarking of aesthetic heritage values.

As noted in our introduction, aesthetic values exist among a range of intangible human values and cultural ecosystem services provided by the GBR that are tied to ecosystem health. Considering the GBR's current *very poor* outlook (GBRMPA 2019) and the increasing threat posed by global warming (noting the occurrence in 2020 of the third GBR mass coral bleaching event within five years), it seems likely that aesthetic values for parts of the GBRWHA will continue to decline over the short-term at least. However, other parts of the WHA may retain their high aesthetic value, and impacted areas can recover given sufficient time. Monitoring of aesthetic values can contribute to the evidence base for promotion and storytelling about such places, and can potentially provide hope, foster pride, and inspire communities to act and support actions that mitigate threats and improve the GBR's longer-term outlook.

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APPENDIX 1: ENVIRONMENTAL ATTRIBUTES

Appendix 1 Table 1: Environmental attributes that potentially influence aesthetic values in different GBR settings (not comprehensive)

Setting – viewpoint – level of human facilities – use level (*example image*)	Potentially aesthetically pleasing environmental attributes *(assumed / hypothesised)*	Potentially detracting attributes *(assumed / hypothesised)*
1. Coral reef – underwater – limited/no facilities – low use 	• Clear water* • Fish abundance* • Fish diversity (size, shape, colour) • Fish movement • Coral topography* • Live coral cover • Coral diversity (size, shape, colour) • Megafauna presence (mobile or sessile) • Biogenic sound(s) • Low level/no other human presence • Bright sunlight **Statistical correlation shown in Marshall et al. (2019b).*	• Low water clarity • Dead coral • Diseased coral • Abundance of algae • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) • Overcast conditions • High level human presence • Other human activities (e.g. fishing, motor vessels)
2. Coral reef – underwater – limited facilities – high-use tourism site 	• Clear water • Fish abundance • Fish diversity • Fish movement • Coral topography • Live coral cover • Coral diversity • Megafauna presence • Biogenic sound(s) • Bright sunlight • Low level human presence	• Low water clarity • Dead coral • Diseased coral • Abundance of algae • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) • Overcast conditions • High level human presence • Other human activities (e.g. motor vessels) • Damaged/unclean human facilities (e.g. moorings, anchors, other structures)
3. Coral reef – underwater – pontoon facility – high-use tourism site 	• Clear water • Fish abundance • Fish diversity • Fish movement • Coral topography • Live coral cover • Coral diversity • Megafauna presence • Bright sunlight • Design aspects of facilities • Clean/maintained facilities	• Low water clarity • Dead coral • Abundance of algae • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) • Overcast conditions • High level human presence • Other human activities • Damaged/unclean human facilities • Human waste

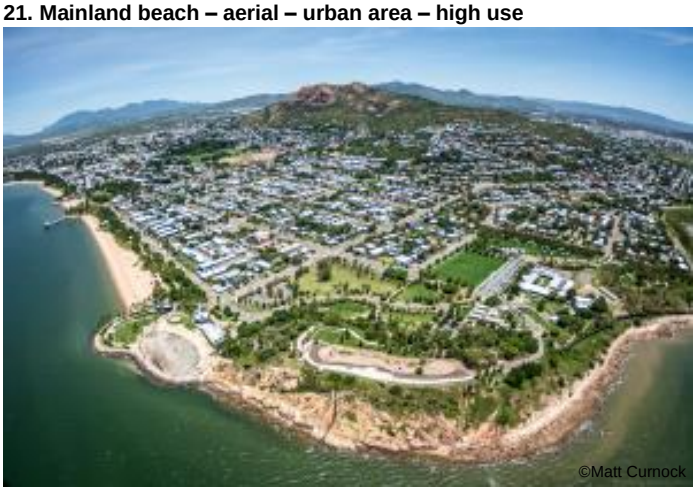
Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
4. Coral reef – surface – no facilities – low use 	• Clear water • Blue water (in deeper areas) • Colour-depth contrast • Fish abundance • Fish diversity • Fish movement • Coral topography • Live coral cover • Coral diversity • Megafauna presence • Calm sea surface • Seabird presence • Biogenic sound(s) • Low cloud cover • Rainbow(s) • Low level/no other human presence	• Low water clarity • Dead coral or coral rubble • Rough sea surface • High cloud cover • Rain • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) • Overcast conditions • Other human presence • Other human activities (e.g. motor vessels)
5. Coral reef – surface – limited facilities – moderate use 	• Clear water • Blue water • Colour-depth contrast • Complex reef structure • Fish abundance • Fish diversity • Fish movement • Live coral cover • Coral diversity • Megafauna presence • Seabird presence • Calm sea surface • Biogenic sound(s) • Low cloud cover • Rainbow(s) • Low level human presence • Design aspects of human facilities (e.g. moorings and markers)	• Low water clarity • Brown/green water (in deeper areas) • Dead coral or coral rubble • Rough sea surface • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris • High level human presence • Other human activities • Damaged/unclean facilities
6. Coral reef – surface – pontoon facility – high-use tourism site 	• Clear water • Blue water • Colour-depth contrast • Complex reef structure • Fish abundance • Fish diversity • Fish movement • Live coral cover • Coral diversity • Megafauna presence • Seabird presence • Calm sea surface • Biogenic sound(s) • Low cloud cover • Rainbow(s) • Design aspects of facilities • Clean/maintained facilities	• Low water clarity • Brown/green water (in deeper areas) • Dead coral or coral rubble • Rough sea surface • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris • High level human presence • Other human activities • Damaged/unclean human facilities • Human waste • Seabird droppings

Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
7. Coral reef – aerial – no facilities – low use  ©Matt Curnock	• Blue water • Colour-depth contrast • Complex reef structure • Anthropomorphic shapes (e.g. "Heart Reef") • Visible islands and cays • Fish movement • Megafauna presence • Seabird presence • Calm sea surface • Low cloud cover • Rainbow(s) • Low level human presence	• Brown/green water (in deeper areas) • Rough sea surface • Overcast conditions • Rain • High level human presence • Floating debris / pollution (e.g. oil spill) • Other human activities (e.g. fishing trawlers, industrial shipping)
8. Coral reef – aerial – pontoon facility – high-use tourism site  ©Matt Curnock	• Blue water • Colour-depth contrast • Complex reef structure • Anthropomorphic shapes • Visible islands and cays • Fish movement • Megafauna presence • Seabird presence • Calm sea surface • Low cloud cover • Rainbow(s) • Design aspects of human facilities	• Brown/green water (in deeper areas) • Rough sea surface • Overcast conditions • Rain • Floating debris / pollution (e.g. oil spill) • Other human activities (e.g. fishing trawlers, industrial shipping) • Damaged/unclean human facilities
9. Coral reef & cay – aerial – no facilities – low/moderate use  ©Matt Curnock	• Blue water • White sand • Colour-depth contrast • Complex reef structure • Anthropomorphic shapes • Visible islands and cays • Fish movement • Megafauna presence • Seabird presence • Calm sea surface • Low cloud cover • Rainbow(s) • Low level/no other human presence	• Brown/green water (in deeper areas) • Rough sea surface • Overcast conditions • Rain • Floating debris / pollution (e.g. oil spill) • High level human presence • Other human activities (e.g. fishing trawlers, industrial shipping)

Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
10. Coral cay – surface – no facilities – low/moderate use 	• Clear water • Blue water • White sand • Colour-depth contrast • Fish abundance • Fish movement • Live coral cover (surrounding areas) • Megafauna presence • Seabird presence • Biogenic sound(s) • Calm sea surface • Low cloud cover • Rainbow(s) • Low level/no other human presence	• Low water clarity • Rough sea surface • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris or pollution • Other human presence • Other human activities (e.g. jetski, fishing, speedboat, helicopter, UAV, industrial shipping) • Human waste
11. Coral cay – shore – no facilities – low use 	• Clear water • Blue water • White sand • Colour-depth contrast • Biogenic debris (e.g. sea shells) • Seabird presence • Biogenic sound(s) • Calm sea surface • Low cloud cover • Rainbow(s) • Low level/no other human presence	• Low water clarity • Rough sea surface • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris or pollution • Other human presence • Other human activities (e.g. jetski, fishing, speedboat, helicopter, UAV, industrial shipping) • Human waste
12. Coral cay/island – shore – resort facilities – high-use tourism site 	• Clear water • Blue water • White/light coloured sand • Colour-depth contrast • Biogenic debris • Seabird/shorebird presence • Foreshore vegetation (green) • Biogenic sound(s) • Calm sea surface • Low cloud cover • Rainbow(s) • Design aspects of human facilities • Clean/maintained facilities	• Low water clarity • Brown/green water • Rough sea surface • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) or pollution • High level human presence • Other human activities • Damaged/unclean human facilities • Human waste

Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
13. Continental island – surface – limited facilities – low/moderate use  ©Matt Curnock	• Clear water • Blue water • White/light coloured sand • Colour-depth contrast • Fish abundance • Fish movement • Live coral cover (surrounding areas) • Megafauna presence • Seabird/shorebird presence • Island vegetation (green) • Geological features • Biogenic sound(s) • Calm sea surface • Low cloud cover • Rainbow(s) • Low level/no other human presence	• Low water clarity • Brown/green water • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris or pollution • Other human presence • Other human activities • Damaged/unclean human facilities (e.g. moorings, reef protection markers)
14. Continental island – surface – limited facilities – high-use  ©Matt Curnock	• Clear water • Blue water • White/light coloured sand • Colour-depth contrast • Megafauna presence • Seabird/shorebird presence • Island vegetation (green) • Geological features • Biogenic sound(s) • Calm sea surface • Low cloud cover • Rainbow(s) • Low level human presence (timing dependent)	• Low water clarity • Brown/green water • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris or pollution • High level human presence • Other human activities • Damaged/unclean vessels • Human waste
15. Continental island – surface – developed area – high use  ©Matt Curnock	• Clear water • Blue water • Island vegetation (green) • Geological features • Fish movement • Biogenic sound(s) • Seabird/shorebird presence • Calm sea surface • Low cloud cover • Rainbow(s) • Design aspects of human facilities • Clean/maintained facilities • Design aspects of vessels (e.g. sailboats, superyachts) • Clean/maintained vessels	• Low water clarity • Brown/green water • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris or pollution • Other human activities • Damaged/unclean facilities • Damaged/unclean vessels • Human waste

Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
16. Continental island – shore – limited/no facilities – low/moderate use 	• Clear water • Blue water • White/light coloured sand • Biogenic debris • Fish movement • Megafauna presence • Seabird/shorebird presence • Island vegetation (green) • Geological features (e.g. mountains) • Calm sea surface • Biogenic sound(s) • Low cloud cover • Rainbow(s) • Low level/no other human presence	• Low water clarity • Brown/green water • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris or pollution • Other human presence • Other human activities • Damaged/unclean human facilities (e.g. toilet, camping facilities) • Human waste
17. Continental island – shore – limited facilities – moderate/high use 	• Clear water • Blue water • White/light coloured sand • Biogenic debris • Fish movement • Megafauna presence • Seabird/shorebird presence • Island vegetation (green) • Geological features (e.g. mountains) • Calm sea surface • Biogenic sound(s) • Low cloud cover • Rainbow(s) • Low level/no other human presence	• Low water clarity • Brown/green water • Overcast conditions • Rain • Anthropogenic sound/noise • Anthropogenic debris or pollution • High level human presence • Other human activities • Damaged/unclean human facilities (e.g. toilet, camping facilities) • Human waste
18. Continental island – aerial – developed area – high use 	• Blue water • Visible islands and cays • Megafauna presence • Seabird presence • Calm sea surface • Low cloud cover • Rainbow(s) • Design aspects of human facilities	• Brown/green water • Rough sea surface • Overcast conditions • Rain • Anthropogenic debris or pollution • Other human activities (e.g. fishing trawlers, industrial shipping)

Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
19. Mainland beach – shore – semi-urban area – low/moderate use  ©Matt Curnock	• Clear water • Blue water • Light coloured sand • Biogenic debris (e.g. sea shells) • Fish movement • Megafauna presence • Shorebird presence • Foreshore vegetation (green) • Calm sea surface • Low cloud cover • Rainbow(s) • Biogenic sound(s) • Low level human presence	• Low water clarity • Brown/green water • Rough sea surface • Anthropogenic debris or pollution • Anthropogenic sound/noise • High level human presence • Other human activities (e.g. motor vessels, industrial shipping, jetski) • Human waste
20. Mainland beach – shore – urban area – high use  ©Matt Curnock	• Blue water • Light coloured sand • Biogenic debris • Megafauna presence • Shorebird presence • Foreshore vegetation (green) • Calm sea surface • Low cloud cover • Design aspects of human development • Design aspects of vessels (e.g. sailboats) • Art installations	• Brown/green water • Rough sea surface • Anthropogenic debris or pollution • Anthropogenic sound/noise • Other human activities • Damaged/unclean human facilities • Human waste
21. Mainland beach – aerial – urban area – high use  ©Matt Curnock	• Blue water • Light coloured sand • Fish movement • Megafauna presence • Coastal vegetation (green) • Calm sea surface • Low cloud cover • Design aspects of human development • Design aspects of vessels (e.g. sailboats)	• Brown/green water • Rough sea surface • Overcast conditions • Rain • Anthropogenic debris or pollution

Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
22. Mangroves – surface – no facilities – low use 	• Clear water • White/light coloured sandy substrate • Green foliage • Complex root structure • Fish abundance • Fish movement • Megafauna presence (e.g. turtles, rays, sharks) • Shorebird presence • Calm sea surface • Low cloud cover • Biogenic debris • Biogenic sounds • Low level/no other human presence	• Low water clarity • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) or polltuion • Overcast conditions • Other human presence • Other human activities • Human waste
23. Mangroves – underwater – no facilities – low use 	• Clear water • White/light coloured sandy substrate • Green foliage • Complex root structure • Fish abundance • Fish movement • Megafauna presence • Shorebird presence • Calm sea surface • Low cloud cover • Biogenic debris • Biogenic sounds • Low level/no other human presence	• Low water clarity • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) or pollution • Overcast conditions • Other human presence • Other human activities • Human waste
24. Historic shipwreck - underwater - limited facilities - low/moderate use 	• Clear water • Fish abundance • Fish diversity (size, shape, colour) • Fish movement • Live coral cover • Coral diversity (size, shape, colour) • Megafauna presence • Biogenic sound(s) • Low level human presence • Bright sunlight	• Low water clarity • Dead coral • Diseased coral • Abundance of algae • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) or pollution • Overcast conditions • High level human presence • Other human activities (e.g. fishing, motor vessels)

Setting – viewpoint – level of human facilities – use level (example image)	*Potentially aesthetically pleasing environmental attributes* (assumed / hypothesised)	*Potentially detracting attributes* (assumed / hypothesised)
25. Coral restoration site - underwater - limited facilities - low/moderate use  	• Clear water • Fish abundance • Fish diversity (size, shape, colour) • Fish movement • Live coral cover • Coral diversity (size, shape, colour) • Megafauna presence • Biogenic sound(s) • Low level human presence • Bright sunlight • Design aspects of restoration works (e.g. arrangement of corals)	• Low water clarity • Dead coral • Diseased coral • Abundance of algae • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) or pollution • Overcast conditions • High level human presence • Other human activities • Non-natural installation devices (e.g. metal/concrete attachments)
26. Art installation – underwater – limited facilities – low/moderate use  	• Clear water • Fish abundance • Fish diversity (size, shape, colour) • Fish movement • Live coral cover • Coral diversity (size, shape, colour) • Megafauna presence • Biogenic sound(s) • Low level human presence • Bright sunlight • Design aspects of art installation(s) • Placement of art and relationship to natural surroundings	• Low water clarity • Dead coral • Diseased coral • Abundance of algae • Anthropogenic sound/noise • Anthropogenic debris (e.g. plastic rubbish) or pollution • Overcast conditions • High level human presence • Other human activities (e.g. fishing, motor vessels) • Damaged/unclean installations, attachment devices (e.g. rust; algal growth)

APPENDIX 2: RESEARCH PARTICIPANT INFORMATION SHEET

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Research Participant Information Sheet

Developing a Long-Term Aesthetics Monitoring Program for the Great Barrier Reef

Project overview

You are invited to take part in a research study that seeks to develop recommendations to inform long-term monitoring of aesthetic values in the Great Barrier Reef World Heritage Area. The study is being conducted by Matt Curnock and Petina Pert from CSIRO Land and Water, in collaboration with research partners from Reef Ecologic: Adam Smith and Nathan Cook. The study is being jointly funded by the National Environmental Science Program (NESP) Tropical Water Quality Hub, and CSIRO. The purpose of this project is to understand indicators, potential data sources and other parameters that will be required for the design and implementation of an Aesthetics Long-Term Monitoring Program (ALTMP) in the Great Barrier Reef. Findings from the study will help policy makers in their future decisions and activities related to assessment and monitoring of the Reef's aesthetic values.

What does participation involve?

Participation in this study will involve partaking in an interview or small group discussion that will take up to 60 minutes. Interviews may be conducted in person or over the phone, led by CSIRO and/or Reef Ecologic researchers, and will take place at a time and venue that is convenient to you. The interview will cover the following topics:

1. The objectives of aesthetics monitoring for a range of end-users
2. Indicators that are associated with aesthetic values in different settings
3. Data availability and complementarity with other monitoring programs
4. Data uses and communication needs that are likely to arise from such monitoring in future.

We will also gather some information about the people who participate in the study (e.g. representation of different institutions, and individuals' field of expert knowledge). **No statements or quotes will be attributed to any respondents without their specific permission;** i.e. we will ask first if we can attribute particular ideas to you/your organisation, and we will respect your decision if you do not give such permission.

Interviews will *not* be audio recorded, but key points from the discussion will be written down through the conversation. Key themes and ideas will then be summarised and presented to stakeholders at a workshop in October 2019; followed by a NESP report in December, and an eventual monitoring program design proposal by June 2020.

(PAGE 1 OF 2)

Risk and benefits

Aside from giving up your time, there are no foreseeable risks associated with participating in this study.

Withdrawal from the research project

Participation in this study is completely voluntary and you do not have to take part. Your decision whether to participate will not affect your current or future relationship with the researchers or anyone else at CSIRO. If any topic is raised during the interview that you prefer not to discuss, you only need to tell the interviewer and the topic will not be pursued. Similarly, you are free to stop the interview at any time. In this case, any information you have provided will not be included in the study results. If you wish to withdraw after the interview has finished, simply notify the researchers listed below and your interview data will be destroyed. You may withdraw from this study at any time up until publication of the final outputs.

Confidentiality

All information provided by you will be treated confidentially. Your name, workplace or any other personal information will not be attributable to any specific results arising from the study. De-identified, non-sensitive data collected by the project may be shared with other researchers for the purposes of verifying published results or advancing other research on this topic. Any data collected as part of this study will be securely stored as per CSIRO's Recordkeeping Procedure.

How will my information be used?

It is anticipated that the information obtained through the interviews will be published and/or presented in a variety of forums. This includes the production of technical reports on aesthetics monitoring program design, as well as scientific journal publications and conference presentations. Data collected through the interviews may also be used in future research being undertaken by CSIRO on aesthetic values assessment and monitoring.

Ethical clearance and contacts

This study has been approved by CSIRO's Social Science Human Research Ethics Committee (reference number 092/19) in accordance with the *National Statement on Ethical Conduct in Human Research (2007)*. If you have any questions concerning your participation in the study please contact the researchers via their contact details below. Alternatively any concerns or complaints about the conduct of this study can be raised with the Manager of Social Responsibility and Ethics on (07) 3833 5693 or by email at csshrec@csiro.au.

Dr Matt Curnock
Project Leader
CSIRO Land and Water
Ph: (07) 4753 8607 or 0408 871 603
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A/Prof. Adam Smith
Managing Director
Reef Ecologic
Ph: (07) 4724 5047 or 0418 726 584
Email: Adam.Smith@reefecologic.org

Thank you for taking the time to help with this research project. Please keep this sheet for your information.

(PAGE 2 OF 2)

APPENDIX 3: END-USER & STAKEHOLDER INTERVIEW TEMPLATE

Developing an aesthetics long-term monitoring program for the Great Barrier Reef

Before meetings/interviews, provide relevant background information via NESP project 5.5 and 5.6 info sheets.

Respondents are aware that their **participation is voluntary**, they can skip any questions they don't wish to answer, and **can withdraw from the study at any time**.

Interviews will *not* be audio recorded, but key points from the discussion will be written down through the conversation. Key themes and ideas will then be summarised and presented to stakeholders at a workshop in October 2019; followed by a NESP report in December, and an eventual RIMReP monitoring program design proposal by June 2020.

No statements or quotes will be attributed to any respondents **without their specific permission** (*i.e. we will ask first if we can attribute particular ideas to you/your organisation, and we will respect your decision if you do not give such permission*).

If you are interested in following the progress and outcomes of this project, please share your email and we will send out updates on progress and outcomes, with opportunities for your feedback.

Depending on level of detail in your responses – this interview may take between 30 and 60 minutes.

NESP 5.5 Project leader contact: Matt Curnock - matt.curnock@csiro.au; Tel: 07 4753 8607
CSIRO Social Science Human Ethics Coordinator: csshrec@csiro.au; Tel: 07 3833 5693

Respondent name(s): _____ Date of meeting: ____ / ____ /2019

Institution & section (if relevant): _____

Email address (optional – for project updates and feedback): _____

- - - - - - INTERVIEW START - - - - - -

1. **What are the most important aesthetic features of the GBR that need to be monitored (in your experience/opinion)?**

2. **What benefits do you think might arise from monitoring these and other aesthetic values in the GBR?**

3. **What would you/your section want from an aesthetics monitoring program?** *(please consider what sort of information you might need to use)*

4. **How do you think the data from an aesthetics monitoring program should be used and reported?**

5. **What sorts of messages coming out of an aesthetics monitoring program do you think are the most important?** (*please consider different audiences and stakeholders with whom you interact*)

6. **Do you have any concerns about how the data from an aesthetics monitoring program might be used?** *(e.g. are there any sensitivities? And if so, how should these be handled?)*

7. **Who should be involved in contributing to this monitoring?**

   - Who should have a say in the monitoring program design?
   - Who should be involved in the data collection?
   - Who are the main end users for reporting?
   - Who should ultimately be responsible for program ownership, data collection & curation?
   - Who should fund it?

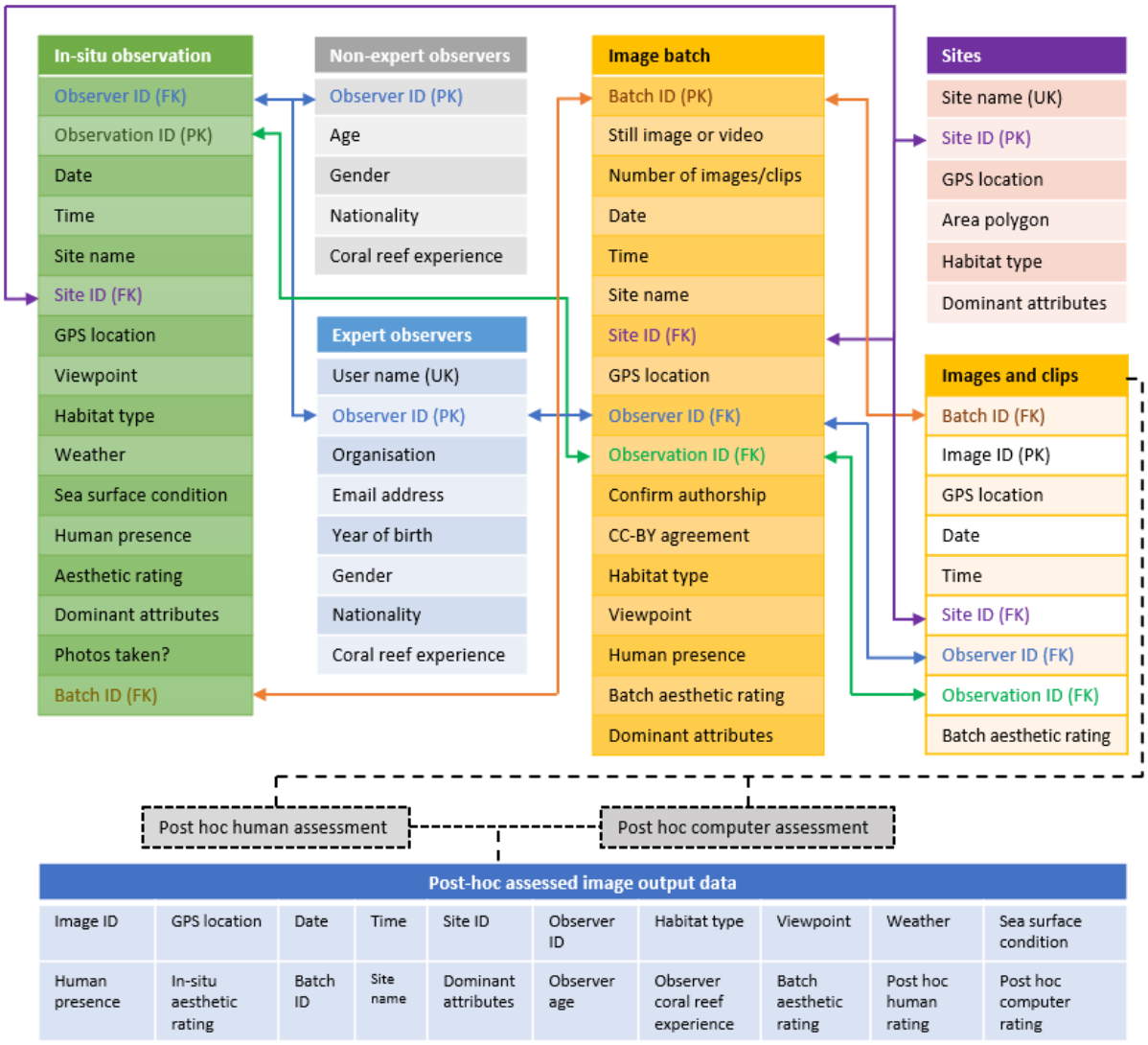
8. **In five years' time, what do you think an aesthetics monitoring program in the GBR should be delivering?**

9. **Considering the different settings in the table below, choose one or two that are most relevant to your knowledge & expertise, and:**
   - *What do you think the objectives of an aesthetics monitoring program should be?*
   - *What are the relevant attributes (or indicators) of aesthetic value, specific to that setting?*
   - *How could data be collected to monitor those indicators over the long-term?*
   - *Is any data currently available that would be suitable? if so, please describe…*
   - *Are there any existing monitoring programs (scientific or citizen science) that could contribute to monitoring those indicators?*

	Objectives of aesthetics monitoring in this context?	Relevant attributes or indicators?	How data could be collected? (*Is there any suitable data that is currently available?*)	Are there existing programs that could contribute to such monitoring?
Coral reefs				
Islands and cays				
Other habitats in the WHA (e.g. seagrass areas, mangroves, other?)				
Historic shipwrecks				
High use tourism sites with a visible human footprint – e.g. a pontoon, mooring, etc.				
Built infrastructure and facilities in the WHA, above and below water (e.g. jetties, rock walls, …)				
Remote reef sites that are rarely visited or seen by the public				
Coral restoration sites				
Underwater art installations				
Aerial perspectives of the WHA				
Other sensory attributes (non-visual) relevant to the aesthetic experience of the WHA?				
International perspectives (e.g. for Chinese tourists)				

APPENDIX 4: RELATIONAL DATABASE SCHEMA

The following figure represents a suggested and approximate relational database schema for a proposed ALTMP database that would facilitate entry, storage, retrieval and analyses of data and metadata identified in Section 6. Descriptive parameters for each variable in the schema are provided in Tables 1-6 below.



PK = primary key; FK = foreign key; UK = unique key.

Appendix 4 Figure 1: Approximate relational database schema for ALTMP database (requires trial development and refinement)

Appendix 4 Table 1: Descriptive parameters for in-situ observation data fields

Variable	Description and rules	Data format
Observer ID	Unique ID assigned to each observer	Auto-number
Observation ID	Unique ID assigned to each observation/survey entry.	Auto-number
Date	Date of observation	Year-Month-Day
Time	Time of observation	24hr format (GMT+10): 00:00
Site name	Unique name for site	Short text
Site ID	Unique ID assigned to each named site with known GPS location and area polygon	Auto-number
GPS location	Latitude and longitude from GPS	Decimal degrees to 5 decimal places
Viewpoint	Select one category representing the observer viewpoint for this observation	1=underwater, 2=surface level, 3=elevated or aerial view
Weather	Select one category representing generalised weather conditions at time of observation	1=clear skies, 2=fine but partly cloudy, 3=overcast, 4=raining
Sea surface condition	Select one category from the Beaufort scale representing sea surface conditions at time of observation	Rating scale 1-10; cf. Beaufort scale on Wikipedia
Human presence	Select one category representing the number and density of people visible in the area at time of observation	1=alone; 2=between one and five other people; 3=between 6 and 20 other people; 4=more than 20 other people.
Aesthetic rating	Aesthetic response rating for this particular observation: "*Please rate the aesthetic beauty of this place by choosing one number on the scale*"	Ten-point rating scale (1=very ugly, unpleasant; 10=exceptionally beautiful)
Dominant attributes	Short list of main features / attributes observed during this particular observation	Short text, up to five keywords
Photos taken?	Did the observer take photos of the focal site (area) during this observation?	Y / N
Batch ID	Unique ID assigned to each batch of images (linked to Image batch data)	Auto-number

Appendix 4 Table 2: Descriptive parameters for non-expert observer data fields

Variable	Description and rules	Data format
Observer ID	As described above (Table 1)	As above (Table 1)
Age	Observer's age in years at time of observation	Numeric, scalar
Gender	Observer's gender (category)	1=Female, 2=Male, 3=Other, 4=Prefer not to say
Nationality	Country in which the observer normally resides	Select one option from drop down alphabetical list of countries
Coral reef experience	Self-rated coral reef experience: "*How would you rate your level of knowledge and experience of coral reefs?*"	Ten-point rating scale (1=low familiarity with coral reefs, health and ecology; 10=highly experienced and knowledgeable about coral reef health and ecology)

Appendix 4 Table 3: Descriptive parameters for expert observer data fields*

Variable	Description and rules	Data format
User name	Unique user name chosen by observer; can be used to login for multiple data entries	Short text/alphanumeric characters
Observer ID	As described above (Table 1)	As above
Organisation	Optional; observer's employer/affiliate organisation	Short text
Email address	Observer's email address	Short text/alphanumeric characters
Year of birth	Observer's birth year, to determine age at time of observation(s)	Numeric, 4 characters
Gender	As above (Table 2)	As above (Table 2)
Nationality	As above (Table 2)	As above (Table 2)
Coral reef experience	As above (Table 2)	As above (Table 2)

*Note: privacy considerations and data protection requirements will apply

Appendix 4 Table 4: Descriptive parameters for image batch data fields

Variable	Description and rules	Data format
Batch ID	Unique ID assigned to batch of images or video clips	Auto-number
Still image or video	Select category for either still images or video clips	1=still images; 2=video clips
Number of images/clips	Number of images/clips in batch	Numeric, scalar
Date	Date of image/video capture	Year-Month-Day
Time	Time of image/video capture	24hr format (GMT+10): 00:00
Site name	As above (Table 1)	As above (Table 1)
Site ID	As above (Table 1)	As above (Table 1)
GPS location	As above (Table 1)	As above (Table 1)
Observer ID	As above (Table 1)	As above (Table 1)
Observation ID	As above (Table 1)	As above (Table 1)
Confirm authorship	Contributor confirms copyright	Y/N
CC-BY agreement	Contributor agrees to CC-BY licensing	Y/N
Habitat type	Select one category representing the dominant habitat type for the site	1=coral reef, 2=sand cay, 3=forest; 4=continental island, 5=mainland beach, 6=mangroves
Viewpoint	As above (Table 1)	As above (Table 1)
Human presence	As above (Table 1)	As above (Table 1)
Batch aesthetic rating	Aesthetic response rating for the observation during which the image batch was captured (cf. Table 1).	Ten-point rating scale (1=very ugly, unpleasant; 10=exceptionally beautiful)
Dominant attributes	As above (Table 1)	As above (Table 1)

Appendix 4 Table 5: Descriptive parameters for sites data fields

Variable	Description and rules	Data format
Site name	As described above (Table 1)	As above (Table 1)
Site ID	As above (Table 1)	As above (Table 1)
GPS location	Fixed (unchanging) GPS location that identifies a unique site	As above (Table 1)
Area polygon	Polygon on map that represents a defined area that is likely to be surveyed frequently. The GPS location should be the centroid.	GIS shapefile
Habitat type	As above (Table 4)	As above (Table 4)
Dominant attributes	Short list of main features / attributes that are a fixed/permanent or regularly observed feature of this particular site	Short text, up to five keywords (e.g. shipwreck, lighthouse, pontoon, mooring, potato cod, maori wrasse, art installation, coral restoration, sea birds, etc.)

Appendix 4 Table 6: Descriptive parameters for individual images and clips data fields

Variable	Description and rules	Data format
Batch ID	As described above (Table 4)	As above (Table 4)
Image ID	Unique ID assigned to each image	Auto-number
Date	As above (Table 1)	As above (Table 1)
Time	As above (Table 1)	As above (Table 1)
Site ID	As above (Table 1)	As above (Table 1)
Observer ID	As above (Table 1)	As above (Table 1)
Observation ID	As above (Table 1)	As above (Table 1)
Batch aesthetic rating	As above (Table 4)	As above (Table 4)

APPENDIX 5: PILOT SURVEY INSTRUMENTS

Appendix 5a: Pilot survey instrument for non-expert in situ aesthetic assessments of a coral reef site with underwater art installation (John Brewer Reef)

Underwater Art Visitor Experiences in the Great Barrier Reef
John Brewer Reef 'Coral Greenhouse' Visitor Survey – April 2020

In this survey, we are seeking feedback on your experiences during your visit to the Great Barrier Reef. We are particularly interested your perceptions of reef sites that feature underwater art. The results from this pilot survey will help us to better understand and improve future visitor experiences at such sites. If you have any questions about the survey, please contact Reef Ecologic (Dr Adam Smith: adam.smith@reefecologic.org; 0418 726 584). **The survey will take approximately 10 minutes of your time. Thank you for supporting this study!**

Part 1: A little bit about yourself

1. How would you rate your level of knowledge and experience of coral reefs? *(Please circle one number)*

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Novice *(Low familiarity with coral reefs, health and ecology)* — Expert *(Highly experienced and knowledgeable about coral reef health and ecology)*

Optional personal details:

2. Your age: _____ 3. Gender (*Circle one*): M / F / Other 4. Nationality: _____

5. Are you a first-time visitor to this part of the Great Barrier Reef? (*Circle one*): Y / N

Part 2: Your experiences overall from today

6. How satisfied are you overall with your visit to the Great Barrier Reef today? *(Please circle one number)*

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very dissatisfied — *Extremely satisfied*

7. What was the best part of your experience today? *(Please explain briefly)*

_____

8. Was there any part of the experience that wasn't so good? *(If so, please explain briefly)*

_____

9. Will you visit this part of the Great Barrier Reef again? *(Please circle one)* No / Maybe / Yes

10. Will you recommend visiting this part of the Great Barrier Reef to others? No / Maybe / Yes

11. Did you snorkel at the *Coral Greenhouse* site today? (*Circle one*): Y / N

12. Did you SCUBA dive at the *Coral Greenhouse* site today? Y / N

13. How would you rate the aesthetic beauty of this site, above the water:

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very ugly/unpleasant — *Exceptionally beautiful*

- What contributed most to your rating above?

_____

14. How would you rate the aesthetic beauty of this site, under the water:

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very ugly/unpleasant — *Exceptionally beautiful*

- What contributed most to this rating?

_____

--- Please turn over to complete the final few questions ---

For the following statements, please rate your level of agreement or disagreement by circling a number on the 10-point scale (1 = Very Strongly Disagree, and 10 = Very Strongly Agree)

Statement: *(GBR = Great Barrier Reef)*	**Very Strongly DISAGREE**	**Very Strongly AGREE**
15. My knowledge of coral reef health has increased from today's GBR experience	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
16. My appreciation of Indigenous cultural heritage has increased from today's GBR experience	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
17. The underwater sculpture contributes to an improved visitor experience in this part of the GBR	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
18. Underwater art like this helps to raise awareness about threats to the GBR	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
19. The underwater sculpture is in harmony with the nearby natural surroundings	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
20. I am concerned that the underwater sculpture may be harmful to marine life	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
21. Human-made art installations do not belong in the Great Barrier Reef	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
22. I appreciate the artistic value of this underwater sculpture	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
23. I would like to see more underwater art in the Great Barrier Reef	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
24. Human intervention in the Great Barrier Reef is needed to help preserve it for future generations	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10

25. Did you take any underwater photos or video during your visit to this site? No / Yes

- *If yes* – would you be willing to donate copies of your photos to a research project that is developing a machine learning algorithm to assess underwater aesthetic values? Y / N
  - *If so* – please provide your email address and we will contact you soon with details of this project and how to transfer digital files:
  - *Email:* _____

Note: We will not share your email with anyone else or use it for any other purpose!

26. Are there any comments you would like to make about the underwater art installation, or about this study?

_____

_____

_____

_____

_____

Thank you for your support for this research!

Please return completed survey to the Reef Ecologic researcher (or contact Dr Adam Smith: reefecologic@gmail.com)

Appendix 5b: Pilot survey instrument for non-expert in situ aesthetic assessments of a coral reef site with underwater art installations and coral restoration activity (Manta Ray Bay)

Underwater Art & Coral Restoration in the Great Barrier Reef
Manta Ray Bay Visitor Survey – March 2020

In this survey, we are seeking feedback on your experiences during your visit to the Great Barrier Reef. We are particularly interested your perceptions of underwater art and coral restoration. The results from this pilot survey will help us to better understand and improve future visitor experiences at such sites. If you have any questions about the survey, please contact Reef Ecologic (Dr Adam Smith: adam.smith@reefecologic.org; 0418 726 584). **The survey will take approximately 10 minutes of your time. Thank you for supporting this study!**

Part 1: A little bit about yourself

1. How would you rate your level of knowledge and experience of coral reefs? *(Please circle one number)*

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Novice *(Low familiarity with coral reefs, health and ecology)*

Expert *(Highly experienced and knowledgeable about coral reef health and ecology)*

Optional personal details:

2. Your age: _____ 3. Gender *(Circle one)*: M / F / Other 4. Nationality: _____

5. Are you a first-time visitor to this part of the Great Barrier Reef? *(Circle one)*: Y / N

Part 2: Your experiences overall from today

6. How satisfied are you overall with your visit to the Great Barrier Reef today? *(Please circle one number)*

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very dissatisfied *Extremely satisfied*

7. What was the best part of your experience today? *(Please explain briefly)*

_____

8. Was there any part of the experience that wasn't so good? *(If so, please explain briefly)*

_____

9. Will you visit this part of the Great Barrier Reef again? *(Please circle one)* No / Maybe / Yes

10. Will you recommend visiting this part of the Great Barrier Reef to others? No / Maybe / Yes

11. Did you snorkel at *Manta Ray Bay* today? *(Circle one)*: Y / N

12. If so, how would you rate the aesthetic beauty of this site, under the water:

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very ugly/unpleasant *Exceptionally beautiful*

- What contributed most to your rating above?

_____

13. How would you rate the aesthetic beauty of this site, above the water:

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very ugly/unpleasant *Exceptionally beautiful*

- What contributed most to this rating?

_____

--- Please turn over to complete the final few questions ---

For the following statements, please rate your level of agreement or disagreement by circling a number on the 10-point scale (1 = Very Strongly Disagree, and 10 = Very Strongly Agree)

Statement: *(GBR = Great Barrier Reef)*	**Very Strongly DISAGREE**	**Very Strongly AGREE**
14. My knowledge of coral reef health has increased from today's GBR experience	1--2--3--4--5--6--7--8--9--10	
15. My appreciation of Indigenous cultural heritage has increased from today's GBR experience	1--2--3--4--5--6--7--8--9--10	
16. The underwater sculptures contribute to an improved visitor experience in this part of the GBR	1--2--3--4--5--6--7--8--9--10	
17. Underwater art like this helps to raise awareness about threats to the GBR	1--2--3--4--5--6--7--8--9--10	
18. The underwater sculptures are in harmony with the nearby natural surroundings	1--2--3--4--5--6--7--8--9--10	
19. I am concerned that the underwater sculptures may be harmful to marine life	1--2--3--4--5--6--7--8--9--10	
20. Human-made art installations do not belong in the Great Barrier Reef	1--2--3--4--5--6--7--8--9--10	
21. I appreciate the artistic value of these underwater sculptures	1--2--3--4--5--6--7--8--9--10	
22. I would like to see more underwater art in the Great Barrier Reef	1--2--3--4--5--6--7--8--9--10	
23. The coral restoration at this site contributes to an improved visitor experience	1--2--3--4--5--6--7--8--9--10	
24. Coral restoration is needed to help damaged coral reef sites recover	1--2--3--4--5--6--7--8--9--10	
25. The replanted corals look natural when compared to their surroundings	1--2--3--4--5--6--7--8--9--10	
25. Human intervention in the Great Barrier Reef is needed to help preserve it for future generations	1--2--3--4--5--6--7--8--9--10	

26. Did you take any underwater photos or video during your visit to this site? No / Yes

- *If yes* – would you be willing to donate copies of your photos to a research project that is developing a machine learning algorithm to assess underwater aesthetic values? Y / N
  - *If so* – please provide your email address and we will contact you soon with details of this project and how to transfer digital files:
  - *Email:* _____

Note: We will not share your email with anyone else or use it for any other purpose!

27. Are there any comments you would like to make about the underwater art installations, or coral restoration, in general?

_____

_____

Thank you for your support for this research!

Please return completed survey to the Reef Ecologic researcher (or contact Dr Adam Smith: reefecologic@gmail.com)

Appendix 5c: Pilot survey instrument for non-expert in situ aesthetic assessments of a high use tourism coral reef site with pontoon facilities (Moore Reef)

Aesthetic responses in the Great Barrier Reef
Moore Reef Visitor Survey – March 2020

In this survey, we are seeking feedback on your experiences during your visit to the Great Barrier Reef. We are particularly interested in your perceptions and aesthetic experience. The results from this pilot survey will help us to better understand and improve future visitor experiences at such sites. If you have any questions about the survey, please contact Reef Ecologic (Dr Adam Smith: adam.smith@reefecologic.org; 0418 726 584). **The survey will take approximately 10 minutes of your time. Thank you for supporting this study!**

Part 1: A little bit about yourself

1. How would you rate your level of knowledge and experience of coral reefs? *(Please circle one number)*

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Novice *(Low familiarity with coral reefs, health and ecology)*

Expert *(Highly experienced and knowledgeable about coral reef health and ecology)*

Optional personal details:

2. Your age: _____ 3. Gender (*Circle one*): M / F / Other 4. Nationality: _____

5. Are you a first-time visitor to this part of the Great Barrier Reef? (*Circle one*): Y / N

Part 2: Your experiences overall from today

6. How satisfied are you overall with your visit to the Great Barrier Reef today? *(Please circle one number)*

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very dissatisfied *Extremely satisfied*

7. What was the best part of your experience today? *(Please explain briefly)*

_____

8. Was there any part of the experience that wasn't so good? *(If so, please explain briefly)*

_____

9. Will you visit this part of the Great Barrier Reef again? *(Please circle one)* No / Maybe / Yes

10. Will you recommend visiting this part of the Great Barrier Reef to others? No / Maybe / Yes

11. Did you snorkel or scuba dive at *Moore Reef* today? (*Circle one*): Y / N

12. If so, how would you rate the aesthetic beauty of this site, <u>under the water</u>:

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very ugly/unpleasant *Exceptionally beautiful*

- What contributed most to your rating above?

_____

13. How would you rate the aesthetic beauty of this site, <u>above the water</u>:

1 - - - - - 2 - - - - - 3 - - - - - 4 - - - - - 5 - - - - - 6 - - - - - 7 - - - - - 8 - - - - - 9 - - - - - 10

Very ugly/unpleasant *Exceptionally beautiful*

- What contributed most to this rating?

_____

--- Please turn over to complete the final few questions ---

For the following statements, please rate your level of agreement or disagreement by circling a number on the 10-point scale (1 = Very Strongly Disagree, and 10 = Very Strongly Agree)

Statement: *(GBR = Great Barrier Reef)*	**Very Strongly DISAGREE**	**Very Strongly AGREE**
14. My knowledge of coral reef health has increased from today's GBR experience	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
15. My appreciation of Indigenous cultural heritage has increased from today's GBR experience	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
16. I am concerned about the future of the Great Barrier Reef	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
17. The underwater visibility during my visit today was very good	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
18. There was abundant fish life during my visit today	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
19. The number of other people present at the Reef today was too many	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
20. The weather during my visit to the Reef today was very nice	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
21. The corals at the Reef site(s) today looked healthy	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10
22. Human intervention in the Great Barrier Reef is needed to help preserve it for future generations	1 - - 2 - - 3 - - 4 - - 5	- - 6 - - 7 - - 8 - - 9 - - 10

26. Did you take any underwater photos or video during your visit to this site? No / Yes

- *If yes* – would you be willing to donate copies of your photos to a research project that is developing a machine learning algorithm to assess underwater aesthetic values? Y / N
  - *If so* – please provide your email address and we will contact you soon with details of this project and how to transfer digital files:
  - *Email:* _____

Note: We will not share your email with anyone else or use it for any other purpose!

27. Are there any comments you would like to make about the topics covered in this survey?

_____

_____

_____

_____

_____

_____

_____

Thank you for your support for this research!

Please return completed survey to the Reef Ecologic researcher (or contact Dr Adam Smith: reefecologic@gmail.com)

Appendix 5d: Pilot survey instrument for crew/researchers: day trip site visit summary data (generic)

GBR aesthetics survey administrator site visit summary form

This form is for crew/researchers collecting passenger surveys – one form is to be completed per day/trip to the target site – this form then accompanies the collected passenger surveys. If you have any questions about the survey, please contact Reef Ecologic (Dr Adam Smith: adam.smith@reefecologic.org; 0418 726 584).

Thank you for supporting this study!

---

1. Operator name: _____ 2. Your name: _____

3. Site name: _____

4. Date: _____ 5. No. of pax: _____

6. Number of completed, returned passenger surveys: _____

7. Please rate the **weather and sea conditions** during this visit: (*circle appropriate numbers*)

- Sea state: 1 - - - - - - - 2 - - - - - - - 3 - - - - - - - 4 - - - - - - - 5
  Very calm Calm Moderate Rough Very rough
- Cloud cover: 1 - - - - - - - 2 - - - - - - - 3 - - - - - - - 4 - - - - - - - 5
  Clear skies Fully overcast
- UW visibility: 1 - - - - - - - 2 - - - - - - - 3 - - - - - - - 4 - - - - - - - 5
  Very poor Exceptionally good

8. Any **outstanding factors** that may have influenced passengers' experience today?

- *If so, please describe briefly:*

_____

_____

9. Did you take any **underwater photos or video** during your visit to this site?

☐ No ☐ Yes.... *If yes,* would you be willing to donate copies of your photos to a research project that is developing a machine learning algorithm to assess underwater aesthetic values?

- ***If so*** – please provide your email address and we will contact you soon with details of this project and how to transfer digital files:
- *Email:* _____

Note: We will not share your email with anyone else or use it for any other purpose!

10. Any **other comments** about this site visit today?

_____

_____

Thank you for your support for this research!

Please return completed survey to the Reef Ecologic researcher (or contact Dr Adam Smith: reefecologic@gmail.com)

If you can read this you don't need glasses

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