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1 Beauty and the reef: Evaluating the use of non-expert ratings for monitoring
2 aesthetic values of coral reefs.

3
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14

15 Abstract

16 UNESCO World Heritage sites are affected by global change. The Great Barrier Reef (GBR) is
17 an iconic World Heritage site whose values for which the site was inscribed, including its natural
18 beauty, are dramatically declining. However, there is currently no program or documented
19 methods for long term monitoring of aesthetics for coral reefs. Here, Here, we quantified and
20 assessed the drivers of the GBR aesthetic value perception form a survey of 1,417 individuals
21 who rated 181 photos on a 10-point scale for their level of attractiveness. Each photo was rated
22 at least 380 times. Coral topography, fish abundance and visibility were positively correlated

23 with aesthetic ratings. Older people and those with interest in coral reefs and who dived on the
24 reef rated photos more highly. Reporting on aesthetic values of the UNESCO World Heritage
25 Sites will become increasingly as declines in their ecological state continue.

26 Keywords

27 Aesthetic, value, beauty, appreciation, cultural ecosystem services, attitudes, perception,

28 Great Barrier Reef

29 1. Introduction

30 The reframing of nature by the Millennium Ecosystem Assessment report (Millennium
31 Ecosystem Assessment, 2003), in particular, as providing goods and services, has enabled a
32 mechanism by which the importance of natural places can be reconsidered (Diaz et al., 2011).
33 The aesthetic services that are provided by nature have become formally acknowledged and
34 valued, where the provision of aesthetic services is strongly related to all other cultural services
35 including recreation (Ghermandi et al., 2010; Junge et al., 2015). Areas with conditions for
36 recreation and leisure are often valuable due to their aesthetic and cultural heritage and identity
37 qualities (e.g. (Chan et al., 2012; Comberti et al., 2015; Gee and Burkhard, 2010; Jobstvogt et
38 al., 2014)). Likewise, areas with scenic beauty often provide inspiration and opportunities for
39 education, holding significant existence values (e.g., (de Oliveira and Berkes, 2014; Fletcher et
40 al., 2014; Hashimoto et al., 2014; Martínez-Pastur et al., 2015; Outeiro et al., 2015)).
41 Furthermore, De Groot et al. (2002) refers to 'aesthetic information' as an ecosystem service
42 category, provide 'scenery' as an example of an aesthetic service, and a feeling of 'enjoyment'
43 as the benefit of this service. Boyd and Banzhaf (2007) suggest that 'amenity and fulfilment' are
44 examples of aesthetic benefits and 'natural land cover in viewsheds' is the ecosystem service
45 providing the benefits. They argue this differentiation is essential in defining a workable
46 accounting system to facilitate land-use decision-making and management.

47

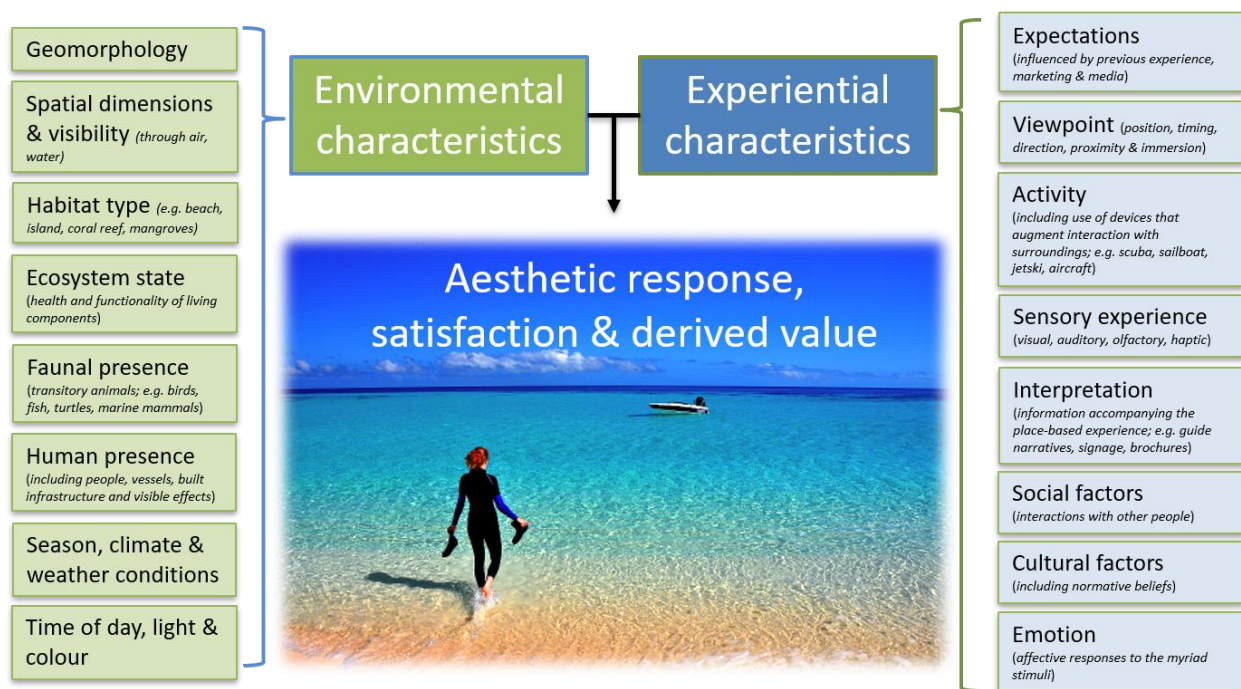
48 For the purpose of this paper, the term *aesthetic value(s)* has been taken as defined by Context
49 Pty Ltd (2013 p. 33), being:

50 *".. the response (the aesthetic response) derived from the experience of an environment*
51 *or parts of an environment. Human senses – sight, touch, smell, sound, movement –*
52 *are important in how humans experience an environment. And culture, knowledge,*

53 *expectations and experience mediate sensory perceptions. Aesthetic response can*
 54 *therefore be said to be linked to:*

- 55 • *the characteristics of an environment*
- 56 • *culturally or personally derived preferences.”*

57 Furthermore, we have summarised the by the many contributing environmental and experiential
 58 characteristics that contribute to aesthetic response, satisfaction and derived value in a natural
 59 setting (Fig. 1).



60
 61 Fig. 1. Characteristics and attributes that contribute to aesthetic response, satisfaction and
 62 derived value in a natural setting (Great Barrier Reef context).

63
 64 The natural beauty and aesthetic appreciation of landscapes has previously been studied in
 65 various terrestrial ecosystems around the world (Arriaza et al., 2004; Beza, 2010; De Pinho et
 66 al., 2014; Frank et al., 2013; Gobster et al., 2007; Hoffman and Palmer, 1996; Howley, 2011;
 67 Rosley et al., 2013; Schirpke et al., 2013; Sheppard, 2004; Van den Berg et al., 1998; van der

68 Jagt et al., 2014; van Zanten et al., 2016; Wet Tropics Management Authority, 2017; Xu et al.,
69 2003), however very few studies have occurred in marine ecosystems (Fenton and Syme, 1989)
70 or more specifically within coral reefs (Dinsdale and Fenton, 2006; Fenton et al., 1998). Coral
71 reef ecosystems worldwide are significant sources of consumptive and non-consumptive
72 economic values (Wielgus et al., 2002) and supply vast numbers of people with goods and
73 services such as seafood, tourism and recreational opportunities, coastal protection, as well as
74 aesthetic and cultural benefits (Martin et al., 2016; Moberg and Folke, 1999; Werner et al.,
75 2014). Many attributes have been described as to what contributes to these non-consumptive
76 aesthetic values including the abundance of fish and corals (Dixon et al., 1993; Wilkinson, 1996;
77 Williams and Polunin, 2000), existence of iconic species/habitats (Jobstvogt et al., 2014; Levin
78 et al., 2010; Werner et al., 2014), and water clarity (Dixon et al., 1993; Hatton MacDonald et al.,
79 2015; Lee, 2017; Tosic et al., 2014; Wilkinson, 1996).

80
81 The development of indicators and quantifying the aesthetic value that people place on different
82 landscapes, seascapes, and ecosystems has been approached in a number of ways by
83 researchers over time. Primarily these have focused on using landscape assessment methods
84 which either focus on understanding experiential preferences, the physical
85 attributes/attractiveness of a place (Tardieu and Tuffery, 2019), landscape preferences, (Atauri
86 et al., 2000; de la Fuente de Val et al., 2006; de Lucio and Múgica, 1994; Huang, 2013; Múgica
87 and de Lucio, 1996), scenic quality, or the experience of the place. Two different methodological
88 approaches that assess landscape aesthetics either from an objective or a subjective point of
89 view have been established in the past (Frank et al., 2013). More recent approaches such as
90 those by Casalegno et al. (2013) and van Zanten et al. (2016) have used crowd-source
91 datasets, machine learning, (Haas et al., 2015; Seresinhe et al., 2015; Spalding et al., 2017)
92 and geo-tagged digital photographs uploaded to social media platforms to quantify and
93 objectively measure the perceived aesthetic value of ecosystems.

94

95 The emergence of aesthetic values methods in the Australian heritage practice although only
96 new, is important as there is no established World Heritage methodology for assessing natural
97 beauty and aesthetic values under Criterion vii (i.e. contain superlative natural phenomena or
98 areas of exceptional natural beauty and aesthetic importance). In the Great Barrier Reef and
99 Wet Tropics World Heritage Areas in Australia attempts have been made to define and measure
100 aesthetic values (Context Pty Ltd, 2013; Wet Tropics Management Authority, 2017). More
101 recently new methods have been developed utilising non-expert visual assessments (Marshall
102 et al., 2019) and innovative technologies using artificial intelligence (Becken et al., 2018). Given
103 the importance of the tourism industry in these areas, those features and attributes that
104 currently draw visitors to these areas are important, particularly to tourism operators in the
105 areas. Furthermore, a number of values for which the Great Barrier Reef was originally
106 inscribed for are on the decline after back to back coral bleaching events recently in 2016 and
107 2017, terrestrial run-off of sediments and nutrients and associated Crown-of-Thorns Starfish
108 (COTS) (*Acanthaster planci*) outbreaks, acidification associated with climate change, impacts
109 from severe cyclones, and coral diseases (Brodie and Waterhouse, 2012; De'ath et al., 2012;
110 Hughes et al., 2015; Hughes et al., 2017), which have all affected the aesthetics and natural
111 beauty of some parts of the Region above and below the water (Great Barrier Reef Marine Park
112 Authority, 2019).

113

114 Appealing features of methods which use non-expert rating scores of aesthetic beauty include
115 simplicity and scalability, and as Marshall et al. (2019) and Haas et al. (2015) have shown,
116 relevance/correlation to environmental attributes associated with Reef health. However, before
117 such a method can be implemented and used in a management context, managers need to
118 understand the method's sensitivity, extrapolative power, and any potential biases associated
119 with non-expert visual ratings of scenes. In this study we evaluate (a) the sensitivity of rating

120 scores used in Marshall et al. (2019) to compare underwater coral reef scenes, (b) the sampling
121 design requirements to establish appropriate confidence levels, and (c) biases associated with
122 demography and knowledge levels/expertise.

123 2. Methods

124 2.1 Study site

125 The Great Barrier Reef (GBR) of Australia is one of the world's largest coral reef systems. It
126 houses globally-significant biodiversity, a rich diversity of underwater habitats, and a scenic
127 appeal that is universally recognised (Hughes et al., 2003). These values make it an
128 international tourism attraction: in 2013, the Great Barrier Reef received an estimated 53.3M
129 days of use, with 98% of all days comprising tourism visitation (Marshall et al., 2016). Tourism
130 operators and commercial fishers are particularly appreciative of the natural beauty of the
131 region, with the tourism industry alone worth over \$5.2 billion each year (Marshall et al., 2016).
132 It also holds immense value for local communities, where 'beautiful' is one of the first words that
133 come to local residents' minds when thinking of the GBR (Marshall et al., 2016). Residents and
134 tourists seek opportunities to appreciate the natural aesthetics of the GBR through experiences
135 such as diving and snorkelling, visiting beaches, boating and scenic flights (Marshall et al.,
136 2016).

137 2.2 Data analysis

138 We developed a linear mixed effect model to generate expectations of how image scores were
139 related to eight covariables expected to influence the aesthetic score. These included coral size,
140 fish size, fish diversity, presence of algae, coral cover, topography, fish density, and visibility
141 (Marshall et al., 2019). Respondents and images were used as random effects. Variance
142 inflation factor (VIF) scores 3.28, indicating low collinearity among covariates. We then identified
143 XXXX and YYYY, defined as respondents scoring more than two standard deviations higher or
144 lower than expectations from our model, respectively. Our approach thus reveals the

145 respondents that tend to provide more extreme scores given the general characteristics of the
146 images they evaluate. Finally, we assessed the link between socioeconomic characteristics and
147 whether a respondent was XXXX, average, or YYYY using a Fisher's exact test.

148

149 In order to help practitioners find a balance between low cost and high accuracy, we examined
150 how error in the image scores varied according to the number of respondents (i.e. sample size).
151 Specifically, we calculated the error (i.e. score's 95% confidence interval) at varying sample
152 sizes (N = 3 to 380 respondents in increments of 2, taken randomly without replacement from
153 the original pool of respondents). This process was repeated 100 times for each of the 181
154 images in order to calculate the median error each image add at various sample size.

155

156 Five indicators were selected that reflected distinct attributes of coral reefs: (i) coral cover; (ii)
157 coral pattern; (iii) coral topography; (iv) fish abundance; and (v) visibility (Marshall et al., 2019).

158

159 All analyses were implemented in R statistical analysis software v3.4.0.

160

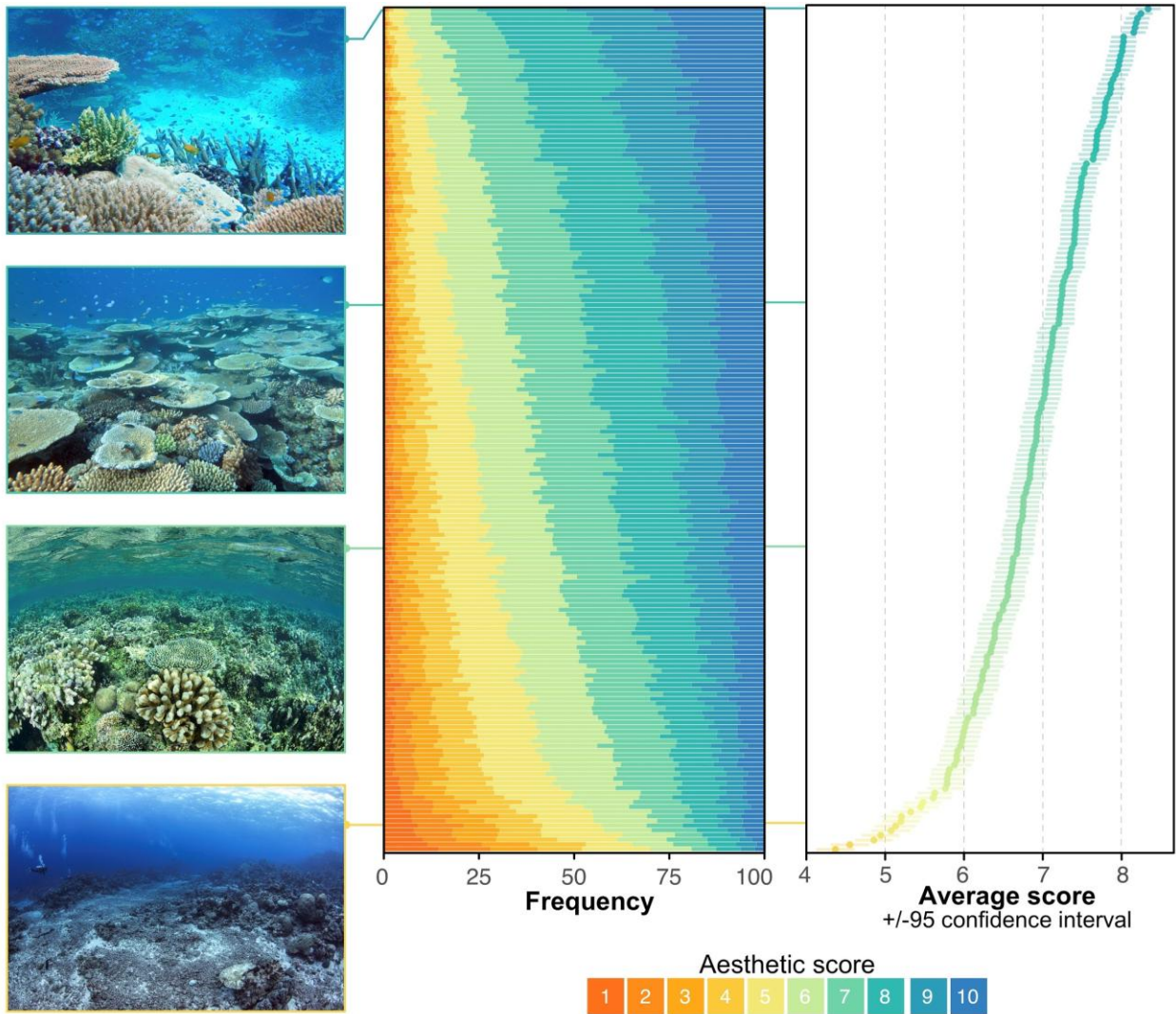
161

162

163 3. Results

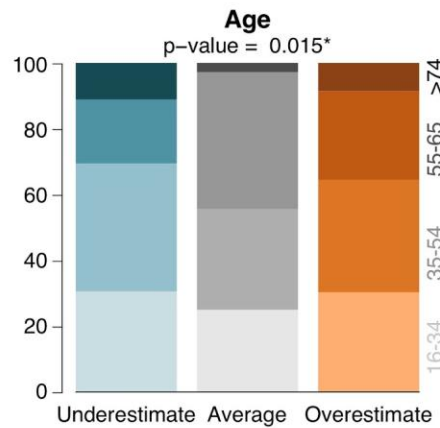
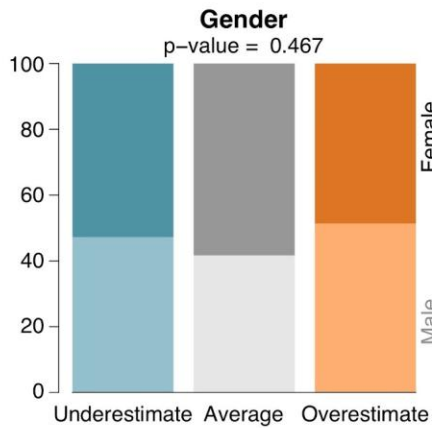
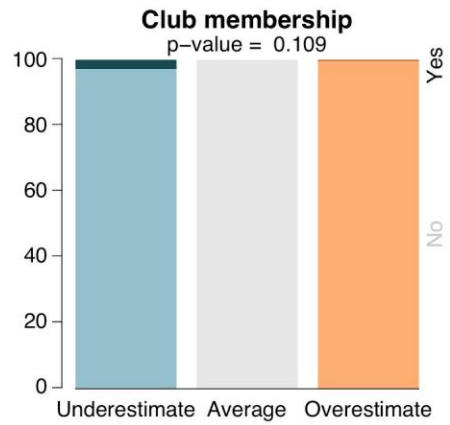
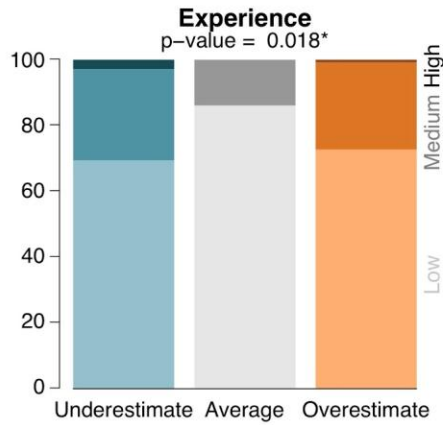
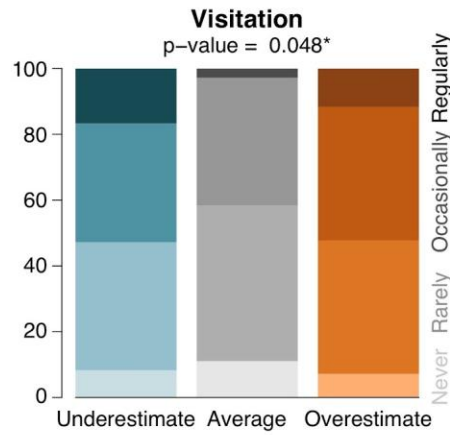
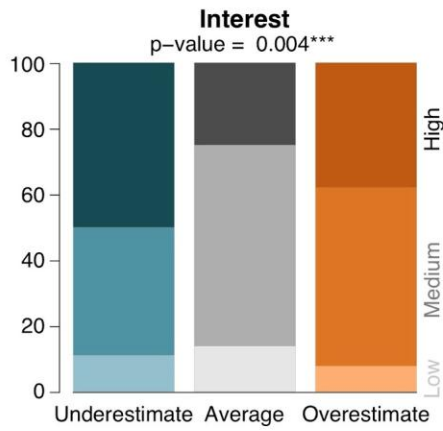
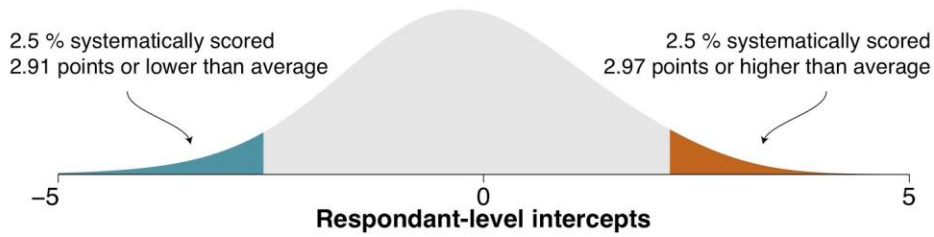
164 The average aesthetic score ranged between X and X. Four images (Fig. 2) indicate the
165 frequency and average aesthetic score.

166



167

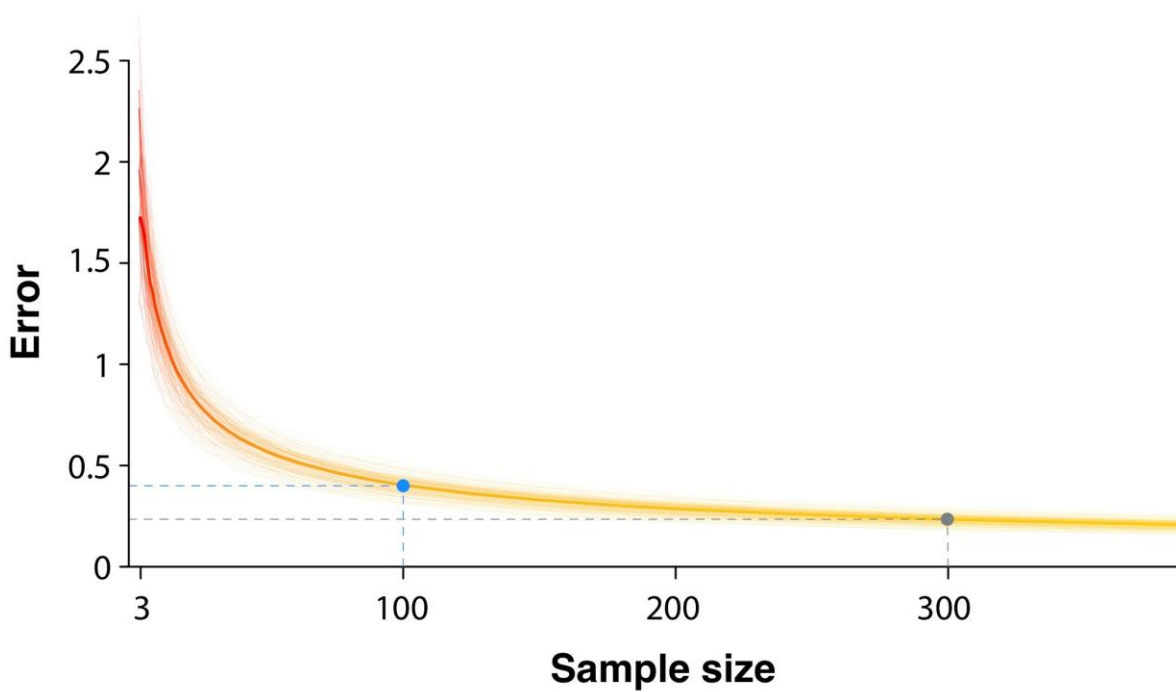
168 Fig. 2 XXXXXXXXXXXXXXXXXXXX



169

170 Fig. 3 XXXXXXXXXXXXXXXXXXXX

- 171 • Have a higher level of interest in coral reefs ($p=0.004^{***}$)
- 172 • More likely to visit reef regularly ($p=0.048^*$)
- 173 • Higher self-assessed coral reef experience ($p=0.018^*$)
- 174 • Higher proportion of >65's ($p=0.015^*$)
- 175 • No apparent prevalence of bias in either positive or negative direction
- 176 • While these groups inflate the error margin, they tend to cancel each other out around
- 177 the mean score.



179
 180 Fig. 4. Sample size describes how many people you would need to assess a photo/coral reef
 181 scene, to be confident in the representativeness of the mean score and at what point do you no
 182 longer change the mean response.

183
 184

185 4. Discussion

186 • CHALLENGES

187

188 Reporting through monitoring, and actively managing, aesthetic quality is potentially a critically
189 useful strategy for natural resource managers that aim to effectively deliver both conservation
190 and social outcomes. The advantages of monitoring aesthetic values lie essentially around the
191 opportunity to better engage with the public, correspondingly achieving conservation (Frank et
192 al., 2013). People appreciate and relate to aesthetics more than any other aspect of the natural
193 environment (Marshall et al., 2018; Marshall et al., 2016; Marshall et al., 2017). Aesthetics is
194 also a unifying value associated with natural places, whilst biodiversity is often a divisive factor
195 (Hill et al., 2016; Lecuyer et al., 2018; Schmidt and Peterson, 2009; Young et al., 2010). In the
196 case of iconic places such as the Great Barrier Reef, aesthetic values were a major factor in the
197 establishment of World Heritage Area status, and the reporting of aesthetic quality and its
198 maintenance is likely to become mandatory. For these reasons, efforts are currently underway
199 to explore how aesthetic quality might be recorded and reported on within the Great Barrier
200 Reef (NESP reference).

201

202 Perhaps the reason that aesthetic values have not been explicitly used by natural resource
203 managers to further conservation goals and support is because aesthetics are seen as
204 subjective and essentially unmanageable (Context Pty Ltd, 2013; Dramstad et al., 2006).

205 However, preliminary work by the National Environment and Science Program (Becken et al.,
206 2018; Marshall et al., 2019) has strongly suggested that developing indicators to rate aesthetic
207 quality is possible (Marshall et al., 2019). In sum, the development of aesthetic indicators for
208 use in specific environments such as marine environments are still very much in their infancy,
209 but the momentum supporting the development of aesthetic metrics, or indicators, is growing

210 (Belhassen et al., 2017; Haas et al., 2015; Hein et al., 2019; Jaap, 2000; Tamayo et al., 2018;
211 Turek, 2000; Vercelloni et al., 2018; Vlami et al., 2017; Wessel et al., 2018).

212

213 The emerging social-ecological field continues to expand methodologies to improve techniques
214 in monitoring aesthetic heritage values, using potential indicators and computations of aesthetic
215 value. However, ongoing examination of which locations or biophysical elements are the most
216 important to the Reef's spectacular seascapes and scenery, remains an information gap.

Summary of benefits

The large size of the property and the fact that it was inscribed on the World Heritage List under all four natural criteria supports the evidence for the wide array of benefits provided by the property to the people living both within and outside the property. In addition to nature conservation and conserving cultural and wilderness values, the property provides a wide range of ecosystem services, furnishes a wealth of scientific knowledge and provides jobs through tourism, fishing, park management, research and education. Local populations can benefit from traditional, recreational and commercial fishing and hunting (some Traditional Owners continue to hunt dugong) provided that it is sustainable. In 2011–12, recreational activities (including fishing) were the second largest direct use of the World Heritage Area, generating \$244 million (value-added), a substantial increase on the estimate of its value in 2006–07 (\$153 million). The activities generated employment equivalent of 2724 full-time jobs, up from approximately 1700 in 2006–07. Of the four recreational activities, recreational fishing is the most popular with an estimated 3.8 million fishing trips taking place in 2015–16, the expenditure generated from recreational fishing activities amounts to \$70 million. The total value of all recreational activity associated with the GBR in 2015–16 is estimated to contribute around \$346 million to the Australian economy (including \$284 million to the GBR Region).

217

218 **5. Conclusion**

219 There are numerous potential management (and other) uses of aesthetic assessments and
220 monitoring with information needs that vary substantially. The rapid assessment approach is
221 potentially useful for some purpose with statistical design requirements and limitations now
222 better understood. Our findings can help World Heritage site managers better contextualise the
223 results and limitations from such monitoring and ensure that future aesthetic monitoring
224 programs can be designed to meet management and reporting needs.

225

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228

229

230

231 **References**

232 Arriaza, M., Cañas-Ortega, J.F., Cañas-Madueño, J.A., Ruiz-Aviles, P., 2004. Assessing the
233 visual quality of rural landscapes. *Landscape and Urban Planning* 69, 115-125.
234 doi:10.1016/j.landurbplan.2003.10.029

235 Atauri, J.A., Bravo, M.A., Ruiz, A., 2000. Visitors' landscape preferences as a tool for
236 management of recreational use in natural areas: a case study in Sierra de Guadarrama
237 (Madrid, Spain). *Landscape Research* 25, 49-62.

238 Becken, S., Connolly, R., Stantic, B., Scott, N., Mandal, R., Le, D., 2018. Monitoring aesthetic
239 value of the Great Barrier Reef by using innovative technologies and artificial
240 intelligence. , Griffith Institute for Tourism Research Report No 15. Griffith Institute for
241 Tourism, Griffith University, Queensland.

242 Belhassen, Y., Rousseau, M., Tynyakov, J., Shashar, N., 2017. Evaluating the attractiveness
243 and effectiveness of artificial coral reefs as a recreational ecosystem service. . *Journal of*
244 *Environmental Management* 203, 448-456.

245 Beza, B.B., 2010. The aesthetic value of a mountain landscape: a study of the Mt. Everest Trek.
246 *Landscape and Urban Planning* 97, 306-317. doi:10.1016/j.landurbplan.2010.07.003

247 Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized
248 environmental accounting units. *Ecological Economics* 63, 616-626.

249 Brodie, J., Waterhouse, J., 2012. A critical review of environmental management of the 'not so
250 Great' Barrier Reef. *Estuarine, Coastal and Shelf Science* 104-105, 1-22.
251 doi:10.1016/j.ecss.2012.03.012

252 Casalegno, S., Inger, R., DeSilvey, C., Gaston, K.J., 2013. Spatial covariance between
253 aesthetic value & other ecosystem services. *PLoS ONE* 8, e68437.
254 doi:10.1371/journal.pone.0068437

255 Chan, K.A., Guerry, A., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., Bostrom, A.,
256 Chuenpagdee, R., Gould, R., Halpern, B., Hannahs, N., Levine, J., Norton, B.,
257 Ruckelshaus, M., Russell, R., Tam, J., Woodside, U., 2012. Where are Cultural and
258 Social in Ecosystem Services? A Framework for Constructive Engagement. *BioScience*
259 62, 744-756. doi:10.1525/bio.2012.62.8.7

260 Comberti, C., Thornton, T.F., de Echeverria, V.W., Patterson, T., 2015. Ecosystem services or
261 services to ecosystems? Valuing cultivation and reciprocal relationships between
262 humans and ecosystems. *Global Environmental Change* 34, 247-262.
263 doi:10.1016/j.gloenvcha.2015.07.007

264 Context Pty Ltd, 2013. Defining the aesthetic values of the Great Barrier Reef: Final Report.
265 Context Pty Ltd, Brunswick, Victoria, p. 264.

266 De'ath, G., Fabricius, K.E., Sweatman, H., Puotinen, M., 2012. The 27-year decline of coral
267 cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of*
268 *Sciences of the United States of America* 109, 17995-17999.

269 De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification,
270 description and valuation of ecosystem functions, goods and services. *Ecological*
271 *Economics* 41, 393-408.

272 de la Fuente de Val, G., Atauri, J.A., de Lucio, J.V., 2006. Relationship between landscape
273 visual attributes and spatial pattern indices: a test study in Mediterranean-climate
274 landscapes. *Landscape and Urban Planning* 77, 393-407.

275 de Lucio, J.V., Múgica, M., 1994. Landscape preferences and behavior of visitors to Spanish
276 National Parks. *Landscape and Urban Planning* 29, 145-160.

277 de Oliveira, L.E.C., Berkes, F., 2014. What value São Pedro's procession? Ecosystem services
278 from local people's perceptions *Ecological Economics* 107, 114-121.
279 doi:10.1016/j.ecolecon.2014.08.008

280 De Pinho, J.R., Grilo, C., Boone, R.B., Galvin, K.A., Snodgrass, J.G., 2014. Influence of
281 aesthetic appreciation of wildlife species on attitudes towards their conservation in
282 Kenyan agropastoralist communities. *PLoS ONE* 9, e88842.
283 doi:10.1371/journal.pone.0088842

284 Diaz, S., Quetier, F., Caceres, D.M., Trainor, S.F., Perez-Harguindeguy, N., Bret-Harte, M.S.,
285 Finegan, B., Pena-Claros, M., Poorter, L., 2011. Linking functional diversity and social
286 actor strategies in a framework for interdisciplinary analysis of nature's benefits to
287 society. *Proc Natl Acad Sci U S A* 108, 895-902. doi:10.1073/pnas.1017993108

288 Dinsdale, E.A., Fenton, D.M., 2006. Assessing coral reef condition: eliciting community
289 meanings. *Society & Natural Resources* 19, 239-258. doi:10.1080/08941920500460815

290 Dixon, J.A., Scura, L.F., van't Hof, T., 1993. Meeting Ecological and Economic Goals: Marine
291 Parks in the Caribbean. *Ambio* 22, 117-125.

292 Dramstad, W.E., Tveit, M.S., Fjellstad, W.J., Fry, G.L.A., 2006. Relationships between visual
293 landscape preferences and map-based indicators of landscape structure. *Landscape
294 and Urban Planning* 78, 465-474.

295 Fenton, D.M., Syme, G.J., 1989. Perception and evaluation of the coastal zone: implications for
296 coastal zone planning. *Coastal Management* 17, 295-308.
297 doi:10.1080/08920758909362092

298 Fenton, D.M., Young, M., Johnson, V.Y., 1998. Re-presenting the great barrier reef to tourists:
299 Implications for tourist experience and evaluation of coral reef environments. *Leisure
300 Sciences* 20, 177-192. doi:10.1080/01490409809512279

301 Fletcher, R., Baulcomb, C., Hall, C., Hussain, S., 2014. Revealing marine cultural ecosystem
302 services in the Black Sea. *Marine Policy* 50, 151-161. doi:10.1016/j.marpol.2014.05.001

303 Frank, S., Fürst, C., Koschke, L., Witt, A., Makeschin, F., 2013. Assessment of landscape
304 aesthetics—Validation of a landscape metrics-based assessment by visual estimation of
305 the scenic beauty. *Ecological Indicators* 32, 222-231. doi:10.1016/j.ecolind.2013.03.026

306 Gee, K., Burkhard, B., 2010. Cultural ecosystem services in the context of offshore wind
307 farming: A case study from the west coast of Schleswig-Holstein. *Ecological Complexity*
308 7, 349-358. doi:10.1016/j.ecocom.2010.02.008

309 Ghermandi, A., Nunes, P.A.L.D., Portela, R., Rao, N., Teelucksingh, S.S., 2010. Recreational,
310 Cultural, and Aesthetic Services from Estuarine and Coastal Ecosystems. FEEM
311 Working Paper No. 121.2009. doi:10.2139/ssrn.1532803

312 Gobster, P.H., Nassauer, J.I., Daniel, T.C., Fry, G., 2007. The shared landscape: what does
313 aesthetics have to do with ecology? *Landscape Ecology* 22, 959-972.
314 doi:10.1007/s10980-007-9110-x

315 Great Barrier Reef Marine Park Authority, 2019. Great Barrier Reef Outlook Report 2019. Great
316 Barrier Reef Marine Park Authority, Townsville.

317 Haas, A.F., Guibert, M., Foerschner, A., Co, T., Calhoun, S., George, E., Hatay, M., Dinsdale,
318 E., Sandin, S.A., Smith, J.E., Vermeij, M.J., Felts, B., Dustan, P., Salamon, P., Rohwer,
319 F., 2015. Can we measure beauty? Computational evaluation of coral reef aesthetics.
320 *PeerJ* 3, e1390. doi:10.7717/peerj.1390

321 Hashimoto, S., Nakamura, S., Saito, O., Kohsaka, R., Kamiyama, C., Tomiyoshi, M., Kishioka,
322 T., 2014. Mapping and characterizing ecosystem services of social–ecological
323 production landscapes: case study of Noto, Japan. *Sustainability Science* 10, 257-273.
324 doi:10.1007/s11625-014-0285-1

325 Hatton MacDonald, D., Ardeshiri, A., Rose, J.M., Russell, B.D., Connell, S.D., 2015. Valuing
326 coastal water quality: Adelaide, South Australia metropolitan area. *Marine Policy* 52,
327 116-124. doi:10.1016/j.marpol.2014.11.003

328 Hein, M.Y., Birtles, A., Willis, B.L., Gardiner, N., Beeden, R., Marshall, N.A., 2019. Coral
329 restoration: Socio-ecological perspectives of benefits and limitations. *Biological*
330 *Conservation* 229, 14-25.

331 Hill, S.L.L., Harfoot, M., Purvis, A., Purves, D.W., Collen, B., Newbold, T., Burgess, N.D., Mace,
332 G.M., 2016. Reconciling Biodiversity Indicators to Guide Understanding and Action.
333 *Conservation Letters* 9, 450-412.

334 Hoffman, R.E., Palmer, J.F., 1996. *Silviculture and forest aesthetics within stands*, The New
335 York center for forestry research and development. State University of New York,
336 College of Environmental Sciences and Forestry, Syracuse.

337 Howley, P., 2011. Landscape aesthetics: Assessing the general publics' preferences towards
338 rural landscapes. *Ecological Economics* 72, 161-169.
339 doi:10.1016/j.ecolecon.2011.09.026

340 Huang, S.-C.L., 2013. Visitor responses to the changing character of the visual landscape as an
341 agrarian area becomes a tourist destination: Yilan County, Taiwan. *J. Sustain. Tour.*
342 21, 154-171.

343 Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., 2003. Climate
344 change, human impacts, and the resilience of coral reefs. *Science* 301(5635), 929-933.
345 doi:10.1126/science.1085046

346 Hughes, T.P., Day, J.C., Brodie, J., 2015. Securing the future of the Great Barrier Reef. *Nature*
347 *Climate Change* 5, 508-511. doi:10.1038/nclimate2604

348 Hughes, T.P., Kerry, J.T., Alvarez-Noriega, M., Alvarez-Romero, J.G., Anderson, K.D., Baird,
349 A.H., Babcock, R.C., Beger, M., Bellwood, D.R., Berkelmans, R., Bridge, T.C., Butler,
350 I.R., Byrne, M., Cantin, N.E., Comeau, S., Connolly, S.R., Cumming, G.S., Dalton, S.J.,
351 Diaz-Pulido, G., Eakin, C.M., Figueira, W.F., Gilmour, J.P., Harrison, H.B., Heron, S.F.,
352 Hoey, A.S., Hobbs, J.A., Hoogenboom, M.O., Kennedy, E.V., Kuo, C.Y., Lough, J.M.,
353 Lowe, R.J., Liu, G., McCulloch, M.T., Malcolm, H.A., McWilliam, M.J., Pandolfi, J.M.,
354 Pears, R.J., Pratchett, M.S., Schoepf, V., Simpson, T., Skirving, W.J., Sommer, B.,
355 Torda, G., Wachenfeld, D.R., Willis, B.L., Wilson, S.K., 2017. Global warming and
356 recurrent mass bleaching of corals. *Nature* 543, 373-377. doi:10.1038/nature21707

357 Jaap, W.C., 2000. Coral reef restoration. *Ecological Engineering* 15, 345-364.

358 Jobstvogt, N., Watson, V., Kenter, J.O., 2014. Looking below the surface: The cultural
359 ecosystem service values of UK marine protected areas (MPAs). *Ecosystem Services*
360 10, 97-110. doi:10.1016/j.ecoser.2014.09.006

361 Junge, X., Schüpbach, B., Walter, T., Schmid, B., Lindemann-Matthies, P., 2015. Aesthetic
362 quality of agricultural landscape elements in different seasonal stages in Switzerland.
363 *Landscape and Urban Planning* 133, 67-77. doi:10.1016/j.landurbplan.2014.09.010

364 Lecuyer, L., White, R.M., Schmook, B., Calme, S., 2018. Building on common ground to
365 address biodiversity conflicts and foster collaboration in environmental management.
366 Journal of Environmental Management 220, 217-226.
367 doi:doi.org/10.1016/j.jenvman.2018.05.014

368 Lee, L.-H., 2017. Appearance's Aesthetic Appreciation to Inform Water Quality Management of
369 Waterscapes. Journal of Water Resource and Protection 09, 1645-1659.
370 doi:10.4236/jwarp.2017.913103

371 Levin, P.S., Damon, M., Samhuri, J.F., 2010. Developing meaningful marine ecosystem
372 indicators in the face of a changing climate. Stanford Journal of Law, Science & Policy 2,
373 36-48.

374 Marshall, N., Marshall, P., Curnock, M., Pert, P., Smith, A., Visperas, B., 2019. Identifying
375 indicators of aesthetics in the Great Barrier Reef for the purposes of management. PLoS
376 One 14, e0210196. doi:10.1371/journal.pone.0210196

377 Marshall, N.A., Barnes, M.L., Birtles, A., Brown, K., Cinner, J.E., Curnock, M., Eakin, H.,
378 Goldberg, J., Gooch, M., Kittinger, J.N., Marshall, P., Manuel-Navarrete, D., Pelling, M.,
379 Pert, P.L., Smit, B., Tobin, R., 2018. Measuring What Matters in the Great Barrier Reef.
380 Frontiers in Ecology and the Environment 16, 271-277.

381 Marshall, N.A., Bohensky, E., Curnock, M., Goldberg, J., Gooch, M., Nicotra, B., Pert, P.,
382 Scherl, L.M., Stone-Jovicich, S., Tobin, R.C., 2016. Advances in monitoring the human
383 dimension of natural resource systems: an example from the Great Barrier Reef.
384 Environmental Research Letters 11. doi:10.1088/1748-9326/11/11/114020

385 Marshall, N.A., Curnock, M.I., Goldberg, J., Gooch, M., Marshall, P.A., Pert, P.L., Tobin, R.C.,
386 2017. The Dependency of People on the Great Barrier Reef, Australia. *Coastal*
387 *Management* 45, 505-518.

388 Martin, C.L., Momtaz, S., Gaston, T., Moltschaniwskyj, N.A., 2016. A systematic quantitative
389 review of coastal and marine cultural ecosystem services: Current status and future
390 research. *Marine Policy* 74, 25-32. doi:10.1016/j.marpol.2016.09.004

391 Martínez-Pastur, G., Peri, P., Lencinas, M., García-Llorente, M., Martín-López, B., 2015. Spatial
392 patterns of cultural ecosystem services provision in Southern Patagonia. *Landscape*
393 *Ecology* 31, 383-399. doi:10.1007/s10980-015-0254-9

394 Millennium Ecosystem Assessment, 2003. *Ecosystems and human well-being: a framework for*
395 *assessment*, Washington, DC.

396 Moberg, F., Folke, C., 1999. Ecological goods and services of coral reef ecosystems. *Ecological*
397 *Economics* 29, 215-233.

398 Múgica, M., de Lucio, J.V., 1996. The role of on-site experience on landscape preferences. A
399 case study at Doñana National Park (Spain). *Journal of Environmental Management* 47,
400 229-239.

401 Outeiro, L., Gajardo, C., Oyarzo, H., Ther, F., Cornejo, P., Villasante, S., Ventine, L.B., 2015.
402 Framing local ecological knowledge to value marine ecosystem services for the
403 customary sea tenure of aboriginal communities in southern Chile. *Ecosystem Services*
404 16, 354-364. doi:10.1016/j.ecoser.2015.04.004

405 Rosley, M.S.F., Lamit, H., Rahman, S.R.A., 2013. Perceiving the Aesthetic Value of the Rural
406 Landscape Through Valid Indicators. *Procedia - Social and Behavioral Sciences* 85,
407 318-331. doi:10.1016/j.sbspro.2013.08.362

408 Schirpke, U., Tasser, E., Tappeiner, U., 2013. Predicting scenic beauty of mountain regions.
409 *Landscape and Urban Planning* 111, 1-12. doi:10.1016/j.landurbplan.2012.11.010

410 Schmidt, P.M., Peterson, M.J., 2009. Biodiversity Conservation and Indigenous Land
411 Management in the Era of Self-Determination. *Conservation Biology* 23, 1458-1466.

412 Seresinhe, C.I., Preis, T., Moat, H.S., 2015. Quantifying the Impact of Scenic Environments on
413 Health. *Sci Rep* 5, 16899. doi:10.1038/srep16899

414 Sheppard, S.R.J., 2004. Visual analysis of forest landscapes. *Planning* 44, 177-198.

415 Spalding, M., Burke, L., Wood, S.A., Ashpole, J., Hutchison, J., zu Ermgassen, P., 2017.
416 Mapping the global value and distribution of coral reef tourism. *Marine Policy* 82, 104-
417 113. doi:10.1016/j.marpol.2017.05.014

418 Tamayo, N.C.A., Anticamara, J.A., Acosta-Michlik, L., 2018. Estimates of Values of Philippine
419 Reefs' Ecosystem Services. *Ecological Economics* 146, 633-644.

420 Tardieu, L., Tuffery, L., 2019. From supply to demand factors: What are the determinants of
421 attractiveness for outdoor recreation? *Ecological Economics* 161, 163-175.
422 doi:10.1016/j.ecolecon.2019.03.022

- 423 Tosic, M., Narváez-Flórez, S., Parra, J.P., 2014. Selection of parameters in the design of beach
424 coastal water quality monitoring programs. *Intropica* 8, 43-51.
- 425 Turek, J.G., 2000. Science and technology needs for marine fishery habitat restoration, *Oceans*
426 2000 Mts/leee - Where Marine Science and Technology Meet, Vols 1-3, Conference
427 Proceedings, pp. 1707-1712.
- 428 Van den Berg, A.E., Vlek, C.A., Coeterier, J.F., 1998. Group differences in the aesthetic
429 evaluation of nature development plans: a multilevel approach. *Journal of Environmental*
430 *Psychology* 18, 141–157 doi:0.1006/jevp.1998.0080
- 431 van der Jagt, A.P.N., Craig, T., Anable, J., Brewer, M.J., Pearson, D.G., 2014. Unearthing the
432 picturesque: The validity of the preference matrix as a measure of landscape aesthetics.
433 *Landscape and Urban Planning* 124, 1-13. doi:10.1016/j.landurbplan.2013.12.006
- 434 van Zanten, B.T., Van Berkel, D.B., Meentemeyer, R.K., Smith, J.W., Tieskens, K.F., Verburg,
435 P.H., 2016. Continental-scale quantification of landscape values using social media
436 data. *Proc Natl Acad Sci U S A* 113, 12974-12979. doi:10.1073/pnas.1614158113
- 437 Vercelloni, J., Clifford, S., Caley, M.J., Pearse, A.R., Brown, R., James, A., Christensen, B.,
438 Bednarz, T., Anthony, K., Gonzalez-Rivero, M., Mengersen, K., Peterson, E.E., 2018.
439 Using virtual reality to estimate aesthetic values of coral reefs. *R Soc Open Sci* 5,
440 172226. doi:10.1098/rsos.172226

441 Vlami, V., Kokkoris, I.P., Zogaris, S., Cartalis, C., Kehayias, G., Dimopoulos, P., 2017. Cultural
442 landscapes and attributes of "culturalness" in protected areas: An exploratory
443 assessment in Greece. *Science of the Total Environment* 595, 229-243.

444 Werner, S.R., Spurgeon, J.P.G., Isaksen, G.H., Smith, J.P., Springer, N.K., Gettleson, D.A.,
445 N'Guessan, L., Dupont, J.M., 2014. Rapid prioritization of marine ecosystem services
446 and ecosystem indicators. *Marine Policy* 50, 178-189. doi:10.1016/j.marpol.2014.03.020

447 Wessel, C.C., McDonald, A., Cebrian, J., 2018. An evaluative tool for rapid assessment of
448 derelict vessel effects on coastal resources. *Journal of Environmental Management* 207,
449 262-268.

450 Wet Tropics Management Authority, 2017. *Natural Beauty and Aesthetic Value of the Wet*
451 *Tropics World Heritage Area*. Wet Tropics Management Authority, Cairns.

452 Wielgus, J., Chadwick-Furman, N.E., Dubinsky, Z., Shechter, M., Zeitouni, N., 2002. Dose-
453 Response Modeling of Recreationally Important Coral Reef Attributes: A Review and
454 Potential Application to the Economic Valuation of Damage. *Coral Reefs* 21, 253-259.

455 Wilkinson, C.R., 1996. *Global Change and Coral Reefs: Impacts on Reefs, Economies and*
456 *Human Cultures*. *Global Change Biology* 2, 547-558.

457 Williams, D.W., Polunin, N.V.C., 2000. Differences between Protected and Unprotected Reefs
458 of the Western Caribbean in Attributes Preferred by Dive Tourists. *Environmental*
459 *Conservation* 27, 382-391.

460 Xu, W., Lippke, B.R., Perez-Garcia, J., 2003. Valuing Biodiversity, Aesethetics, and Job Losses
461 Associated with Ecosystem Management Using Stated Preferences. *Forest Science* 49,
462 247-257.

463 Young, J.C., Marzano, M., White, R.M., McCracken, D.I., Redpath, S.M., Carss, D.N., Quine,
464 C.P., Watt, A.D., 2010. The emergence of biodiversity conflicts from biodiversity impacts:
465 characteristics and management strategies. *Biodiversity and Conservation* 19, 3973-
466 3990. doi:10.1007/s10531-010-9941-7
467