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1 **Convergence of stakeholders' environmental threat perceptions** 2 **following mass coral bleaching of the Great Barrier Reef**

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5

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23 **Abstract**

24 Managing human use of ecosystems in an era of rapid environmental change requires an
25 understanding of diverse stakeholders' behaviors and perceptions to enable effective
26 prioritization of actions to mitigate multiple threats. Specifically, research examining how
27 threat perceptions are shared or diverge among stakeholder groups, and how these can
28 evolve through time, is increasingly important. Here, we investigate environmental threat
29 perceptions related to Australia's Great Barrier Reef and explore their associations before
30 and after consecutive years of mass coral bleaching. Using survey responses from 2013 and
31 2017 involving commercial fishers, tourism operators, and coastal residents (n=5,254), we

32 found that the threats perceived as most serious by these groups differed substantially in
33 the pre-bleaching period but became strongly aligned post-bleaching. Climate change
34 became the most frequently reported threat by all stakeholder groups following the coral
35 bleaching events, and perceptions of fishing and water quality also ranked high. For the
36 three stakeholder groups of fishers, tourism operators, and coastal residents, the
37 prioritization of these three threats tended to diverge in 2013, but convergence became
38 evident post-bleaching. These results indicate an emergence of areas of agreement within
39 and across stakeholder groups. Changes in perceptions were likely influenced by high profile
40 environmental disturbance events and media representations of attributable threats. Our
41 study provides insights into the plasticity of environmental threat perceptions and highlights
42 how their convergence in response to major events may create new opportunities for
43 strategic public engagement and increasing support for management actions.

44 **Introduction**

45 Stakeholder support for conservation and environmental management initiatives is key to
46 their successful implementation (Bennett & Dearden 2014; Alexander et al. 2018). Failure to
47 secure community support can lead to public resistance and backlash from stakeholders,
48 non-compliance and ultimately, a lack of achievement of social and ecological objectives
49 (Pollnac et al. 2010; Gurney et al. 2014). Different perceptions among different users and
50 audiences about the relative seriousness of environmental threats is often at the heart of
51 such resistance, affecting public support for management strategies designed to respond to
52 those threats (Voyer et al. 2013).

53 People perceive environmental threats in diverse ways. Complex threats like climate change
54 are characterized by great variation in perceptions and experience, such that no unifying
55 theory is applicable (Wolf & Moser 2011). This is because risk judgement, where individuals
56 assess risks based on the probability of a threat and its relative consequences, incorporates
57 considerations such as personal worldviews, affiliation and proximity, emotional affect, and
58 trust (Slovic 1999; Elliott 2003). These risk assessments are mediated by a variety of societal
59 determinants including experiential and sociocultural factors like social norms and cultural
60 cognition (Slovic 1999; Kahan & Braman 2006; Gattig & Hendrickx 2007). Furthermore, they
61 are amplified or attenuated by institutions such as the media and political systems
62 (Kasperson & Kasperson 1996; Voyer et al. 2013; Foxwell-Norton & Lester 2017). As a result,
63 perceptions may differ greatly among social subgroups (e.g. livelihood groups).

64 The socially constructed nature of environmental threat perceptions also raises the question
65 of how sensitive such perceptions are to contextual change, including environmental
66 change. Indeed, in addition to potentially affecting individuals' personal experiences,
67 environmental crises often attract increased levels of media coverage of the threat in
68 question, which may lead to shifts in public concern over certain issues (Carmichael & Brulle
69 2017; Curnock et al. 2019). However, the social effects of such crises are context-dependent,
70 and such shifts in concern only happen in amenable public arenas, where widely shared
71 cultural, institutional and political conditions enable sustained attention to the crisis (Ungar
72 2014). Analyzing how threat perceptions within a community change in response to events
73 or shocks within a social-ecological system can help to better understand the emergence

74 and dissipation of common and conflicting perceptions, and identify the key drivers of these
75 changes (Siegrist 2013). Such knowledge is valuable for resource managers seeking to
76 engage successfully with communities to raise awareness and encourage participation in the
77 design and implementation of socially relevant management actions (Kochalski et al. 2019).
78 However, despite recognition of the potential plasticity of community perceptions of
79 environmental threats, most assessments of perceptions are static and the temporal
80 dynamics are rarely studied explicitly (Siegrist 2013).

81 In order to fill this gap, we set out to evaluate changes in stakeholders' perceptions of key
82 environmental threats in the context of a major environmental disruption. Specifically, we
83 examine the prioritization of environmental threats within and among three distinct
84 stakeholder groups (commercial fishers, tourism operators, and coastal residents) in the
85 Great Barrier Reef (GBR or Reef) region, Australia, before and after the unprecedented and
86 wide-spread climate-change induced coral bleaching events in 2016 and 2017 (Hughes et al.
87 2018a, 2018b). We ask: (1) Do fishers, tourism operators, and coastal residents perceive
88 environmental threats differently? (2) What are the positive and negative associations
89 between the identified threats? (3) Did threat prioritization and associations within and
90 among stakeholder groups change following the mass coral bleaching events? The GBR
91 represents an important case study to help improve our understanding of the
92 responsiveness of environmental threat perceptions to major risk events among interest
93 groups and the general public. This importance is underpinned by its World Heritage and
94 iconic status, the multiple uses and dependencies of adjacent communities and industry
95 sectors, the complexity of threats it faces from local to global scales, and the myriad
96 intangible social and cultural values with which it is associated (Gurney et al. 2017; Marshall
97 et al. 2019a; Curnock et al., 2019). It is hoped that our study will provide social scientists,
98 conservation practitioners and resource managers with an improved understanding of the
99 dynamic nature of environmental threat perceptions, to facilitate more purposeful and
100 effective public engagement around threat mitigation in their responses to future risk
101 events.

102 **Methods**

103 **The Great Barrier Reef**

104 The Great Barrier Reef (GBR) is the largest coral reef system in the world, spanning 2,300 km
105 along the east coast of Queensland, Australia. Despite being considered one of the best
106 managed systems globally (McCook et al. 2010), live coral cover has declined by an average
107 of 0.67 %/year since 1996 as a result of cumulative impacts from multiple, interacting
108 threats (Mellin et al. 2019). Through an evidence-based assessment process, the Great
109 Barrier Reef Marine Park Authority (GBRMPA) has consistently identified climate change as
110 the greatest threat to the GBR since 2009 (GBRMPA, 2009; 2014; 2019a). Other major
111 threats identified through this process include poor water quality (i.e., nutrient, sediment
112 and pesticide runoff), coastal development, some remaining impacts of fishing and illegal
113 fishing and poaching, and outbreaks of Crown-of-Thorns Starfish (COTS). Collectively these
114 threats have resulted in a downgrading of the overall outlook for the GBR from “poor”
115 (GBRMPA 2009, 2014) to “very poor” in recent years (GBRMPA 2019a).

116 In response to these assessments, a series of management interventions aimed at protecting
117 biodiversity and increasing ecosystem resilience have been developed (Great Barrier Reef
118 blueprint for resilience 2017). Further, a variety of community engagement initiatives and
119 programs led by GBRMPA (e.g. Eye on the Reef, Reef Guardian, Reef Joint Field Management
120 Program, Local Marine Advisory Committees, Reef Advisory Committees) have provided
121 avenues to foster stakeholders’ support for management and engagement in stewardship
122 activities.

123 **GBR stakeholder groups**

124 We compared threat perceptions among three key stakeholder groups of the GBR region,
125 namely commercial fishers, tourism operators and coastal residents. These groups have
126 different levels and types of direct interaction with the GBR and therefore, we hypothesized
127 may have different threat perceptions. The former two groups represent the two largest
128 reef-dependent industries on the GBR region, but they engage with the Reef in different
129 ways and have distinct socio-demographic and political characteristics (Curnock et al. 2014;
130 Tobin et al. 2014). GBR tourism operators tend to be entrepreneurial, have achieved a high
131 level of education, and are sensitive to tourists’ perceptions and media representations of
132 GBR threats (Curnock et al. 2014, 2019; Curnock & Marshall 2019). Commercial fishers have
133 been found to be a relatively homogeneous male-dominated group, and tend to be older

134 and more politically conservative than tourism operators (Tobin et al. 2014; Marshall &
135 Curnock 2019a).

136 **Data collection and coding of threats**

137 Data on environmental threat perceptions was elicited through surveys with 5,254
138 individuals in 2013 (n=3,304) and 2017 (n=1,950) as part of the Social and Economic Long-
139 Term Monitoring Program (SELTMP) for the GBR (Marshall et al. 2016). In the 2013 survey,
140 respondents included 2,975 coastal residents, 210 commercial fishers and 119 owners and
141 managers of marine and island tourism businesses operating in the GBR. In the 2017 survey,
142 they included 1,765 coastal residents, 91 commercial fishers and 94 tourism operators.
143 National and international tourists were also surveyed in the SELTMP but were not included
144 in this analysis because this paper focuses on local stakeholders. Coastal residents and
145 tourists were surveyed using face-to-face interviews in the main population centers along
146 the GBR, and tourism operators and commercial fishers were interviewed by telephone. For
147 both the 2013 and 2017 sampling periods, the research was reviewed and approved by the
148 CSIRO Social Science Human Research Ethics Committee, and was conducted in accordance
149 with the Australian National Statement on Ethical Conduct in Human Research (2007).

150 To elicit threat perceptions, respondents were asked to list the “three most serious threats
151 to the GBR” in a short, open-ended format. Responses were collated and then each was
152 numerically coded (1=yes; 0=no) into 13 broad thematic categories (Table 1; these
153 categories are described further in Curnock et al. (2019)). The coding and analysis did not
154 take into account the ranking or order of threats as listed by the respondents. The SELTMP
155 surveys also obtained information on gender and age, which have been shown to influence
156 perceptions (Jefferson et al. 2014) and were thus used to control for unbalanced sampling
157 across years (Supporting Information). Additional details on survey design and
158 administration in the SELTMP are available at (CSIRO 2019).

159 **Data analysis**

160 We explored changes in threat perceptions through three distinct analyses. First, we focused
161 on the change in occurrence of threats over time *within* stakeholder groups. For each of the
162 12 threat categories (“other” was excluded), we used a general linear model (GLM) with a
163 binomial fit, where the response variable was threat occurrence and the predictor variables

164 were stakeholder group membership, year, gender and age. An interaction between group
165 membership and year was examined to elucidate whether perceptions of the threat differed
166 significantly across the two time periods for different groups. Demographic variables were
167 included to control for bias in unequal distribution of samples on both years.

168 Second, for each threat category we assessed the variation in threat occurrences in each
169 year *among* stakeholder groups. We used GLMs with a binomial fit of threat occurrence as a
170 function of stakeholder group, gender, and age and quantified the variation in the response
171 that was explained by the 'stakeholder group' covariate using the models' estimated
172 variance.

173 Third, we examined the associations between perceived threats in each stakeholder group
174 using probabilistic models of threat co-occurrence. Expected frequency of co-occurrence
175 was determined based on the distribution of each threat being random and independent of
176 the other threats. We compared the observed and expected frequencies of co-occurrence
177 between each pair of threats to determine which threats tended to be statistically more or
178 less identified together than expected by chance. All analyses were implemented in R
179 statistical analysis software version 3.6.2 (R Core Team 2017).

180 **Results**

181 Analysis of within-stakeholder group perception changes revealed both significant increases
182 and decreases in the occurrence of several threats from 2013 to 2017 (Fig. 1). The direction
183 of these changes was generally consistent across the three stakeholder groups. Between
184 2013 and 2017, most notably, there was an increase in the perceived threat of 'climate
185 change' across all groups (though not significant for tourism operators because it was
186 already considered a priority threat by this group in 2013), with commercial fishers showing
187 the largest relative shift. 'Pollution' also became more frequent among the three threats
188 perceived as most serious to the GBR, although increases were only significant for coastal
189 residents and tourism operators. The proportion of respondents perceiving 'coastal
190 development' and 'shipping' among the top three threats fell significantly across all groups.
191 The occurrence of 'fishing' increased sharply among fishers, and decreased slightly (but
192 significantly) among residents. Over the four-year sampling interval, the occurrence of 'poor
193 water quality' also decreased for all stakeholder groups, but the change was only significant

194 for residents. Although significant for residents, the magnitude of the changes in occurrence
195 probability remained relatively low for other threat categories (Fig. 1).

196 In 2013, threats that were perceived as being the most serious for the GBR differed *between*
197 stakeholder groups (Fig. 2). Fishers were primarily concerned with 'coastal development'
198 ($p=0.38$), while tourism operators were most concerned about 'poor water quality' ($p=0.40$),
199 and coastal residents indicated 'shipping' as the most serious threat ($p=0.36$). In 2017,
200 however, 'climate change' became the threat most likely to be identified among the top
201 three most serious threats to the GBR by all stakeholder groups (fishers: $p=0.43$; operators:
202 $p=0.53$; residents: $p=0.55$). 'Fishing' was the second threat most likely to be mentioned by
203 fishers ($p=0.42$) and ranked third for tourism operators ($p=0.23$) and residents ($p=0.26$).
204 Other environmental threats that ranked high in 2017 included poor water quality (fishers:
205 $p=0.30$; operators: $p=0.27$; residents: $p=0.22$), governance (fishers: $p=0.21$; operators:
206 $p=0.23$) and pollution (residents: $p=0.45$).

207 In 2013, it was also noted that there was significant variation *among* stakeholders in their
208 perceptions for all threats except 'poor water quality', with stakeholder group accounting
209 for 12%-34% of the variation in threat perceptions (Fig. 3). Fishers tended to list 'climate
210 change' significantly less frequently than tourism operators and coastal residents. Residents
211 listed 'pollution' and 'shipping' more frequently than other groups. Although not statistically
212 significant, tourism operators tended to identify 'poor water quality' and 'climate change'
213 more frequently than fishers and residents. The variation among stakeholders decreased
214 markedly in 2017, with the variable 'stakeholder group' accounting for just 6%-16% of the
215 variation in environmental threat perceptions (Fig. 3). The largest variations in 2017 were in
216 'pollution' and 'fishing', which occurred more frequently among residents and fishers,
217 respectively.

218 In 2013, interactions between the perceived key threats did not overlap among the
219 stakeholder groups and revealed more negative associations than positive associations for
220 all three stakeholder groups (Fig. 4). For example, 'climate change' was negatively associated
221 with 'natural disasters', 'coastal development' and 'pollution' for fishers; with 'fishing' and
222 'mining' for tourism operators; and with 'COTS' for coastal residents (Fig. 4). In the fishers'
223 network, two other negative associations ('pollution' with 'poor water quality'; and 'fishing'

224 with 'governance') and one positive association ('natural disasters' with 'mining') were
225 evident. In the tourism operators' network, 'coastal development' was negative associated
226 with 'governance', while 'pollution' significantly co-occurred with 'shipping'. In the residents'
227 network, negative associations between 'COTS' and 'governance', and between 'fishing' and
228 the 'pollution'–'humanity' positive association cluster were identified. Contrary to 2013,
229 interactions between the key perceived threats in 2017 revealed more positive than
230 negative associations, with clear overlap between stakeholder groups (Fig. 4). 'Climate
231 change' formed new positive associations with 'fishing' and 'poor water quality' for all
232 stakeholder groups. In the fishers' network, 'fishing' and 'poor water quality' became also
233 positively associated. Tourism operators' and residents' networks both displayed a negative
234 association between 'climate change' and 'COTS'; for the operators' network, this negative
235 association was part of an interactions cluster of 'COTS' (negative) with 'climate change' and
236 'poor water quality' (positive).

237 **Discussion**

238 Community and stakeholder support is often critical for conservation success.
239 Understanding community perceptions of environmental threats, and how these may vary
240 between social subgroups and over time is therefore important for guiding strategic
241 engagement and policy development. Our analysis of environmental threat perceptions of
242 commercial fishers, tourism operators, and coastal residents with respect to the GBR across
243 two time periods revealed three key results. First, environmental threat perceptions can
244 shift in a relatively short time in response to contextual changes. Second, following a major
245 environmental disturbance event, stakeholder groups increasingly identified similar threats,
246 both between and among groups. Lastly, the perceived threat of climate change rose to
247 become the most prominent source of concern for each of the stakeholder groups.

248 **Plasticity of environmental threat perceptions**

249 The major shift in threat perceptions over a relatively short time period in our case study
250 points to the plasticity of these perceptions. Whilst recent studies indicate that people do
251 not consider the media a trusted source of information about the GBR (MacKeracher et al.
252 2018), they also acknowledge the media's centrality in communication about environmental
253 issues (Foxwell-Norton & Lester 2017). The majority of the public, including those who live

254 closest to the GBR, have little direct experience of the Reef and rely on visual
255 representations largely shaped by information and knowledge communicated through the
256 media. In our case, the observed changes in threat perceptions appear to reflect the relative
257 prominence of different threats communicated in the media. For example, the grounding of
258 a coal carrier on a shoal in the GBR in 2010 and controversy over the Abbot Point Capital
259 Dredging Project in 2013 received extensive media coverage at the time, and were
260 considered likely to have influenced public perceptions of the risks posed by shipping and
261 coastal development to the GBR (Lankester et al. 2015). We suspect that the visibility of
262 these two events in the media influenced the high degree of concern about these threats in
263 the 2013 survey. In the 2017 survey, however, our results reveal that climate change
264 became the foremost issue for all local stakeholder groups. The extent, magnitude and
265 ecological impact of the 2016 and 2017 mass bleaching events (Hughes et al. 2018a, 2018b)
266 and the considerable attention from the media that explicitly attributed the events to
267 climate change likely increased people's concerns about this issue (Eagle et al. 2018;
268 Curnock et al. 2019; Boudet et al. 2019). Together, these results indicate that shifts in
269 perceptions were related in part to changes in the predominance of particular issues in the
270 media (Lee et al. 2015; Boudet et al. 2019), and are suggestive of the media's importance
271 and likely influence on public perceptions.

272 Media constructions of threats to the GBR have been implicated in the divergence of
273 perceptions held by the public and those of managers regarding which threats are most
274 critical (Moscardo 2008). The contribution of journalistic norms, whereby some issues are
275 given primacy in reporting over others (Boykoff & Boykoff 2007), may provoke or further
276 exacerbate such incongruity (Voyer et al. 2013). For instance, some have proposed that
277 increased attention to plastic pollution in the media over recent years may have a
278 "crowding-out effect" on the urgency of other threats for which the consensus among
279 scientists and managers is better established, such as climate change (Stafford & Jones
280 2019). However, our results from 2017 do not show a negative association between
281 'pollution' and 'climate change' (or any other threat), disputing the presence of such an
282 effect in our case. Although it should be noted that a high proportion of residents cited
283 plastic pollution as a key threat to the GBR (Supporting Information).

284 **Climate change as a primary source of concern for the GBR**

285 In 2017, after the GBR experienced some of the worst and most widespread effects of
286 climate change on live coral (Hughes et al. 2018a) and associated fish assemblages
287 (Richardson et al. 2018), climate change was the most frequently mentioned threat for all
288 stakeholder groups (42-55% of the 2017 sample). Our finding that 55% of coastal residents
289 perceive climate change in the top three threats to the GBR only partly aligns with results
290 from a report (based on data from the same survey that we employed) that found that 68%
291 of respondents considered climate change “an immediate threat requiring action”; Marshall
292 & Curnock 2019). This discrepancy may be because the latter question relates the threat of
293 climate change in general terms, while our paper examines the threat of climate change to
294 the GBR specifically.

295 While many news media representations of the 2016-17 mass coral bleaching events
296 attributed climate change as the cause (Eagle et al. 2018), there was a concurrent
297 “alternative facts” campaign in Australia run by vested-interest groups and conservative
298 news media that denied the climate change attribution (Opray 2019). Survey respondents’
299 political orientation and their primary sources of news in relation to the coral bleaching
300 event could have influenced their threat perceptions and acceptance of climate change as
301 the cause of recent mass bleaching (Lee et al. 2015). As climate-related environmental
302 communication campaigns are susceptible to polarization and misinformation, managers
303 and scientists face serious challenges in a media landscape that is increasingly susceptible to
304 the intentional dissemination of misleading content (van der Linden 2019). In Australia, this
305 is confounded by a highly concentrated media ownership (Holmes & Star 2018) and
306 increasingly skeptical climate change reporting (Bacon 2013).

307 We note that in the Austral summer of 2020, a third climate-induced mass coral bleaching
308 event occurred in the GBR, coinciding with the onset of the global COVID-19 pandemic. The
309 concurrence of these two major events raises questions about whether public perceptions
310 about the threat of climate change have increased in prominence, or if the pandemic has
311 “crowded-out” such concerns by affecting reporting opportunities related to this last
312 bleaching event. Further studies may be able to elucidate the relative effects of these
313 historically significant events.

314 **Convergence of threat perceptions within the community**

315 Achieving consensus among stakeholders is a persistent challenge with consequences that
316 can affect the success of decision-making (Hicks et al. 2013). Shared perceptions within the
317 community can help practitioners identify joint management goals and reduce disagreement
318 between different stakeholder groups that potentially hold dissimilar knowledge and values
319 (Sutton & Tobin 2009; de Nooy 2013). Increased similarity in perceptions of the most serious
320 threats to the GBR across stakeholder groups in 2017 suggests that GBR managers may be
321 better situated to develop management strategies that are likely to receive broad-based
322 support (Horowitz et al. 2018). Our findings also suggest which strategies are likely to work
323 well in public communication because they are directed towards threats that resonate with
324 the majority of stakeholders. In particular, climate change, which now ranks at the top of the
325 list across all stakeholder groups, may represent a relevant entry point for engagement with
326 other relevant issues that also ranked high among fishers, tourism operators and residents,
327 such as water quality and fishing. This also suggests that most people would accept
328 GBRMPA's framing that links climate change resilience to improved water quality and strong
329 fishing regulation (GBRMPA 2019b), and highlights a potential window of opportunity for
330 managers to engage with synergistic policy interventions to protect the Reef and other
331 ecosystems (Morrison et al. 2019).

332 Although threat perceptions held by the different stakeholder groups became more aligned
333 in 2017, some differences remained. Commercial fishers were increasingly concerned about
334 the threat posed by fishing, with concerns centered around overfishing (~50% of fishing
335 threats were related to overfishing; Supporting Information). Whether they considered
336 themselves as contributing to overfishing was not explored further in our survey. However,
337 given that 40% of identified fishing threats related to recreational fishing, it appears that
338 many commercial fishers did not consider their group responsible for the threat. Coastal
339 residents were substantially more concerned about pollution (Fig. 1), including plastic
340 pollution (Supporting Information). This may be because residents' first-hand experience of
341 the GBR is generally limited to local beaches where the most visible threat is marine debris
342 (Marshall et al. 2019b). Further, recent years have seen significant media coverage of the
343 threat of plastic pollution to global ocean environments (Stafford & Jones 2019).

344 Identifying and engaging key stakeholder groups is important, but such groups are rarely
345 homogenous (D'Anna 2016). As a result, decision-makers looking for consensus by focusing
346 engagement on the most serious threats may neglect potentially complex interactions that
347 could lead to sub-optimal outcomes. For example, there is a risk that apparent similarities
348 between stakeholder groups may mask conflicts within these groups that, if not addressed,
349 would ultimately affect whether individuals support management actions. Our analysis of
350 the associations between threats found that most negative associations present in 2013
351 were absent four years later. Instead, positive associations between high-priority threats
352 (i.e. 'climate change', 'poor water quality', and 'fishing') became evident within all
353 groups, suggesting that addressing these threats may now be perceived as complementary.

354 While the most frequently mentioned threats were increasingly identified together, some
355 negative associations remained in the post-coral bleaching period. The perception of COTS
356 as a serious threat tended to be negatively associated with those of climate change (among
357 tourism operators and residents) and water quality (for residents). In such cases, a key
358 challenge is to ensure that communications with stakeholder groups focused on one threat
359 do not undermine or detract from what is being communicated about the others. Two
360 approaches for overcoming this challenge warrant examination. First, separate the
361 communication of policies to diminish the tension. For example, policies to address water
362 quality (e.g. grants to farmers to implement best water management practice) and COTS
363 (e.g. COTS control) could be communicated as separate programs, even if they are linked in
364 the management strategy. A second approach is to ensure communication, and policies
365 themselves, explicitly address these tensions; for example, explaining how culling COTS will
366 have positive impacts on the Reef's resilience to climate change (Anthony et al. 2015) or
367 how addressing water quality will reduce COTS outbreaks (Wooldridge & Brodie 2015).

368 Given the 2017 landscape of threat perceptions, a focus on the most widely recognized
369 threats that has positive associations across stakeholders could inform communication of
370 the integrated management strategies to the community, and could have additive effects
371 through providing extra justifications. This means placing most emphasis on the risk posed
372 by climate change, poor water quality, and certain aspects of fishing, and the need for a
373 management approach that articulates multiple threat-mitigating strategies. For example

374 using land-based management in combination with marine protected area networks
375 (McCook et al. 2010; MacNeil et al. 2019). For engagement with particular stakeholders,
376 however, we recommend close consideration of the dominant priorities within each group.

377 Consistent and balanced messaging in response to an environmental crisis can help to
378 achieve attitudinal and behavioral change when framed in accordance to people's values
379 (Kochalski et al. 2019; van der Linden et al. 2019). Indeed, in the case of the GBR, this has
380 been suggested in relation to different forms of place attachment (Gurney et al. 2017). Given
381 the strong attachments that people hold for the GBR and the negative emotions or grief they
382 are exhibiting in response to its degradation (Marshall et al. 2019c, 2019a), engagement
383 relating to threats that leverages different forms of attachment to the GBR may hold
384 promise (Smith & Leiserowitz 2014). Further, targeting messages about the impact of threats
385 on particular habitats (e.g. beaches, estuaries, and iconic reef sites) and species (e.g. whales,
386 turtles, and corals) that stakeholders value (Marshall et al. 2019b) holds additional potential.
387 Finally, leveraging other information channels (e.g. opinion leaders and change agents) and
388 highlighting evidence of effectiveness may have the potential to facilitate impactful
389 messaging that fosters greater stakeholder support for conservation initiatives (Reynolds et
390 al. 2020).

391 **Conclusion**

392 Understanding stakeholders' perceptions of key threats to the natural environment provides
393 critical insights into what kind of management and communication strategies are most likely
394 to resonate with the relevant community. High-profile environmental crises appear to have
395 an important influence on shaping perceptions and may create new opportunities to engage
396 people with mitigation and adaptation. Our approach provides an empirical account of the
397 plasticity of perceptions and shows how stakeholders associate different environmental
398 threats in relation to an iconic natural asset. These findings highlight the importance of
399 further research on this topic and of social monitoring for natural resource management, to
400 understand evolving threat perceptions (and drivers) among different stakeholder groups
401 and communities, providing insights for improved community engagement in threat
402 mitigation policies and actions. Our study further provides guidance for social scientists on

403 conceptual and empirical approaches and analytical tools to elucidate environmental threat
404 perceptions.

405 **Supporting Information**

406 Community information and survey sample (Appendix S1), the proportion of threat sub-
407 categories across stakeholder groups (Appendix S2), within- and among-stakeholder group
408 variation in threat perception between 2013 and 2017 (Appendix S3), and extend methods
409 for data analysis (Appendix 4) are available online. The authors are solely responsible for the
410 content and functionality of these materials. Queries (other than absence of the material)
411 should be directed to the corresponding author.

412 **Literature Cited**

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571 **Table**

572 **Table 1:** Threat categories used to categorize survey participants responses to the open-ended
 573 question “what are the three most serious threats to the Great Barrier Reef?”. See Supporting
 574 Information for distribution of sub-categories and Curnock et al. (2019) for the process for
 575 identifying the categories.

Threat categories	Example responses
Climate change	Climate change; global or ocean warming; rising temperatures; sea level rise; ocean acidification; coral bleaching
Pollution	Pollution; marine debris; litter; plastic; rubbish
Poor water quality	Agricultural, urban and industrial runoffs; sediments; pesticides; sewage; fertilizers
Coastal development	Port expansions; dredging; infrastructures; harbors; coastal development
Crown-of-thorns starfish (COTS)	COTS; the starfish
Fishing	Commercial and recreational fishing and collecting; illegal foreign and domestic fishing; overfishing; poaching
Shipping	Shipping traffic; collisions; oil spills; big tanker ships; ballast waters
Natural disaster	Natural disasters; storms; cyclones; floods; tsunamis; earthquakes
Governance	Mismanagement; bureaucracy; politics; lack of enforcement; corruption; lack of government support or involvement
Tourism	Tourism; trampling; diver impacts; unsustainable tourism
Mining	Mining industry; Adani; coal
Humanity	Overpopulation; damage from humans; human activities; bad human behavior; people; societal attitudes
Other	Habitat loss; invasive species; other

576

577 **Figure legends**

578 **Figure 1:** Changes in the environmental threat perceptions of stakeholder groups between
579 2013 and 2017. Solid points represent occurrence probability estimates and error bars the
580 bootstrapped 95% confidence intervals. Red and blue colors respectively indicate significant
581 increases and decreases in threat occurrence probability within the stakeholder groups over
582 time. OR: odds ratio. $OR > 1$ indicates increased odds of identifying a given threat among the
583 three most serious threats to the GBR. Only the eight most frequently reported threats are
584 displayed. See Supporting Information for results for all threat categories ($n=12$) except
585 'other'.

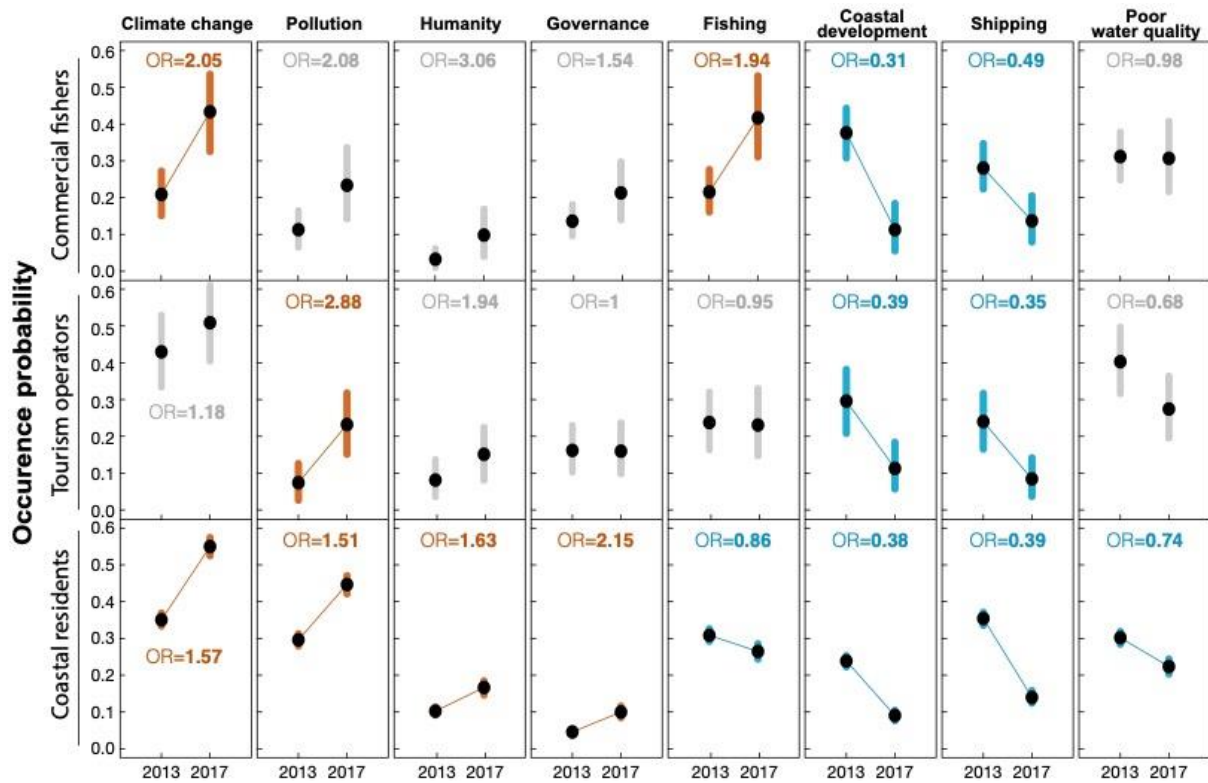
586 **Figure 2:** Changes in the rankings of perceived threats to the GBR between 2013 and 2017
587 across stakeholder groups. The thickness of a band indicates the probability of a particular
588 threat being identified as one of the three most serious threats to the GBR (thicker band
589 means higher probability).

590 **Figure 3:** Variation in threat perceptions among stakeholder groups in 2013 (yellow) and 2017
591 (green). Different letters at the top of bars indicate significant differences among stakeholder
592 groups within each year, as revealed by generalized linear models. N.S.: not significant; F:
593 commercial fishers; O: tourism operators; R: coastal residents. The eight most frequently
594 identified threats are displayed. See Supporting Information for results for all 12 threat
595 categories except 'other'.

596 **Figure 4:** Network diagrams showing interactions among threats prioritized as most serious to
597 the Great Barrier Reef by commercial fishers, tourism operators, and residents in 2013 and
598 2017, based on co-occurrence analysis. The size of the node reflects the threat's occurrence
599 probability (larger node means higher probability). Green ties (interactions) indicate non-
600 random tendencies to co-occur and orange ties indicate non-random tendencies to be
601 associated negatively between pairs of threats (nodes). Ties are only highlighted where the
602 observed frequency of interaction differs from expected random frequency.

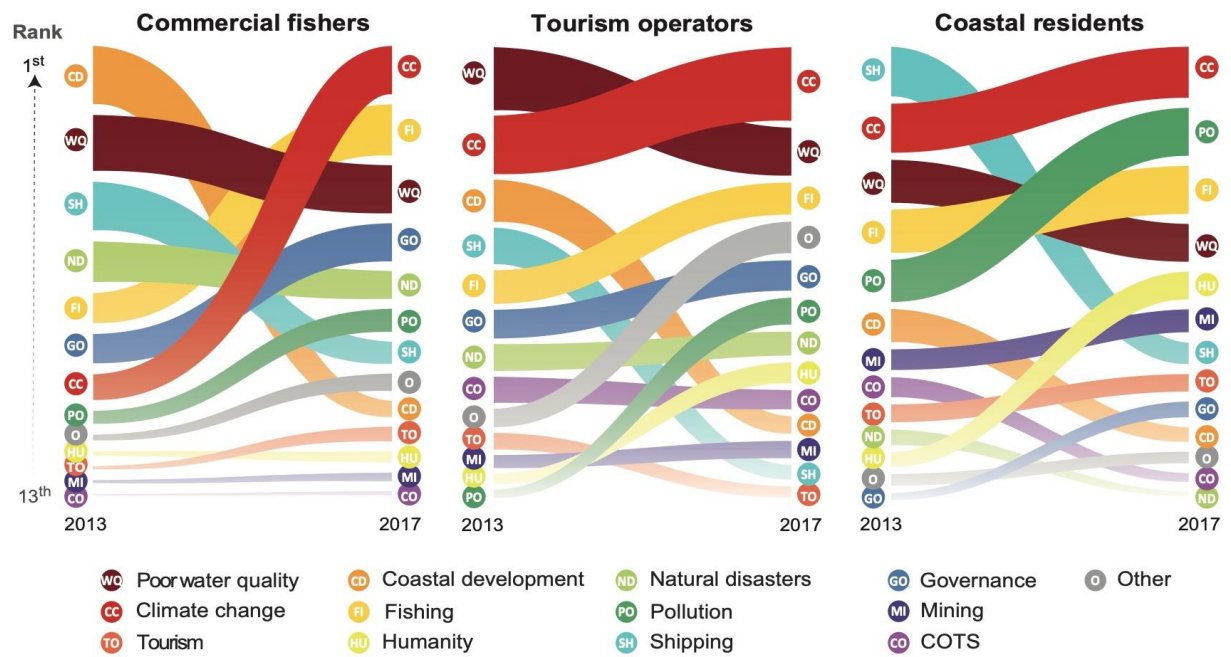
603 **Figures**

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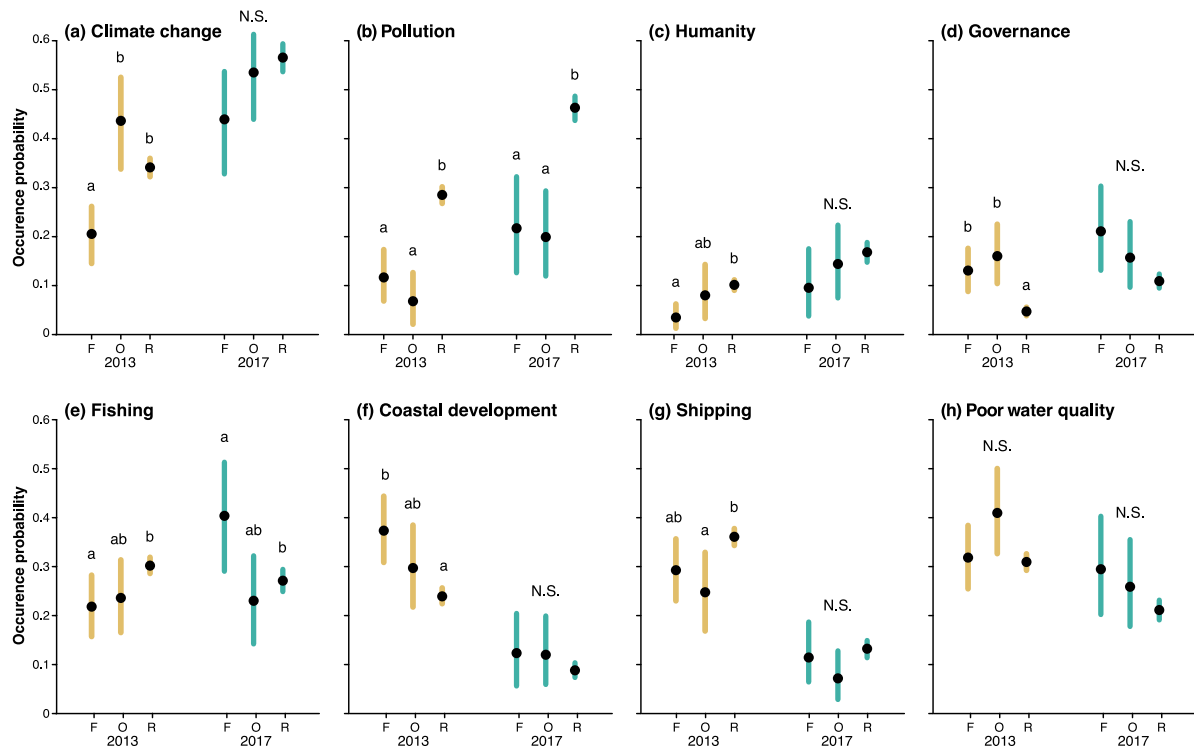
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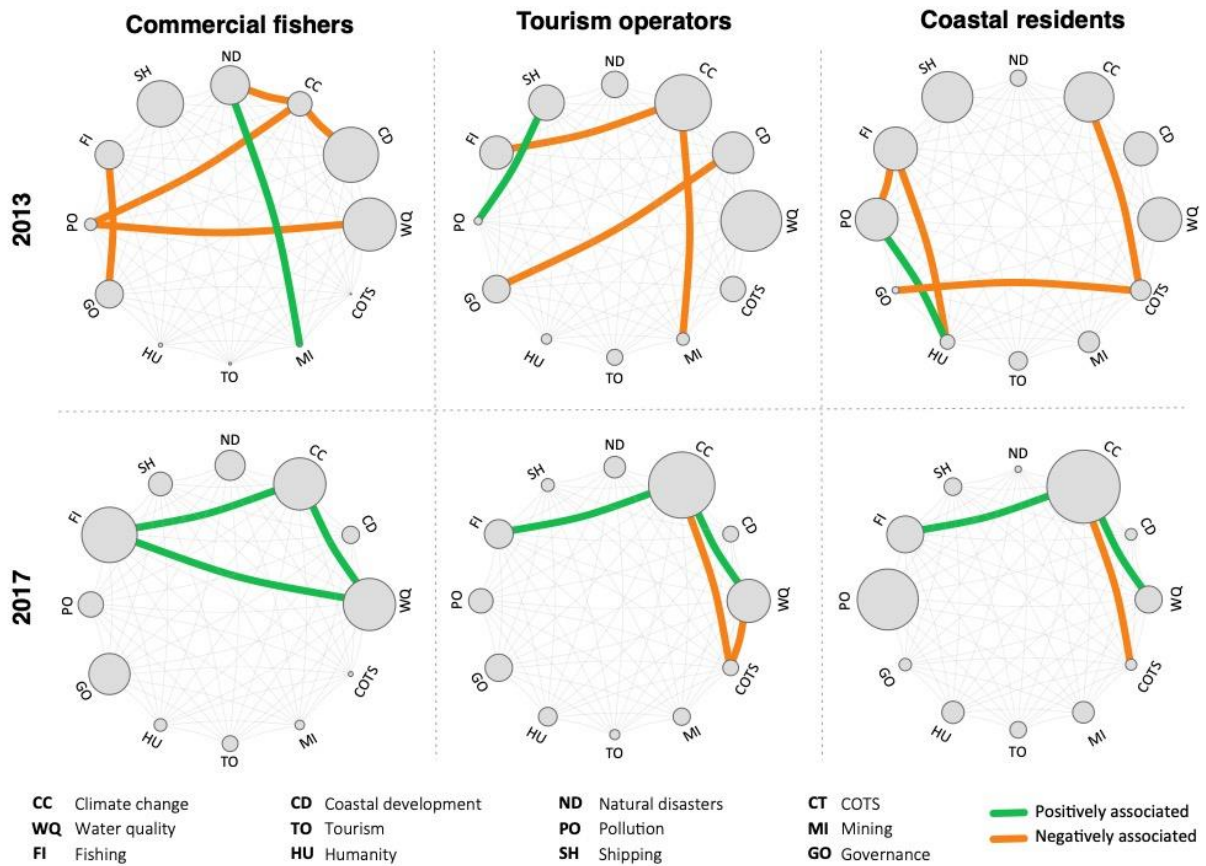
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619

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626

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 631 random tendencies to co-occur and orange ties indicate non-random tendencies to be
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