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RESEARCH ARTICLE

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Climate impacts on the ocean are making the Sustainable Development Goals a moving target travelling away from us

Gerald G. Singh[1] | Nathalie Hilmi[2] | Joey R. Bernhardt[1] | Andres M. Cisneros Montemayor[1] | Madeline Cashion[1] | Yoshitaka Ota[3] | Sevil Acar[4] | Jason M. Brown[5] | Richard Cottrell[6,7] | Salpie Djoundourian[8] | Pedro C. González-Espinosa[1,9] | Vicky Lam[1] | Nadine Marshall[10,11] | Barbara Neumann[12] | Nicolas Pascal[13] | Gabriel Reygondeau[1] | Joacim Rocklöv[14] | Alain Safa[15] | Laura R. Virto[16] | William Cheung[1]

[1]Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, British Columbia, Canada; [2]Centre Scientifique de Monaco, Monaco, Monaco; [3]School of Marine and Environmental Affairs, University of Washington, Seattle, Washington; [4]Center for Climate Change and Policy Studies, Boğaziçi University, Istanbul, Turkey; [5]Faculty of Environment, Simon Fraser University, Burnaby, British Columbia, Canada; [6]Centre for Marine Socioecology, University of Tasmania, Hobart, Tasmania, Australia; [7]Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia; [8]Adnan Kassar School of Business, Department of Economics, Lebanese American University, Byblos, Lebanon; [9]Geography Department, The University of British Columbia, Vancouver, British Columbia, Canada; [10]College of Science & Engineering, James Cook University, Townsville, Queensland, Australia; [11]Land and Water Flagship, Commonwealth Scientific and Industrial Research Organization, Townsville, Queensland, Australia; [12]Institute for Advanced Sustainability Studies (IASS), Potsdam, Germany; [13]Centre de Recherches Insulaires et Observatoire de l'Environnement (CRIOBE), Paris, France; [14]Department of Public Health and Clinical Medicine, Unit of Occupational and Environmental Medicine, Umeå University, Umeå, Sweden; [15]Skill Partners, Grasse, France and [16]i3, Management Research Centre, Ecole Polytechnique & European Institute on Marine Studies, University of West Brittany, Brest, France

Correspondence
Gerald G. Singh, Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada.
Email: g.singh@oceans.ubc.ca

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Abstract

1. Climate change is impacting marine ecosystems and their goods and services in diverse ways, which can directly hinder our ability to achieve the Sustainable Development Goals (SDGs), set out under the 2030 Agenda for Sustainable Development.
2. Through expert elicitation and a literature review, we find that most climate change effects have a wide variety of negative consequences across marine ecosystem services, though most studies have highlighted impacts from warming and consequences of marine species.
3. Climate change is expected to negatively influence marine ecosystem services through global stressors—such as ocean warming and acidification—but also by amplifying local and regional stressors such as freshwater runoff and pollution load.
4. Experts indicated that all SDGs would be overwhelmingly negatively affected by these climate impacts on marine ecosystem services, with eliminating hunger being among the most directly negatively affected SDG.
5. Despite these challenges, the SDGs aiming to transform our consumption and production practices and develop clean energy systems are found to be least affected by marine climate impacts. These findings represent a strategic point of

entry for countries to achieve sustainable development, given that these two goals are relatively robust to climate impacts and that they are important pre-requisite for other SDGs.

6. Our results suggest that climate change impacts on marine ecosystems are set to make the SDGs a moving target travelling away from us. Effective and urgent action towards sustainable development, including mitigating and adapting to climate impacts on marine systems are important to achieve the SDGs, but the longer this action stalls the more distant these goals will become.

KEYWORDS

climate change, expert elicitation, marine ecosystem services, ocean sustainability, Sustainable Development Goals

1 | INTRODUCTION

The ocean provides a variety of functions that benefit people (Palumbi et al., 2009; Peterson & Lubchenco, 1997), and ocean sustainability can promote all aspects of sustainable development, as represented in the Sustainable Development Goals (SDGs; Singh et al., 2018). A healthy ocean can benefit people through a range of mechanisms such as providing raw materials and food sources (Pauly, Christensen, Dalsgaard, Froese, & Torres, 1998), regulating local climates (Charlson, Lovelock, Andreae, & Warren, 1987), providing development and employment opportunities (Golden et al., 2017) and providing places sacred to different cultural groups (Oviedo & Jeanrenaud, 2007). However, climate change is projected to alter marine ecosystems in complex ways which can affect the benefits people derive from the ocean, such as altering marine food webs and rising sea levels (Doney et al., 2011; Harley et al., 2006). In an era of unprecedented global change, understanding how climate change is altering the connections between marine ecosystems and the benefits they contribute to people are imperative. In this paper, we review the effect that climate change has on the oceans and identify how these effects translate to progress towards and ultimately our ability to achieve the SDGs.

Marine ecosystem services, the ecological processes that render benefits to people,[1] face a broad array of risks from climate change, including ocean acidification (which is specific to marine systems), changes to temperature, precipitation, storm frequency and variation, UV radiation, as well as changes to pH and sea level (Doney et al., 2011; Halpern et al., 2008; Harley et al., 2006). Coastal areas are home to a large proportion of the global human population (McGranahan, Balk, & Anderson, 2007; Neumann, Vafeidis, Zimmermann, & Nicholls, 2015), and many small island states are among the world's least developed countries while being highly dependent on marine ecosystem services (Guillaumont, 2010). Thus, marine ecosystems and ecosystem services are an important link between climate change and the SDGs.

The SDGs go beyond the desire to simply end poverty and environmental degradation and instead establish goals for a ‘future we want’ (UN, 2015). The SDGs are wide ranging, including goals for poverty alleviation (SDG 1), eliminating hunger (SDG 2) and improving health (SDG 3), ensuring minimum education standards (SDG 4), reducing inequalities for women (SDG 5) and marginalized groups (SDG 10), enhancing access to clean water (SDG 6) and energy sources (SDG 7), economic growth and job creation (SDG 8), making infrastructure (SDG 9) and cities (SDG 11) environmentally sustainable, restructuring supply and consumption systems (SDG 12), conserving and sustainably using marine (SDG 14) and terrestrial (SDG 15) systems, and enhancing policy coherence and partnerships (SDG 17), rule of law (SDG 16) and creating regulations for climate change minimization and adaptation (SDG 13).

While research and policy attention on the SDGs have mainly focused on the interrelationships of the SDGs (Le Blanc, 2015; Nilsson et al., 2018; Singh et al., 2018), and policy priorities to advance specific or a suite of SDGs (Blanchard et al., 2017; Griggs et al., 2013), there is a nascent understanding of how our changing world is affecting our ability to achieve the SDGs to begin with. While important advances have been made in exploring the consequences of climate change on fisheries (Cheung et al., 2010; Cheung, Reygondeau, & Frölicher, 2016; Sumaila, Cheung, Lam, Pauly, & Herrick, 2011), our understanding of the implications of climate change effects on the oceans regarding the SDGs is inadequate. Moreover, climate change has wide-reaching effects across ecosystems, with implications for global conservation, resource management, economies and human migration patterns. The complex effects of climate change can have nonintuitive consequences for SDG attainment. Will climate change's effects on increasing fish growth rates help make SDG 2 (ending hunger) more achievable, or will the increased climatic variability and shifting range sizes make SDG 2 less achievable? Will sea level rise reduce our ability for inclusive, safe and environmentally sustainable coastal development or expand it? According to the Strategic Sustainable Development framework, planning towards sustainability requires not only an understanding of desired goals, but a rigorous assessment of

[1]While we acknowledge that there are many ways to conceptualize the relationship of people with the environment (Diaz, et al. 2018), the ecosystem service framing allows us to systematically address human-environment relationships in ways that are conducive to much of the academic literature (Lele, et al. 2013).

current conditions in relation to desired goals in order to determine sequential policy priorities to achieve desired goals (Broman & Robèrt, 2017). Climate change is effectively changing the baseline from which we act to achieve the SDGs (Beg et al., 2002) and climate change may not affect our ability to achieve the SDGs equally. Determining which SDGs are likely more or less affected by climate change can aide policy-makers in determining which SDGs are more currently attainable and should be prioritized as entry points to eventually achieve the SDGs broadly.

Here, using a combination of literature review and expert elicitation methods, we ask two questions: (a) How does climate change affect marine ecosystem services? and (b) What is the relationship between climate-impacted marine ecosystem services and our ability to achieve SDGs?

2 | MATERIALS AND METHODS

We used an ecosystem services framework to understand how climate change impacts on ocean and marine ecosystems may affect our ability to achieve the SDGs. As climate change is known to have a variety of environmental consequences, an ecosystem services approach allowed us to tie climate change impacts with SDGs, since ecosystem services directly tie environmental dynamics to human well-being (Lele, Springate-Baginski, Lakerveld, Deb, & Dash, 2013). First, we conducted a scoping literature review to identify the known and predicted consequences of climate change on marine ecosystem services along four broad categories of ecosystem services (provisioning, regulating, habitat and supporting and cultural services). Second, we conducted a hierarchical expert elicitation process to identify kinds of relationships between impacted marine ecosystem services and the main targets in 16 of the 17 SDGs. Our approach is visualized in Figure 1 below.

2.1 | Climate change impacts on marine ecosystem services

In order to assess the consequences of climate change impacts on marine ecosystem services, we conducted a scoping review of the literature (Miller, Ota, Sumaila, Cisneros-Montemayor, & Cheung, 2018). We relied on The Economics of Ecosystems and Biodiversity (TEEB) framework of ecosystem services classification (http://www.

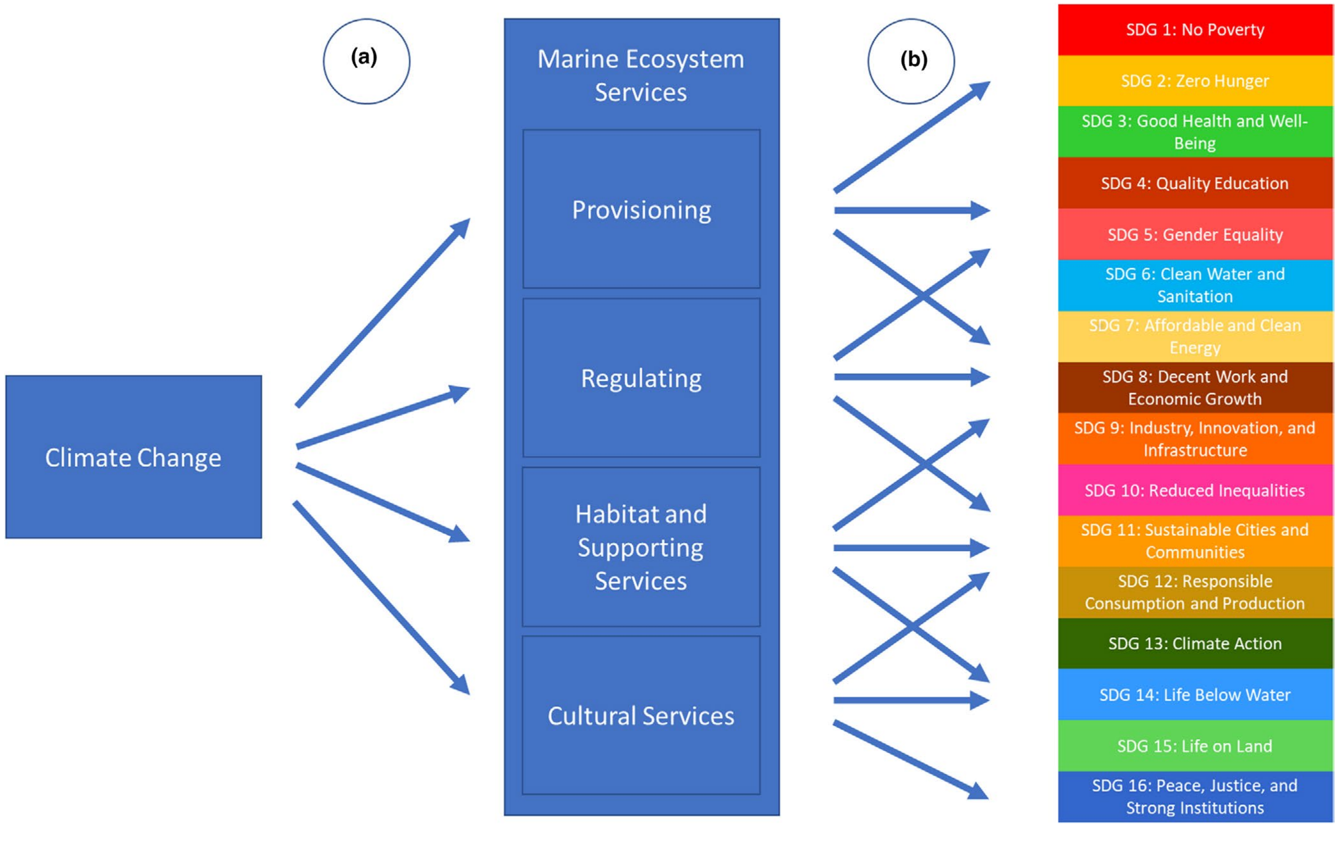

FIGURE 1 Methodological framework of relating the cascading effects of climate change on ecosystem services and Sustainable Development Goals (SDGs). Our investigation into the impact of climate change on sustainable development uses (a) scoping literature review to outline identified relationships between climate change and marine ecosystem services and (b) expert elicitation to evaluate the kinds of relationships from impacted marine ecosystem services (identified in a) on our ability to achieve the SDGs. Ecosystem service categories are based on The Economics of Ecosystems and Biodiversity (TEEB) and sustainable development categories as defined by the SDGs. Our analysis explores the links (arrows) identified by (a) and (b). The arrows are not meant to be exhaustive, but representative of potential links. The 16 SDGs on the right-hand side represent the different dimensions of the SDGs that were analysed for the scope of this study

teebweb.org/resources/ecosystem-services/, de Groot, Fisher, &. Christie, 2010) to systematically and comprehensively review climate impacts on marine ecosystem services (Table S1).

Our scoping methods involved searching Google Scholar and ISI Web of Knowledge for relevant articles detailing the kinds of climate impacts on the various ecosystem services. We limited our search to articles, including review articles, past 2013 as this was the cut-off year for the previous Intergovernmental Panel on Climate Change (IPCC) report and we reviewed IPCC reports and review articles. The recent IPCC report (AR5) represents the most comprehensive understanding of climate change up to that point (IPCC, 2014), and so reviewing articles past the IPCC cut-off year (including review articles that outline impacts identified before that year) allowed us to update the latest comprehensive understanding of climate change impacts without duplicating effort. We used a series of search terms (Table S1) to conduct our literature review. The search terms included terms for all ecosystem services classification, as well as the terms 'climate impacts' and 'climate change impacts'.

In accordance with literature review methods to retrieve information from peer-reviewed articles, systematic searches were carried out with the terms in Table S1 strategically chosen to retrieve mechanisms linking climate change to a comprehensive set of marine ecosystem services (Miller et al., 2018). Searches were conducted to find the terms anywhere in the articles. For each set of search terms, the estimated top 80% (or higher) of papers were reviewed (see below for how we determined the number of papers to review). After screening the title and abstract for relevance, the text of the paper was read to determine the ecosystem service it describes impacts on, and determine the mechanisms by which climate change is affecting the various marine ecosystem services.

To ensure that we consulted a majority of the literature for each ecosystem service, we used an empirical standard. First, we found the ecosystem service with the largest number of papers in the search engines. Within that ecosystem service, we reviewed and recorded the number of relevant papers until we found a search page without any relevant papers. We determined the number of search pages we would have to review to capture 80% of the total relevant papers and used that as our common search limit across all ecosystem service categories. This process led us reviewing the top 10 pages of the search engines for each ecosystem service, and because our standard was taken from the ecosystem service with the greatest number of papers, we likely captured >80% of the relevant papers for all other ecosystem services. Across all marine ecosystem services, we reviewed 142 papers. Specifically, we reviewed five papers addressing impacts on marine aesthetics, two papers addressing impacts on marine biological control, 11 papers addressing impacts on carbon sequestration and storage, 19 papers addressing impacts on erosion prevention, 35 papers addressing impacts on marine food sources, six papers addressing impacts on fresh water in coastal systems, eight papers addressing impacts on marine habitat, six papers addressing impacts on local climate, 21 papers addressing impacts on marine genetic biodiversity, three papers addressing impacts on medicinal resources, four papers addressing impacts on extreme event moderation, 15 papers addressing impacts on marine recreation and health, five papers addressing impacts on spiritual experience and sense of place in marine systems, seven papers addressing impacts on marine tourism and one paper addressing impacts across all ecosystem services.

Once all papers were collected and reviewed, we summarized the variety of ways that climate change impacts ecosystem services and recorded the direction of change (negative or positive impact). From each reviewed paper, we recorded the mechanism of impact, the direction of climate effects on the ecosystem service (either positive or negative) relative to current conditions, the spatial scope of the effect, the kind of study and the marine ecosystem type where the impact was recorded. We structured our data collection with a pathways of effects model, according to the following structure:

General Climate Change Stressor → Impact Mechanism → Ecosystem Service Category

A pathways of effects model includes general climate stressors leading to impact mechanisms that link the general stressors with the ecosystem services (sensu Singh et al., 2017a, 2017b). The purpose of such pathways of effects models is to create transparent and general structure for characterizing impact in a systematic way. For our study, general climate stressors were determined by consulting the peer-reviewed literature on environmental impact frameworks which systematically categorize and quantify climate effects (Halpern et al., 2015, 2009, 2008; Teck et al., 2010). The categories from these frameworks were then pared down by determining which categories adequately described the impacts on ecosystem services identified in our literature review. The final list of general climate stressors included: warming, extreme weather, precipitation change, sea level rise, acidification and various simultaneous stressors. The specific impacts outlined in the papers were coded to group similar mechanisms together; however, within each set of grouped mechanisms, we retained the count of the specific impacts. For example, if two papers described how ocean warming led to species loss, but one paper outlined loss in a fish species and the other a loss in a bivalve, we recorded that as two impacts under the same mechanism. The list of grouped specific impacts included: bloom events, changes in chemical flows, geopolitics, oceanography, local climate, phenology, selection pressure, habitat alteration, aquaculture damage, coastal squeeze, coral bleaching, mental health effects, disease transmission, species shifts and loss, individual organism effects, land-sea interface, temperature increase, human migration, biomass change, infrastructure damage, invasive species, livelihood disruption, trophic effects, regime shift, sea ice loss and storm surges. This pathways of effects model also allowed us to use network analysis to identify which general and specific climate change stressors have been noted most frequently as affecting specific ecosystem services. Using this information, we generated a network of effects from climate change to the various marine ecosystem services, weighing the stressors from climate change to ecosystem services by the number of links they have across ecosystem services (Singh et al., 2017b).

2.2 | Effects of impacted ecosystem services on SDGs

We conducted an expert elicitation to assess relationships between changes in marine ecosystem services from climate change (relative to current conditions) and the likely consequence this change has on our progress towards the SDGs. We chose to only review the first 16 SDGs as SDG 17 (Partnerships for the Goals) relates to international policy cooperation and capacity building needed to achieve the other goals and is not dependent on ecosystems (Singh et al., 2018). We also only chose to look at the consequences of the main targets within the SDGs (those that are numbered such as SDG 14.1) and not secondary targets (those that are lettered such as SDG 14.a) because the secondary targets do not provide temporal and thematic detail to what achievement means, requiring extra interpretation.

2.2.1 | Choice of experts

We solicited input from three main categories of experts to inform our study: (a) experts on ecosystem service approaches and research, (b) experts on marine ecosystem services and planning and (c) experts on specific marine ecosystem services for ecosystem services described in our analysis. All experts were chosen based on publication record, education and experience with a particular ecosystem service and the recommendation of both the authors as well as other recognized external experts, and interest in collaborating with the study. The identification of experts required multiple steps. First, lists of potential experts were compiled by the lead authors and coordinating lead authors for the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Second, this list was corroborated and expanded by the publication record and experience. Third, we asked individuals on this list to join the study or further nominate experts. Finally, we prioritized experts who were recommended at multiple stages and whose experience best matched the particular marine ecosystem services we investigated. In the end, we elicited knowledge from 17 experts, and our compiled experts represented those with training in resource policy, environmental governance, natural capital accounting and resource economics, engineering, epidemiology, biogeochemistry, coastal ecology, food security, marine conservation, fisheries management, marine biogeography, environmental sociology, environmental planning, geography, finance, environmental social science and spiritual ecology (see Table S2).

2.2.2 | Structured elicitation

Our structured elicitation used a modified Delphi process of iterative expert input, adapted from other approaches using email (McBride et al., 2012; Singh et al., 2018). Email-based elicitation approaches through facilitators have been shown to be effective in eliciting expert judgements from structured processes, and have the added benefit of providing practical benefits of maintaining anonymity of experts and relative ease of logistics (McBride et al., 2012). We used a hierarchical design, whereby the general expert on ecosystem services first provided input, then this input was given to the expert on marine ecosystem services and marine planning, who was instructed to point out areas of agreement or disagreement and this updated input is given to the topic specialists, who were again instructed to point our areas or agreement or disagreement. Experts at each stage of the elicitation were briefed on the elicitation process and specific framework for selecting relationship types over email (McBride & Burgman, 2012; McBride et al., 2012). Specifically, experts were asked to determine the relationships between climate-impacted ecosystem services (the change to the ecosystem service caused by climate change) and the specific targets within the first 16 SDGs. Any uncertainties expressed by the experts were clarified by the assessment team.

At each stage there was embedded feedback, whereby the latter stage expert would consider their responses by reflecting on the choices and reasoning from the prior expert. Between the first and second stage, the experts challenged their reasoning behind their decisions in an in-person discussion, and the expert on marine ecosystems and ecosystem service planning had a chance to update their responses. The topic area expert was instructed to think about support for or disagreement with the submitted responses after the second stage. They were encouraged to think about the reasoning behind the responses submitted to them and provide justifications for any agreement or disagreement, and provide relevant literature to support their conclusions. Experts from earlier stages were then allowed to view these responses, discuss over email and the topic experts then provided their final responses. By asking successive stages of experts to agree or disagree with prior stages, and base their reasoning on mechanistic understanding of the relationship, we used informative inputs to guide the elicitation and focused the subsequent elicitations to challenge and provide structured reasoning behind their assessments—both of which have been demonstrated to increase the performance of experts (Singh et al., 2017a; 2017b). This hierarchical design is based on a recognition of uneven weighting of expert responses (whereby, specialist knowledge is weighted heavier for the particular marine ecosystem service corresponding to their expertize) and expertize is refined through iteration, increased specific knowledge and embedded expert discussions and challenges to their judgements (McBride & Burgman, 2012; Morgan, 2014). This iterative elicitation strategy using email, feedback and justified reasoning is designed to minimize predictable biases such as dominance, overconfidence, framing effects, availability and linguistic uncertainty (Burgman et al., 2011; Martin et al., 2012; McBride & Burgman, 2012; Morgan, 2014; Singh et al., 2017a; 2017b).

2.2.3 | Decision structure

The structured protocol follows a hierarchical decision process to characterize relationships (sensu Singh et al., 2018), resulting in one of the eight different relationships. At each stage, experts were asked to consider which option was most likely. The first step in the process is determining if a relationship exists. If the expert decides that a relationship exists, then they were tasked with determining if the relationship is positive to the SDG target, negative or either. If positive or negative relationships were chosen, experts were tasked with identifying if the relationship is proximal (where climate-impacted ecosystem services have a proximal causal relationship with the impact on the SDG target) or distal (where climate-impacted ecosystem services have distal relationship with the impact on the SDG target). Impacts on marine ecosystem services can have both proximal and distal relationships across SDGs. Negative impacts on fish populations can have proximate consequences for ocean conservation goals, particularly related to fisheries (SDG 14) but more distal effects for poverty reduction (SDG 1), because the relationships depend on people's dependence on fish for food and income, and the ability to catch fish. As a further example of a distal relationship, having enough food can contribute to the stability needed for inclusive participation in decision-making (SDG 16.7), but there are many social and political factors that are more proximate that may regulate whether inclusive participation occurs. If proximal relationships were chosen, then experts were tasked with determining if the relationship was direct or indirect (the relationship is mediated through a third variable). The decision process is outlined in Figure 2 and described in Table S3. Examples are shown in Figure S1.

Experts were instructed to consider relationships at a global spatial scale and to consider the temporal scale embedded in the SDG targets. For the global scale, experts were asked to consider the aggregate response across the planet, meaning that if sometimes an adverse impact on ecosystem services is associated positively with an SDG target but most of the time the association is negative, they should choose a negative relationship. For example, if ending hunger across the planet requires intact habitats for food species despite the fact that at a particular national scale food acquisition may not be tied to functional habitats, adverse impacts on habitats for species would have a negative-proximal-indirect relationship with SDG 2.1 (ensuring sufficient food to all people). For temporal scale, experts were asked to consider how climate-impacted ecosystem services are likely to affect our ability to achieve the SDG target by the given target date. Most SDG targets have target dates of 2030, with some 2020 and a few 2025. Targets without achievement dates were treated as having a date of 2030 (Singh et al., 2018). If experts thought that there were different relationship dynamics in the short term (before the achievement date) compared to the longer term (at the achievement date), then experts were asked to provide responses for the short and long term. Given that decision structures cannot eliminate uncertainty (particularly linguistic uncertainty in what exactly the distinctions between categories pertain to—see Regan, Colyvan, & Burgman, 2002), we asked experts to voluntarily provide justification for their choices, and these justifications were similarly reviewed by later stage experts.

2.2.4 | Characterizing uncertainty

We characterized three levels of certainty (low, medium, high) in expert-defined relationships based on the degrees of support, incorporating the level of agreement between experts and any

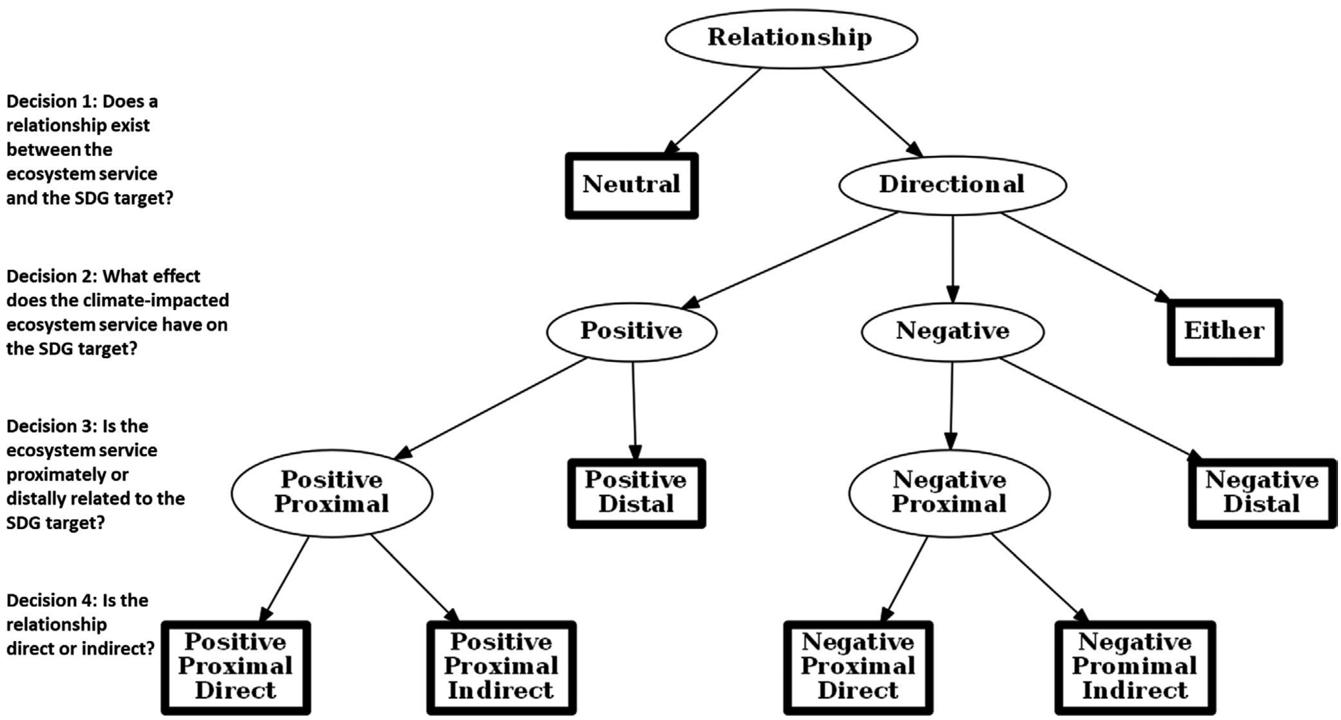

FIGURE 2 Decision tree used to determine the kinds of relationships between impacted marine ecosystem services and Sustainable Development Goal (SDG) targets. The relationship experts were tasked with characterizing were climate-impacted ecosystem services (changes to ecosystem services caused by climate change) and the specific targets within the 16 analysed SDGs. The decision tree followed a four-step series of questions. The final relationship categories are represented by bold squares

additional supporting literature or supporting comments provided by the topic specialist. This method of characterizing uncertainty utilizes a transparent methodology adapted from the IPCC process (Mastrandrea et al., 2010). Expert judgements agreeing with the final determination, as well as the final determination by the topic specialist, each counted as one degree of support. Each stage of expert input had the potential to contribute one degree of support. Any supporting comments provided by the topic specialist expert also counted as one degree of support, whereas comments indicating uncertainty subtracted a degree of support, and supporting literature also counted as a degree of support. This process allowed for up to five degrees of support. Relationships with at least three levels of support were considered as having high confidence, while two degrees of support were considered medium confidence and having only one degree of support was considered low confidence. The uncertainty and expert confidence framework are presented in Figure S2.

We summarized which ecosystem services, when impacted by climate change, are related across the largest number of SDG targets for direct, indirect and supportive relationships. Similarly, we report which SDG is considered by experts to be most affected by climate effects across ecosystem services. We also identified which relationships are more certain and less certain according to experts, in order to target research.

3 | RESULTS

3.1 | Climate impacts on marine ecosystem services

Across almost all marine ecosystem services, the total number of negative impacts from general climate change stressors is substantially larger than the total number of positive impacts as identified in the literature review (Table 1). The only ecosystem service that did not follow this pattern was aesthetic appreciation, which had an equal number of positive and negative impacts across climate change stressors. The peer-reviewed literature identified the most climate impact pathways on food (131 total impacts) followed by impacts on erosion prevention (44 total impacts). Among general climate stressors, most impacts characterized in the peer-reviewed literature stem from increased warming (204 total impacts), followed by extreme events (61 total impacts).

Most impact pathways reported in the peer-reviewed literature outlined relationships from ocean warming through species shifts and loss (including extinction, biodiversity reductions and species range shifts), and impacts on food production (Figure 3). Warming was the general climate stressor with the greatest variety of connections to impact mechanisms (24 connections with impact mechanisms) followed by extreme weather (15 connections with impact mechanisms). Precipitation change, sea level rise and acidification all had fewer than 10 connections with impact mechanisms. The effect pathway most commonly found in the literature for ocean acidification was effects to individual organisms (through direct mortality, reduced calcification and growth rates) affecting food production. Precipitation changes were most commonly identified in the literature as operating through the land-sea interface, affecting runoff rates and flooding and drought cycles to impact tourism. Extreme weather was most often described in the peer-reviewed literature as increasing storm surges which degraded the service of erosion prevention. Sea level rise was most often described as increasing inundation and intertidal habitat loss, negatively effecting erosion prevention functions.

3.2 | Consequences of negative impacts on marine ecosystem services to SDGs

3.2.1 | Direction of effect

The vastly negative impacts of climate change across marine ecosystem services led experts to indicate that most targets in all SDGs will most likely be negatively affected, though most of these negative effects were thought to operate through distal mechanisms (Figure 4). While many SDG targets are not immediately associated with marine ecosystem services, there are known (as determined through identified research) and suspected (as judged by experts) indirect pathways linking climate impacts on SDG targets through marine ecosystem services. The least negatively impacted SDGs (according to the proportion of targets with negative relationships) were sustainable consumption and production (SDG 12) and affordable and clean energy (SDG 7).

Direct effects of climate-impacted marine ecosystem services on SDGs were thought to occur across a minority of SDG targets. The SDGs with the largest proportion of targets directly affected were SDG 2 (eliminating hunger) and SDG 15 (life on land, or terrestrial conservation). Surprisingly, SDG 14 (life below water, or marine conservation and management) was not one of the SDGs whose targets were thought to be most directly affected, despite our analysis of climate change on marine ecosystem services. Experts pointed to the fact that many of the targets in SDG 14 are not simply about marine conservation but about marine development and industries, which are not always directly influenced by ecosystem services but mediated through other factors.

Some SDG targets were thought to be positively influenced by climate-impacted marine ecosystem services. Most of these identified relationships were associated with negative impacts on genetic diversity (and some associated with other ecosystem services such as sense of place), whereby negative impacts on biodiversity lead to a greater sense of urgency, which can result in action taken on climate policy (e.g. SDG 13.2) and become educated on sustainable development (e.g. SDG 12.8). Some other examples of positive impacts are the consequences of marine resource degradation (such as food and freshwater), requiring a shift to diversify economies, utilize other resources and (presumably) focus on sustainable use of these resources. SDG targets thought to be positively impacted by climate-affected ecosystem services were mostly judged to be speculative, indirect and distal in nature, and not agreed on across experts, leading to low certainty.

TABLE 1 The number of climate change impacts from general climate change stressors to marine ecosystem services identified in the literature across 142 references

Ecosystem service	Direction of effect	Warming	Extreme weather	Precipitation change	Sea level rise	Acidification	Various	Total
Food	+	23	1	2	0	0	0	26
	−	74	13	2	4	11	1	105
Raw materials	+	1	0	0	0	0	0	1
	−	0	0	0	1	0	1	2
Fresh water	+	0	0	0	0	0	0	0
	−	0	1	1	4	0	0	6
Medicinal resources	+	0	0	0	0	0	0	0
	−	2	2	0	2	0	0	6
Local climate and air quality	+	0	0	0	0	0	0	0
	−	7	2	1	0	0	0	10
Carbon sequestration and storage	+	3	0	0	1	1	0	5
	−	2	3	0	2	0	1	8
Moderation of extreme events	+	0	0	0	0	0	0	0
	−	2	4	2	1	0	0	9
Waste-water treatment	+	0	0	0	0	0	0	0
	−	1	0	0	0	0	1	2
Erosion prevention	+	1	2	0	0	0	0	3
	−	3	16	1	20	1	0	41
Biological control	+	0	0	0	0	0	0	0
	−	3	0	0	1	0	0	4
Habitat for species	+	1	0	0	0	0	0	1
	−	6	1	0	0	6	0	13
Maintenance of genetic diversity	+	4	0	0	0	1	0	5
	−	22	2	0	0	5	2	31
Recreation and mental and physical health	+	1	0	0	0	0	0	1
	−	18	10	1	6	0	0	35
Tourism	+	7	0	0	0	0	0	7
	−	9	1	4	4	0	0	18
Aesthetic appreciation and inspiration for culture, art and design	+	6	0	0	1	0	0	7
	−	7	0	0	0	0	0	7
Spiritual experience and sense of place	+	0	1	0	3	0	0	4
	−	3	2	0	2	0	0	7

Note:: Impacts are sorted as positive and negative based on the direction of effect relative to their current level of function.

A minority of SDG targets were determined by experts to have relationships with ecosystem services that are too uncertain to determine as positive or negative. Most of these 'either' relationships occurred in SDG targets that depend on human behaviour and where experts were unsure of how people would respond to a climate-affected ecosystem service. For example, experts judged that negative impacts on carbon sequestration services could either lead to increased or decreased environmental protection in equal probability. Similarly, experts thought that a variety of degraded ecosystem services might either increase or decrease research and innovation in relatively equal probabilities.

3.2.2 | Certainty of effect

The majority of expert-identified relationships between climate-affected ecosystem services and SDG targets had high confidence (54%), followed by medium confidence (41%) and a minority had low confidence (5%). The SDGs with the highest proportion of high confidence relationships were SDG 15 (life on land, 67%), SDG 1 (no poverty, 65%) and SDG 10 (reduce inequalities, 64%). SDG 12 (sustainable consumption and production) had the highest proportion of targets with relationships judged with low confidence, but it was still a clear minority of cases (12.5%). The ecosystem service

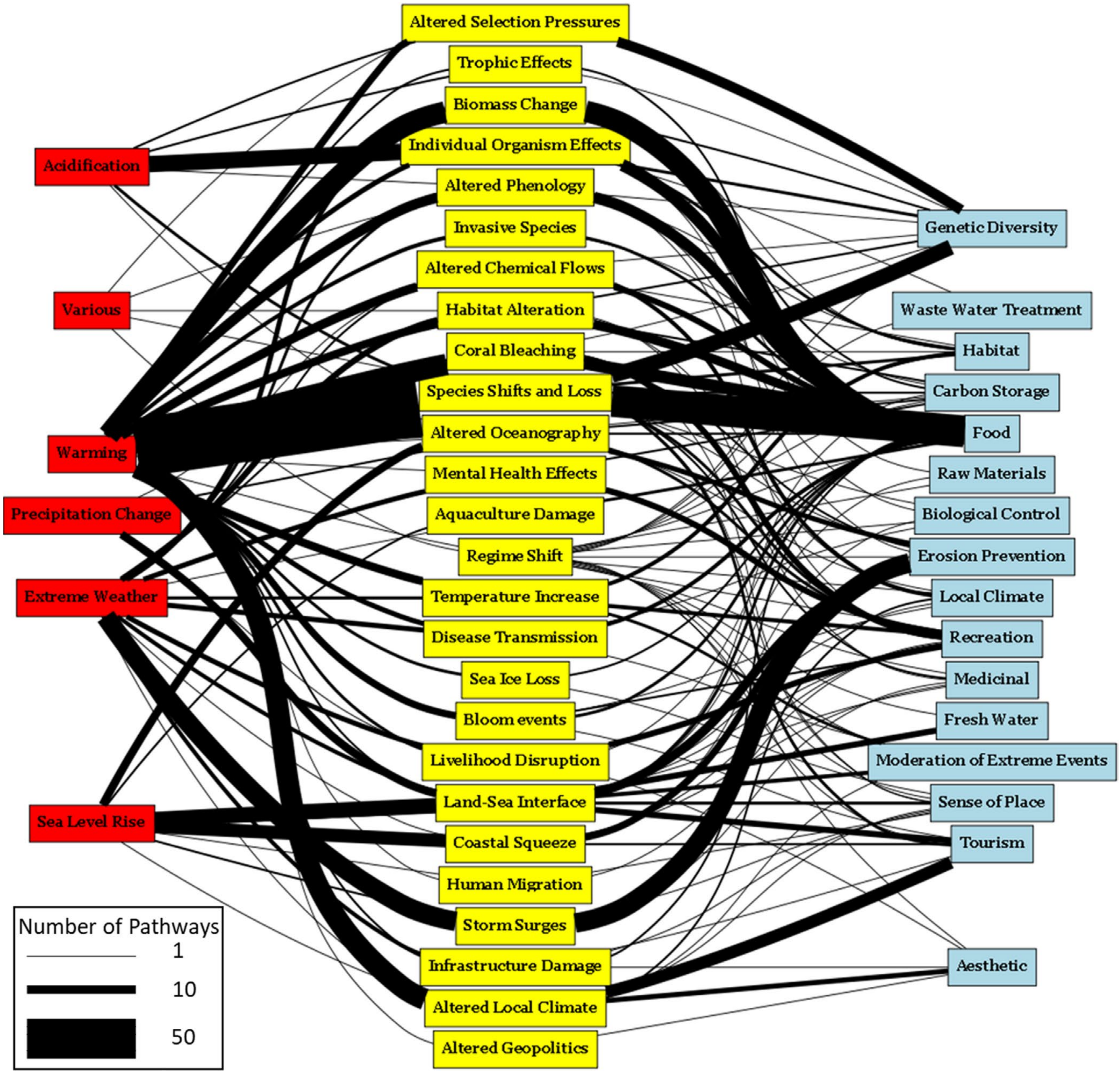

FIGURE 3 A network of pathways of effects from general climate stressors (in red on the left) through impact mechanisms (in yellow in the middle) towards marine ecosystem services (in blue on the right) compiled through literature review. The thickness of the lines indicates the number of specific impact pathways described in peer-reviewed literature, as indicated in the legend

types that experts were most certain in their judgements were aesthetic experience and inspiration for art and culture (92% of relationships had high certainty), and most of the relationships for this ecosystem service were distal and supporting. The other ecosystem services with high certainty expert judgements were erosion prevention (89% high certainty), food (75% of relationships with high certainty) and recreation (79% of relationships with high certainty). By a large margin, the ecosystem service with the highest proportion of low-certainty expert judgements was genetic diversity (40% of relationships with low certainty and only 17% with high certainty). Experts disagreed on the type of relationship and no supporting literature was known to exist explicitly linking loss in genetic diversity across the SDGs. A matrix of all final expert decisions, along with supportive literature, expert comments and certainty level is provided in the Supporting Information.

4 | DISCUSSION

While this study supports previous assessments that climate change has wide ranging consequences for ecosystem services (Doney et al., 2011; Harley et al., 2006; IPCC, 2014), our study reveals that

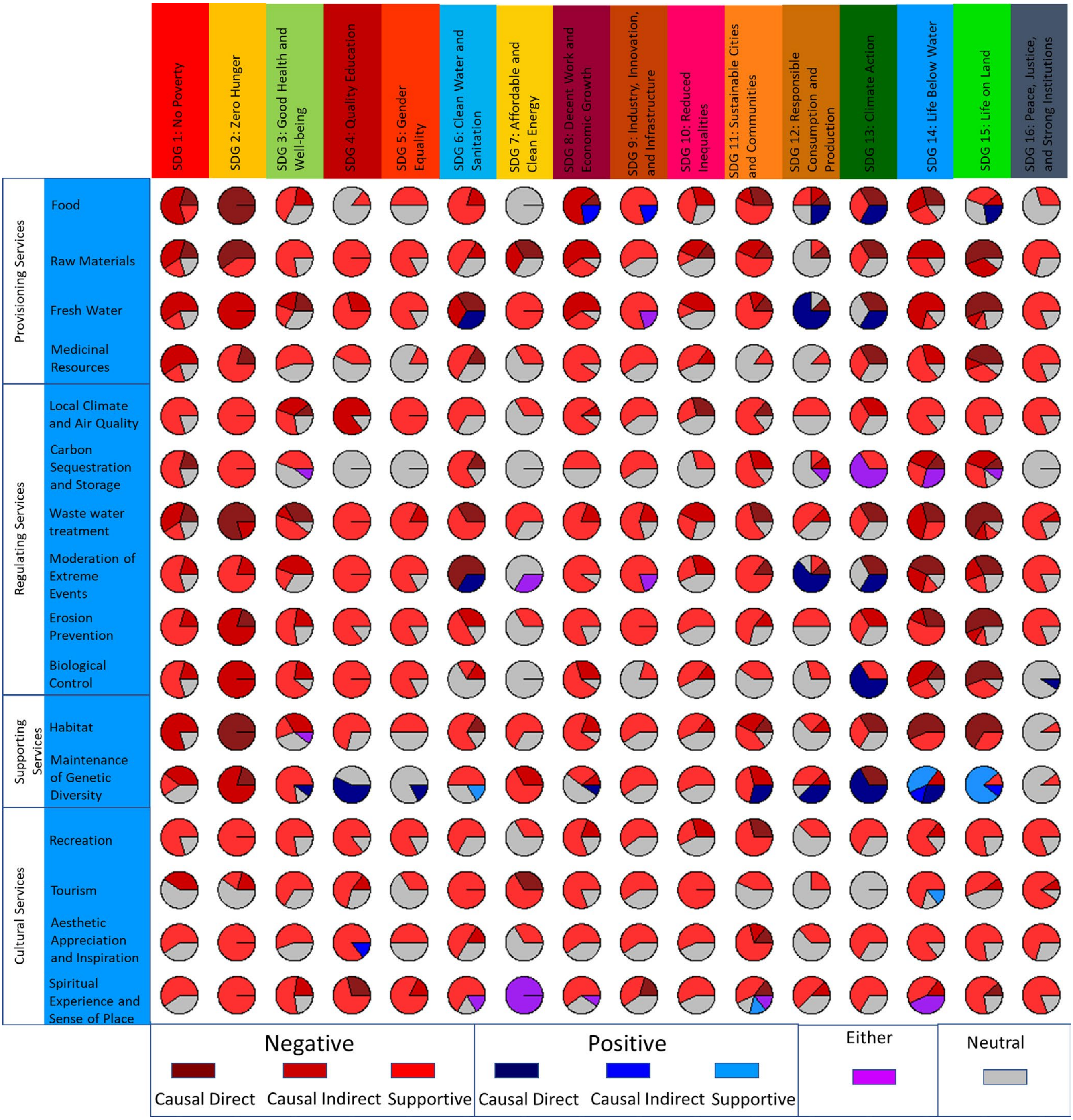

FIGURE 4 Summary of the types of relationships between impacted marine ecosystem services and the Sustainable Development Goals as determined through expert elicitation. Pie charts represent the proportion of targets within each goal that have specific types of relationships with impacted marine ecosystem services

these changes to marine systems are limiting our overall ability to achieve the SDGs across all goals. Though our results show that impacts of climate change on the ocean described in peer-reviewed literature are mostly associated with warming, climate change is a multi-dimensional, global process that changes a variety of environmental dynamics that influence the biosphere. These dynamics include changes to precipitation (Gleick, 2014), storm frequency and intensity (Spalding et al., 2014), sea level rise (Arkema et al., 2013) and ocean acidification (Kroeker, Kordas, Crim, & Singh, 2010). These global changes often aggravate local processes that affect the biosphere, such as runoff (Singh et al., 2017a; 2017b), trophic interactions (Edwards & Richardson, 2004), habitat alteration (Battin et al., 2007), phenological shifts (Edwards & Richardson, 2004), range shifts (Cheung et al., 2009), size changes due to metabolic effects and oxygen limitation (Cheung et al., 2013; Pauly & Cheung, 2018), calcified structure dissolution (Kroeker et al., 2010) and others. In fact, our results show that there is a range of climate change effects that alter local environmental conditions, such as circulation and habitat structure (Bauer et al., 2013; Li et al., 2014), and therefore indirectly affect ecosystem services.

Our review also reveals that climate change impacts have been documented to affect people directly through disruption of livelihoods, such as increasing costs of acquiring fish when they move, and having mental health impacts, such as increasing the risk of psychological distress from natural disasters (Bourque & Cunsolo Willox, 2014; Hunt et al., 2016). Though the peer-reviewed literature does identify some positive impacts of climate change to ecosystem services, such as increasing growth rates of food species (Myers et al., 2017), our results indicate that there are more negative consequences of climate change across ecosystem services. Though this result does not account for the magnitude of positive vs. negative impacts, our results indicate that seven of the 16 ecosystem service categories have no positive impacts from climate change, and our experts unanimously agreed that climate change will have generally negative consequences across marine ecosystem services. Through the determination of negative relationships between climate-impacted marine ecosystem services and SDGs, as well as the relative high confidence in these determinations, our study highlights not just the importance of considering climate change in our ability to achieve the SDGs, but also supports earlier findings about the importance of marine systems towards the SDGs (Singh et al., 2018).

The majority of SDG targets are, or likely will be, detrimentally affected by climate changes to marine ecosystem services. There are a minority of SDG targets that experts thought would be unaffected by global climate change, and there are very few changes that are positive. Other studies have determined that some areas of the world are likely to experience these consequences less than others (Patz, Campbell-Lendrum, Holloway, & Foley, 2005; Wheeler & Von Braun, 2013), and so may benefit in a relative, geopolitical way. For example, Norway's fisheries may not suffer as much (or even benefit) as countries farther south, whose endemic fish are migrating poleward (Cheung et al., 2010). Despite these relative 'winners' in a climate change future, the SDGs include goals and targets focused on justice and reducing global inequalities (UN, 2015). The fact that the 'losers' in climate change are projected to be the global south and equatorial countries, where vulnerabilities are disproportionately high, signals that beyond the specific targets of the SDGs, climate change is detrimentally affecting our ability to achieve the spirit of the SDGs.

The relationships between climate-impacts on marine ecosystem services and SDGs, as determined by experts, were far-reaching, even affecting targets often associated as being 'economic' or 'social' targets. Most targets directly affected by climate-impacted marine ecosystem services were those targets associated with primary industries (i.e. natural resource extraction) and conservation, where the link to natural ecosystems is straightforward, such as SDG 2 (no hunger), and SDG 15 (life on land). Impacts on other SDGs were considered more distal in nature, where impacted ecosystems are mediated through social and economic factors first before affecting an SDG target. For example, experts suggested that erosion amplified by climate change can negatively influence our abilities to sustainably manage chemical use and their release into the water (SDG 12.4). Erosion will negatively affect soil productivity, which experts suggest will likely increase people's reliance on chemical fertilizers and increase the risk of over-application (Jie, Jing-Zhang, Man-Zhi, & Zi-tong, 2002), leading to increased water contamination through runoff. Similarly, experts suggested that climate impacts that negatively influence natural biological control can make local food systems and other provisioning services less stable, and people may respond by migrating (Black et al., 2011), making the SDG target of facilitating safe and orderly migration harder to achieve (SDG 10.7).

While the risk of negative impacts on many SDG targets is heightened with negative changes to ecosystem services, the experts did point out that people's actions would determine the final effect on SDGs where distal relationships exist, and social and economic variables were more proximal to the SDG target. Our analytical framework tasked experts with assessing whether positive or negative (or neither) effects to SDG targets are more probable as a result of climate change impacts on marine ecosystem services. When experts identified distal relationships, they were cautious in their conclusions. In fact, experts often hedged their explanations of how people would react to ecosystem service change, using words like 'may' and 'could', and suggested in discussion that even though the changes to an ecosystem service may influence progress towards (or away from) an SDG target, people's actions may nevertheless lead to a different outcome. The contextual nature of many relationships, where social and economic factors regulate the relationship between ecosystem services and SDGs, challenge some prominent models of sustainable development which treat social and economic factors as embedded within and dependent on environmental factors (Griggs et al., 2013), and other models which treat environment, social and economic factors as linearly and sequentially related (Reid et al., 2017). Instead, we find that even in situations where the environment can be a catalyst to development issues, social and economic factors were still controlling levers. Previous studies on ocean protection concluded that environmental goals are dependent on social and economic factors such as staff presence and budget capacity and community buy-in (Christie, 2004; Gill et al., 2017). Furthermore, a previous study has found that targets that incorporate environmental, social and economic dimensions simultaneously (rather than prioritizing the environment) are pre-requisites across the greatest number of SDG targets, and focusing on economic capacity that can contribute to social and environmental programs can be most beneficial across the SDGs (Singh et al., 2018).

The role of social and economic dimensions in regulating the relationship between climate-impacted ecosystem services and SDGs is also important in many of the positive effects experts identified. Many of these positive effects relied on optimistic interpretations of the future, whereby impacts on ecosystem services yielded pro-sustainable behaviour by people. For example, some experts thought that impacts on genetic diversity could yield greater attention paid to sustainability education (SDG 4.7) as people will be confronted with more degraded ecosystems, and problem awareness can contribute to (but is not sufficient for) environmental action (Bamberg

& Möser, 2007). Many of these positive effects are not guaranteed, and they were often a result of lower certainty expert categorizations. Indeed, degraded ecosystems can become normalized which can lead to complacency or a shift in priorities (Clavero, 2014). Additionally, many of the relationships classified as 'either' by experts, which include the possibility for positive and negative effects and are inherently uncertain, also scored lower on the certainty scale. Despite these caveats, our findings do suggest that people can potentially respond in positive ways towards the SDGs in the face of climate change. This research evaluated impacts based on current contexts and understanding and was not designed to capture human ingenuity and innovation in the face of climate change, but that is an important next step for this research theme.

The uncertain connections between climate-impacted marine ecosystem services and SDGs are broader than the potential positives we discuss above. Many potential negative consequences of climate impacts on marine ecosystem services were also considered to have low certainty from our expert elicitation process. Particularly, the consequences of climate change to genetic diversity to SDGs were most frequently determined with low certainty. The lack of published literature documenting the welfare consequences of a loss of biodiversity in general was credited with this low certainty by the topic specific expert. In some cases, more certainty could be gained through more targeted research, at smaller scales (such as determining whether and under what conditions loss of ecosystem services leads to pro-sustainable motivations and actions). However, many of the uncertainties are also a consequence of the fact that the assessment considers the consequences of different dimensions of well-being in the future (most SDGs have target dates of 2030). Assessments of the future carry inherent uncertainty that are sometimes not mitigated through further study. Simultaneously, the scale of consequences from climate change to biodiversity (and other marine ES) cannot easily be simulated with current scientific methods, meaning that some of the uncertainty in our results cannot be practically reduced, especially not while urgent action on the SDGs is needed. In spite of the uncertainty, we recommend taking a precautionary approach, and not treat the uncertainty in the assessment as a justification to ignore the potential consequences of climate impacts on marine ecosystem services. Strategically, this assessment can serve as a first iteration and set of recommendations for engaging the SDGs, and follow-up assessments over time can provide updated recommendations.

We are not suggesting that progress on the SDGs is impossible, despite the fact that climate change can be safely assumed to worsen in the future (IPCC, 2014). We are, however, suggesting that climate change is affecting the SDGs so that these global goals are a moving target, travelling away from us. Achieving the SDGs will require a renewed and immediate commitment, including towards minimizing climate change impacts. This commitment will require cooperative action, especially in cases where climate change will entrench and worsen disparities (poverty—SDG 1, hunger—SDG 2, inequalities—SDG 10). Despite the negative consequences that climate change presents, it offers a motive, urgency and opportunity for concerted global action. Based on our analysis, a strategic point of entry for countries around the world to achieve the SDGs could be addressing sustainable consumption and production (SDG 12) and affordable and clean energy (SDG 7) since they are potentially less vulnerable to climate change impacts (proportionately they have the fewest negatively affected targets from climate change). Coincidently, they are also SDGs that are important means towards the ends of the other SDGs, and also towards limiting climate change (Nerini et al., 2018). Whether climate change will limit our ability to cooperatively achieve the SDGs or it serves as a catalyst for change is still an open question, but the longer we wait to achieve the SDGs the more distant they will become.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORS' CONTRIBUTIONS

G.G.S., N.H. and W.C. conceived of the project. G.G.S., W.C., J.B., M.C., A.M.C.M. designed the methodology. G.G.S., J.B., N.H., M.C., S.A., J.B., R.C., S.D., P.C.G.-E., V.L., N.M., B.N., N.P., G.R., J.R., A.S., L.R.V. coordinated and performed the expert elicitations and literature review. G.G.S. and M.C. analysed the data and G.G.S. led the writing of the manuscript. Y.O., J.B., A.M.C.M. and W.C. critically and substantively revised the manuscript. All authors approved the manuscript for submission.

DATA ACCESSIBILITY

Data on climate pathways of effect on marine ecosystem services were compiled through literature review. Data on the consequences for achieving the SDGs based on impacted marine ecosystem services were based on expert elicitation. Both of these datasets are available in the supporting files of this paper as well as available from the Dryad Digital Repository https://doi.org/10.5061/dryad.8625cv1 (Singh et al., 2019).

ORCID

Gerald G. Singh https://orcid.org/0000-0003-4333-1988
Joey R. Bernhardt https://orcid.org/0000-0003-1824-2801

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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