Environmental Science and Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Regulatory implications of coral reef restoration and adaptation under a changing climate

Pedro Fidelman[a,e,*], Chris McGrath[b], Maxine Newlands[c], Kirstin Dobbs[d], Belinda Jago[d], Karen Hussey[a]

[a] Centre for Policy Futures, The University of Queensland, Australia
[b] Global Change Institute, The University of Queensland, Australia
[c] James Cook University, Australia
[d] Great Barrier Reef Marine Park Authority, Australia
[e] Centre for Marine Socioecology, Australia

ARTICLE INFO

Keywords:
Ecosystem restoration
Regulation
Coral reef
Climate change
Great Barrier Reef
Australia

ABSTRACT

Coral reef restoration is gaining considerable momentum globally in response to climate change and other anthropogenic impacts on coral reefs. In Australia, as part of the Reef Restoration and Adaptation Program (RRAP), a range of unconventional interventions are currently being investigated to help the Great Barrier Reef resist, repair and recover from climate change. Many of these interventions are based on innovative approaches, such as assisted evolution. The regulatory environment is likely to be critical in determining the feasibility and viability of reef restoration and adaptation interventions. It influences what, where and how to restore, who should be responsible for, engaged in, and benefit from restoration. This study explores the regulatory implications of proposed restoration and adaptation interventions in the context of the Great Barrier Reef. This includes mapping the existing regulatory and governance landscape, establishing an approach to account for regulatory requirements of restoration and adaptation interventions, and examining regulatory issues associated with their development and deployment. The study also scopes administrative capacity; i.e., the capacity of regulators in terms of resources and skills required to assess novel risks and impacts of reef restoration and adaptation interventions. It provides important insights that may prove useful for other jurisdictions, where ecosystem restoration and adaptation has become an imperative under a fast-changing climate.

1. Introduction

Climate change and other anthropogenic drivers are leading to rapid changes in coral reefs (Hughes et al., 2017a, 2018). Bleaching events due to global warming, for instance, are driving mass mortality of corals across the tropics (Hughes et al., 2018). Prospects for coral reefs suggest that they will be largely or totally destroyed even if the 1.5 °C or 2 °C targets of the Paris Agreement are met. Coral reefs are projected to decline by 70–90% at 1.5 °C above pre-industrial mean global temperatures and are expected to disappear (>99% loss) at 2 °C or higher (IPCC, 2018). Further, while the Paris Agreement is a positive step forward, the global community is yet to adopt adequate measures to stabilise global temperature rises at or beneath the targets under such agreement (UNEP, 2018). In addition to urgent global action to curb greenhouse gas emissions, unconventional interventions to enhance biological resilience have been proposed as an attempt to reduce coral decline caused by climate change (Anthony et al., 2017). In Australia, as part of the Reef Restoration and Adaptation Program (RRAP), a range of such interventions are currently being investigated. Many of these interventions are based on innovative approaches, such as assisted evolution (van Oppen et al., 2015).

The regulatory environment is likely to be critical in determining the feasibility and viability of reef restoration and adaptation interventions (hereafter referred to as reef interventions). It plays a key role by influencing what, where and how to restore, who should be responsible for, engaged in, and benefit from restoration (Mansourian, 2017a). The regulatory environment may enable preconditions of restoration, such as codifying scientific knowledge into restoration standards, structuring process for community participation, mobilising financial resources and incentivising action (Aronson et al., 2011; Richardson, 2016). Further, regulation may facilitate and support agencies and enterprises responsible for developing and implementing

* Corresponding author.
E-mail address: p.fidelman@uq.edu.au (P. Fidelman).

https://doi.org/10.1016/j.envsci.2019.04.016
Received 18 December 2018; Received in revised form 29 March 2019; Accepted 29 April 2019

restoration best practice, knowledge and research (Aronson et al., 2011). Conversely, complex regulatory environments may adversely affect restoration if it creates confusion, lacks mechanisms for evaluating restoration success and fails in providing regulatory guidance. In sum, regulation may significantly affect restoration both positively and adversely (Mansourian, 2017b). In this context, this study explores the regulatory implications of reef interventions in relation to the Great Barrier Reef. This includes mapping the existing regulatory and governance landscape, establishing an approach to account for regulatory requirements of reef interventions, and interrogating such interventions to investigate regulatory issues associated with their development and deployment. Lastly, the study also scopes administrative capacity; i.e., the capacity of regulators in terms of resources and skills (Clement and Standish, 2018) required to assess novel risks and impacts of reef interventions.

In this paper, regulation broadly refers to laws, policies, plans and agreements that regulate different aspects of ecosystem restoration (Mansourian, 2017b). Accordingly, the regulations and the entities responsible for their development and implementation (e.g., government agencies) comprise the regulatory environment. In this regard, there is considerable literature on regulation of *environmental* restoration, which focuses on discrete contexts (e.g., rehabilitation of mining sites). On the other hand, *ecological* restoration, the focus of this study, which aims to restore ecological structure, complexity and functionality has received relatively less attention (Richardson, 2016). Further, much of the work on regulatory implications of ecological restoration has been limited to the terrestrial domain, with a focus on forests and landscapes. For instance, Aronson et al. (2011) examine the role of regulation in best promoting, rewarding or enforcing restoration of forests. Mansourian (2016) discusses the intersection of governance (including regulation) with forest landscape restoration. The present study extends the focus of the scholarship on regulation for ecological restoration to the marine domain. In addition, it adds to a growing debate on the use of emerging technologies for conservation (e.g., Redford et al., 2014; van Oppen et al., 2017), where the regulatory implications of these technologies are yet to be adequately addressed. Last, this study provides important insights into the regulatory implications of ecosystem restoration that may prove useful for other jurisdictions where restoration has become an imperative under a fast-changing climate.

2. Case study context

The Great Barrier Reef (GBR) is the world's largest reef system – it extends for 2300 km along the coast of the Australian state of Queensland, encompassing an area of 344,000 km^2. Its outstanding ecological, social and cultural values have warranted recognition and protection in the form of a Commonwealth Marine Park (since 1975) and World Heritage Area (since 1981) (GBRMPA, 2014b). Further, the economic contribution of the GBR to the nation – through reef-dependent industries, such as tourism and fishing – is estimated at 6.4 billion for 2015–2016 (Deloitte Access Economics, 2017). Nevertheless, the GBR is subject to a range of anthropogenic drivers of change, of which climate change is regarded as the major long-term threat (GBRMPA, 2014a). In recent years, recurrent bleaching events due to global warming have resulted in mass mortality of coral reefs (Hughes et al., 2017b). The 2016 bleaching, for example, killed 30% of the reefs across the GBR, leading to a staggering 1000 km-scale transformation of coral assemblages (Hughes et al., 2018). As noted above, the prospects under global warming suggest that corals will continue to be severely affected well into the future (Hughes et al., 2017a).

In the context above, Australia's RRAP comprises an investment by the federal government worth over AUD $100 million, which aims to develop a suite of innovative measures that could be deployed for large-scale reef restoration and adaptation (see http://GBRrestoration.org). Within RRAP, seven types of reef interventions are currently being considered (Table 1). Many of these interventions, given its innovative and unconventional nature, are likely to pose considerable challenges to traditional regulatory practices. These include addressing novel risks and impacts and high levels of uncertainty. Australia's GBR offers, therefore, an adequate case to examine the regulatory implications of reef restoration and adaptation.

3. Methods

This study drew on multiple sources of evidence, e.g., documents, focus groups and interviews following standard protocols for qualitative research (Miles and Huberman, 1994; Patton, 2002). A desktop review of relevant legislation, policy documents and study reports was undertaken to develop a comprehensive 'map' of the GBR regulatory and governance landscape. Sources of documents for the review included legislation databases, such as the Queensland Legislation Website (www.legislation.qld.gov.au), Federal Register of Legislation (www.legislation.gov.au) and Australasian Legal Information Institute (www.austlii.edu.au), and government agencies websites (e.g., the Great Barrier Reef Marine Park Authority and Office of the Gene Technology Regulator). Between April and October 2018, four focus groups were used to gain additional information on the regulatory and governance landscape and validate the mapping of such landscape. They were also used to explore the fit of the regulatory environment including any capacity issues of regulators. The focus groups involved 19 participants including regulators, reef scientists and policy and regulation experts. Drawing on the method developed in Ekstrom and Young (2009) and employed in Fidelman and Ekstrom (2012), network graphs – produced with NodeXL (Smith et al., 2010) – were used to depict the GBR regulatory and governance landscape. This method produced easy and quick access to baseline information on regulatory and governance arrangements relating to the protection and management of the GBR. It also assisted in the identification of key clusters and relations between these arrangements.

The different types of reef interventions (Table 1) were examined to gain a better understanding of the likely regulatory issues that might arise. Interviews with reef scientists and a technical report (Bay et al., 2019) were used to gain a better understanding of the proposed interventions, with respect to intent, operationalisation, geographic location and scale, temporal scale, transboundary issues, risks/impacts, monitoring and evaluation, reversibility, scalability and uncertainty. For each of these interventions, the likely regulatory requirements for their deployment in the GBR were determined based on the key regulatory requirements established in Section 4.2 (Fig. 2).

It is important to note that this study focused on the regulatory implications of novel reef interventions primarily in relation to the existing permitting system – where the challenges associated with these interventions are arising. This does not imply that regulatory implications relate only to permitting. Implications relating to monitoring, enforcement and compliance are also important and likely to emerge in the future when/if the proposed reef interventions are deployed.

4. Results

4.1. Governance landscape

The governance landscape provides the context in which RRAP interventions are going to be developed and deployed. It consists of an intricate network of institutional arrangements (international treaties, domestic laws, policies, plans and decision-making processes) and entities (e.g., government agencies, industry, environmental groups and scientists) spanning multiple levels (from local to international), as depicted in Fig. 1. Institutional arrangements are linked to government agencies responsible for administering them, forming clusters. Two of these clusters stand out for the large number of relevant arrangements: one at the federal government level, where institutional arrangements are linked to the Great Barrier Reef Marine Park Authority (GBRMPA)

Table 1
Types of reef restoration and adaptation interventions considered within RRAP.
Source: GBRrestoration.org

Type 1.	**Cooling and shading** – Interventions aim to prevent coral stress by cooling and shading reef waters. These include pumping cooler waters onto reefs and shading techniques such as applying surface films and reducing sunlight using cloud brightening and misting.
Type 2.	**Reef Structures and Stabilisation** – Methods that aim to enhance recovery through the addition of physical devices/processes designed to improve the reef structure. Examples include artificial reef surfaces and approaches to stabilise rubble.
Type 3.	**Reproduction and recruitment** – Actions that target reproduction, recruitment, and recruit survival to enhance recovery following disturbance. Methods include the reseeding of reefs with local coral stock as well as coral cultured through aquaculture.
Type 4.	**Biocontrol** – Interventions to facilitate reef recovery or maintain reef health using bio-control approaches. Methods include reducing coral predation or competitors such as macro-algae.
Type 5.	**Probiotics and enhanced bleaching survival** – Interventions that aim to prevent coral stress (which causes coral bleaching) or facilitate recovery following stress. These include the manipulation of corals' associations with their resident algae, microbiome, fungi or viruses to enhance survival and growth following stress.
Type 6.	**Assisted evolution** – Interventions that aim to enhance the temperature tolerance and/or other desirable traits of corals to facilitate adaptation of natural populations to environmental change. Methods include moving or breeding existing temperature tolerant coral stock, interbreeding coral species for enhanced vigour or conditioning through stress exposure.
Type 7.	**Synthetic biology and genetic engineering** – Interventions using genetic manipulation that aim to enhance the stress tolerance of the coral or their symbiontic partners.

and Department of the Environment and Energy (DEE); another at the state government level, where these arrangements are linked to the Queensland Department of Environment and Science (DES) and Department of Agriculture and Fisheries (DAF). These clusters represent the key entities and arrangements involved in the protection and management of the GBR. However, several international agreements are relevant to the GBR. They form a cluster that also warrants attention (Fig. 1).

4.1.1. Federal government cluster

GBRMPA is an independent federal statutory authority with primary responsibility over the GBR Marine Park. However, under an intergovernmental agreement, it shares the responsibility for day-to-day planning and management of activities (including compliance) within

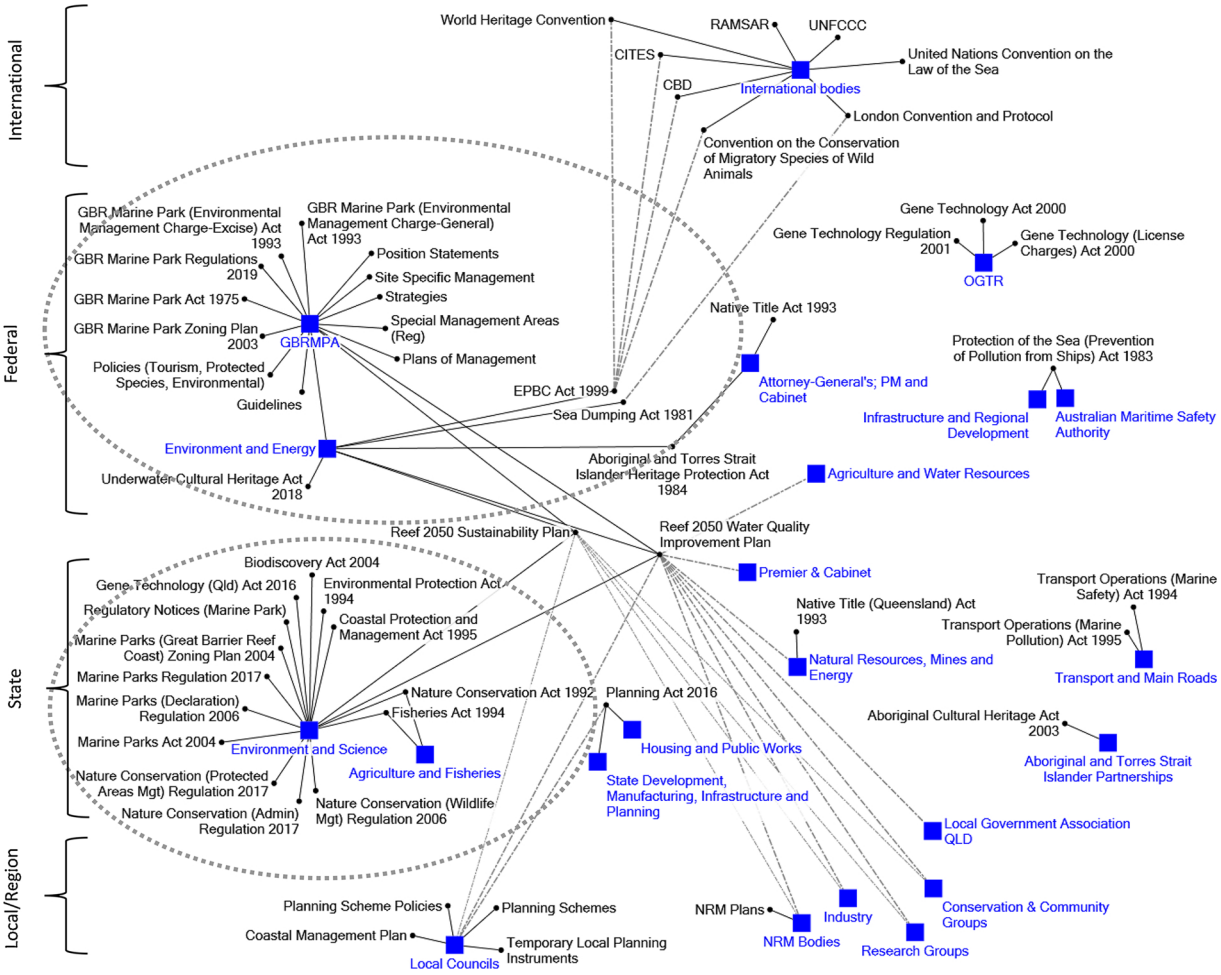

Fig. 1. Key elements of the Great Barrier Reef governance landscape. Note: squares represent organisations, circles represent institutional arrangements (e.g., legislation, regulations, policies and plans); black solid lines link arrangements with organisations responsible for those arrangements; dashed grey lines illustrate links between international agreements and national legislation that give effect to these agreements or illustrate engagement of stakeholders in selected plans (i.e., Reef 2050 Sustainability Plan and Reef 2050 Water Quality Improvement Plan). Circled clusters (doted lines) indicate the key institutional arrangements and entities involved in the protection and management of the GBR.

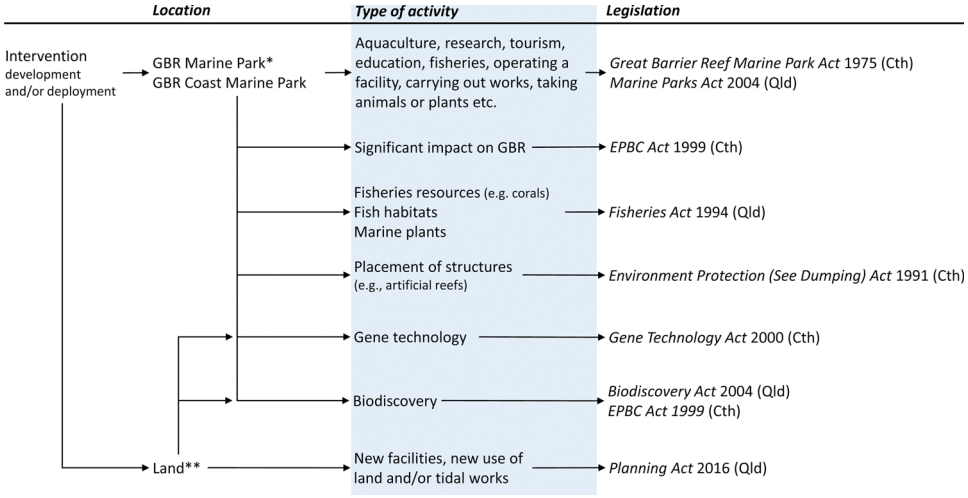

Fig. 2. examples of key regulatory requirements for RRAP interventions according to location of intervention and type of activity associated with the intervention. Note: * Includes air component < 915m of altitude; ** Includes coastal islands; GBR: Great Barrier Reef, EPBC: Environment Protection and Biodiversity Conservation, Cth: Commonwealth, QLD: Queensland.

the Marine Park with relevant Queensland government agencies. GBRMPA administers the *Great Barrier Reef Marine Park Act* 1975 (Commonwealth) (GBRMP Act), which is the main piece of legislation for the protection and management of the GBR. GBRMPA has in place several plans of management (e.g., Cairns Area Plan of Management), Traditional Owner agreements (e.g., Traditional Use of Marine Resources Agreements), policies (e.g., relating to tourism, protected species and the environment), strategies (e.g., for biodiversity conservation and climate change adaptation), guidelines (e.g., on coral transplantation), position statements (e.g., on the translocation of species within the Marine Park) and site-specific management arrangements (e.g., Lady Elliot Island and Reef). Further, it manages 21 Commonwealth islands within the GBR.

DEE – which GBRMPA is one of its portfolio agencies – administers the *Environment Protection and Biodiversity Conservation Act* 1999 (Commonwealth) (EPBC Act), which regulates new development both within and outside the GBR World Heritage Area (GBRWHA) likely to significantly impact on the GBR, the outstanding universal value of the GBRWHA, or other matters of national environmental significance, such as listed threatened species. DEE also administers the *Environment Protection (Sea Dumping) Act* 1981 (Commonwealth), which regulates the placement of structures, including artificial reefs, in the marine environment under the Commonwealth jurisdiction. In addition, DEE is the principal federal government department responsible for the Reef 2050 Plan, which provides an overarching framework for protecting and managing the Reef until 2050.

4.1.2. State government cluster

At the state level, DES is the principal Queensland government agency with portfolio responsibilities directly relevant to the protection and management of the GBR. It administers the *Marine Parks Act* 2004, which establishes the GBR (Coast) Marine Park. Within DES, the Queensland Parks and Wildlife Service (QPWS) has responsibility for the management of the GBR (Coast) Marine Park – which runs the full length of the Commonwealth Marine Park, providing protection for Queensland tidal areas. DES also includes the Office of the Great Barrier Reef, which has an important role in implementing (together with the federal government) the Reef 2050 Plan and the Reef 2050 Water Quality Improvement Plan.

DAF is the agency responsible for fisheries management on the GBR under the *Fisheries Act* 1994 (Queensland). Within DAF, the Queensland Boating and Fisheries Patrol (QBFP) has responsibility for enforcing fisheries laws.

Associated with the state government cluster, is a less prominent – nevertheless important – local government cluster (Fig. 1). Within the GBR catchment, 39 local governments have a major role in planning for development particularly on land. In this regard, they are responsible for planning schemes, which regulate development (other than mining and petroleum activities) within their local government areas. Further, local governments are the assessment manager under the *Planning Act 2016 (Queensland)* (addressed below) for "prescribed tidal works", such as the installation of pontoons within 50 m of the shore adjacent to a local government area.

Other RRAP relevant institutional arrangements at federal and state levels outside the clusters described above include the *Gene Technology Act* 2000 (Commonwealth) and *Planning Act* 2016 (Queensland). These are addressed in Section 4.2.

4.1.3. International agreements cluster

The *World Heritage Convention* is the preeminent international treaty in relation to the GBR. The Outstanding Universal Value of the GBRWHA is recognised and protected by its inscription in the World Heritage List under this convention. The World Heritage Committee plays an international oversight and assistance role under this convention. Its decisions and recommendations can significantly affect the governance of the GBRWHA. In accordance with the *Operational Guidelines for the Implementation of the World Heritage Convention* (UNESCO, 2017), the Australian government regularly informs the Committee of development that may impact on the Outstanding Universal Value of the GBR.

Other obligations under the World Heritage Convention and other international agreements are given effect, in general, through national and state laws. For example, the EPBC Act contains provisions that underpin compliance with the *Convention on Biological Diversity* (CBD), *Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES) and the *World Heritage Convention*. Similarly, the *Environment Protection (Sea Dumping) Act 1981* gives effect to the *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (London Convention and Protocol). Further, several United Nations Sustainable Development Goals, including Goal 14 to *conserve and sustainably use the oceans, seas and marine resources for sustainable development* (UN, 2015), are relevant to the GBR protection and management.

4.2. Regulatory requirements for RRAP interventions

Drawing on the governance landscape described above, this section underscores the main regulatory requirements likely to apply to reef interventions. Such interventions may involve different requirements depending, primarily, on if they occur: (1) within the Marine Park/Coast Marine Park and/or on land, and (2) the nature of the activities associated with the interventions (Fig. 2).

Many activities within the Marine Park, including those in the airspace up to 915 m above the Marine Park, require approval under the GBRMP Act (Table 2). The *Great Barrier Reef Marine Park Regulations* 2019 establish the statutory requirements for applications and the assessment process for permissions. Overall, permit applications are assessed in terms of the nature and scale of the activities proposed and the acceptability of these activities on the environment. The *Great Barrier Reef Marine Park Zoning Plan* 2003 and Plans of Management determine which and where activities are permitted in the GBR. For example, it is unlikely that intervention activities would be permitted in a Preservation Zone. As noted above, GBRMPA has in place various policies, agreements, position statements, strategies and guidelines relating to the GBR protection and management. For example, interventions in areas where Indigenous Land Use Agreement applies would be subjected to the terms of these agreements. Further, under the *Native Title Act* 1993 (Commonwealth), GBRMPA is responsible for notifying native title holders or claimants in relation to areas that will be affected by proposed permissions (GBRMPA, 2017). Another example is the *Guidelines for permit applications for restoration/adaptation projects to improve resilience of habitats in the Great Barrier Reef Marine Park* (GBRMPA, 2018), which refer to many of the proposed RRAP interventions. These guidelines provide an indication of the regulatory requirements and assessment approach to be adopted as part of the permission system for these interventions (these are addressed below). Further in assessing permit applications, GBRMPA is required to consider relevant federal and state legislation and international agreements which Australia is a party (GBRMPA, 2017). Interventions involving both federal and state jurisdictions would require a permit jointly issued by GBRMPA and QPWS under the GBRMP Act and the *Marine Parks Act 2004* (Queensland), respectively.

Certain interventions would require additional assessment and approval under other regulations, for instance:

- interventions that may cause a significant impact[1] on the environment of the Marine Park or other *matters of national environmental significance*[2] requires assessment under the EPBC Act. Current arrangements between GBRMPA and DEE provide for a referral under the EPBC Act to be considered as part of the permit application under the GBRMP Act;
- interventions involving fishery resources (including corals) and activities interfering with fish habitats and marine plants and algae would require permission under the *Fisheries Act* 1994 (Queensland);
- interventions involving placement of structures (e.g., artificial reefs) in the Marine Park would, as noted above, require assessment under the *Environment Protection (Sea Dumping) Act* 1981 (Commonwealth);
- interventions involving genetic engineering would require permission under the *Gene Technology Act* 2000 (Commonwealth);
- interventions involving biodiscovery research, such as the analysis of molecular, biochemical or genetic information about native biological material for the purpose of commercialising the material is regulated under the *Biodiscovery Act* 2004 (Queensland) and EPBC Act (Part 8 of the *EPBC Regulations* 2000), and
- interventions involving a new use of land or construction of new facilities, or those involving tidal works as defined in the *Coastal Protection and Management Act* 1995 (Queensland) may require approval under the *Planning Act* 2016 (Queensland).

Table 2
Summary of activities requiring approval within the GBR Marine Park. Source: GBRMPA (2004).

- aquaculture operations
- harvest and development fisheries
- research (other than limited impact research)
- tourism programs and developments
- educational programs (other than limited impact educational programs)
- vessel or aircraft charter operations
- navigating a managed vessel or aircraft
- operating a facility, including:
  - discharging waste from a facility
  - installation, operation and decommissioning of a facility
  - moorings
  - operating a landing area or a facility for aircraft
- carrying out works, including:
  - dredging
  - dumping of spoil
  - reclamation
  - beach protection works
  - harbour works
- taking animals and plants that pose a threat to human life or safety, marine ecosystems of the Marine Park or use or amenity of a part of the zone or adjacent area

Lastly, workplace health and safety aspects of RRAP interventions are generally regulated under the *Work Health and Safety Act* 2011 (Queensland).

4.3. Regulatory implications

Drawing on the key regulatory requirements for RRAP interventions established above, this section examines the different types of reef interventions. These interventions feature different levels of regulatory complexity. Surface films involve regulatory requirements mostly under the *Great Barrier Reef Marine Park Act* 1975 (Commonwealth); on the other hand, genetic engineering involve several such requirements under multiple Acts (Table 3). These are summarised below.

4.3.1. General (cross-cutting) implications

As would be the case with many activities to be undertaken within the Marine Park and/or in the Marine Coast Park, all proposed RRAP interventions require, under the GBRMP Act, permit issued by GBRMPA, or a permit jointly issued by the Authority and QPWS (under the *Marine Parks Act* 2004 (QLD) if these are deployed in areas involving both jurisdictions.

Further, GBRMPA's guidelines for *Permit applications for restoration/adaptation projects to improve resilience of habitats in the Great Barrier Reef Marine Park* establish different levels of risk (low to high risk) for different reef interventions (GBRMPA, 2018). These apply to RRAP interventions, as follows:

Low risk interventions

- *Algal removal* based on mechanical means; the introduction of biological control mechanisms for algal removal may be regarded as high risk.
- *Rubble stabilisation*; however, substrate stabilisation using mineral accretion may be regarded as medium risk.
- *Larval seeding* involving local scale larval collection and distribution within the same reef complex. It may be regarded as high risk if larvae are cultured through an aquaculture process and selected to have enhanced heat tolerance or other desirable traits.
- *Coral transplantation* within the same reef complex; translocation between reefs are considered as medium risk; translocation based on

[1] For the purposes of the EPBC Act, a significant impact is defined as "…an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts" (*Environmental Protection and Biodiversity Conservation Act* 2000).

[2] Matters of national environmental significance include world heritage property, listed threatened species and ecological communities and migratory species protected under international agreements.

Table 3
Examples of indicative regulatory requirements and levels of risk for RRAP interventions.

Intervention	Nature of activity							Risk*
	GBRMP/GBRCMP	SIMP	FISH	STRU	BDIS	GTEC	NFAC	
Type 1								
Cloud brightening	◆	◆						High
Misting	◆	◆						High
Surface films	◆							Medium
Mixing and pumping	◆	◆						High
Type 2								
Rubble stabilisation	◆							Low-Medium
Artificial reefs	◆	◆		◆			◆	Medium-High
Type 3								
Larval seeding	◆	◆			◆			Low-High
Translocation	◆	◆	◆		◆			Low-High
Type 4								
Macroalgal removal	◆		◆					Low-High
Type 5								
Symbiotic manipulation	◆	◆			◆			High
Type 6								
Assisted gene flow	◆	◆						Medium
Interspecific hybridisation	◆	◆	◆		◆			High
Coral hardening	◆	◆	◆		◆			High
Type 7								
Genetic engineering	◆	◆	◆		◆	◆		High
Relevant legislation	*GBRMP Act* 1975, *Marine Parks Act* 2004 (QLD)	*EPBC Act* 1999	*Fisheries Act 1994*	*Sea Dumping Act* 1994, *GBRMP Act* 1975	*Biodiscovery Act* 2014 (Qld), *EPBC Act* 1999	*Gene Technology Act* 2000	*Planning Act* 2016 (QLD)	

GBRMP/GBRCMP: within Great Barrier Reef Marine Park/Great Barrier Reef *Coast* Marine Park.
SIMP: involves significant impact on Great Barrier Reef.
FISH: involves fisheries resources, habitats, marine plants (including algae).
STRU: involves installation (dumping) of structures.
GTEC: involves gene technology.
NFAC: involves new facility, new use of land and/or tidal works.
BDIS: involves biodiscovery.
QLD: Queensland.
* Based on GBRMPA (2018).

the propagation/cultivation of corals in aquaculture facilities may be regarded as high risk, particularly, if propagation/cultivation involves trading to entities doing reef restoration projects in the Marine Park.

Medium risk interventions

- *Surface films*
- *Artificial reefs* $<20m^2$; (medium ($>50m^2$) and Large ($>100m^2$) are considered as high risk)
- *Assisted gene flow* within the same species

High risk interventions

- *Cloud brightening*
- *Misting*
- *Mixing and pumping*
- *Symbiont manipulation* to reduce coral disease using coral microbiota as probiotics or through phage therapy
- *Interspecific hybridisation*
- *Coral hardening*
- *Genetic engineering*

Many of the proposed RRAP interventions, given their novel nature, may involve tailored approaches to assessment and permitting. These approaches "…require the applicant to provide more information and require the authority to undertake a detailed assessment. These […] are non-standard/non-routine in nature." (GBRMPA, 2018: 8).

Overall, interventions considered to be of medium risk or higher may require proof of concept or supporting rationale for likely success in the Marine Park. They may also require:

- Pilot study (considered as a research activity) involving tailored assessment; may require a deed of agreement. If such a pilot study is regarded as successful, a non-research focused permit to deploy the intervention can be sought.
- Subject to the scale and risk involved, the operational application may require a tailored or public information package assessment, deed/bond, public advertising and/or an environmental management plan.

The medium and high-risk interventions outlined above may trigger the EPBC Act, depending on the scale, location, magnitude and intensity of their activities. As mentioned previously, this Act regulates activities that may cause a significant impact on the environment of the Marine Park or other matters of national environmental significance (see section 4.2).

4.3.2. Specific implications

Coral translocation, hybridisation, hardening and *genetic engineering* involving harvest of corals in state waters and/or large-scale aquaculture processes may trigger the *Fisheries Act* 1994 (Queensland). As mentioned previously, this Act also applies to marine plants and algae; accordingly, *macroalgal removal* may trigger such Act.

Artificial reefs and *human-made structures* placed in the GBR Marine Park may require consideration under the *Environment Protection (Sea*

Dumping) Act 1981 (Commonwealth). GBRMPA is the delegate for this Act when permits are required in the GBR Marine Park. GBRMPA position statement titled *No Structures Sub-zones* lists a number of locations – those described in the former *Cairns Section Zoning Plan* 1992 – that should remain: "*(a) in a natural state, largely unaltered by human works; and (b) free from structures and permanently-moored facilities, except for approved vessel moorings, approved management, research and monitoring facilities and approved navigational markers which are essential for the protection, wise use, understanding and enjoyment of the Marine Park*" (GBRMPA, 2016). Artificial reefs proposed in No Structures Sub-zone locations are considered in terms of their compatibility with the objective outlined in (a) and (b) referred to above. Further, construction of reef structures on land before deployment in the marine environment may require approval under the *Planning Act* 2016 (Queensland), depending on a range of factors such as the existing use and zoning of the land. If the artificial reefs are regarded as "tidal works" they may also require approval under the *Planning Act* 2016 (Queensland).

Interventions involving processes to enhance desirable traits (e.g. heat tolerance) of corals and their symbionts, such as *larval seeding, coral translocation, symbiotic manipulation, hybridisation, hardening* and *genetic engineering* may require consideration the under the *Biodiscovery Act 2004* (Queensland), which regulates the collection and use of biological material native to Queensland and its waters for biodiscovery research (defined as "*…the analysis of molecular, biochemical or genetic information about native biological material for the purpose of commercialising the material*"). In this case, an agreement or permit may be required from DES. Similarly, Part 8 of the *Environment Protection and Biodiversity Conservation Regulations* 2000 (Commonwealth) regulates biodiscovery in the Great Barrier Reef. In this case, permission may be assessed as part of an application under the GBRMP Act.

Interventions involving *genetic engineering* may also trigger the *Gene Technology Act* 2000, if they involve such *dealings with* genetically modified organisms (GMOs) as:

(a) conducting experiments with the GMO;
(b) making, developing, producing or manufacturing the GMO;
(c) breeding the GMO;
(d) propagating the GMO;
(e) using the GMO during manufacture of a thing that is not the GMO;
(f) growing, raising or culturing the GMO;
(g) importing the GMO;
(h) transporting the GMO;
(i) disposing of the GMO; and,

includes the possession, supply or use of the GMO for the purposes of, or during, an activity listed in (a)-(i) (Part 2 of the *Gene Technology Act* 2000 (Commonwealth)).

A GMO license is, therefore, required for genetic manipulation of corals and eventual deployment in the Marine Park. However, the Office of the Gene Technology Regulator (OGTR) is yet to deal with genetic manipulation of corals. Overall, the OGTR has assessed GMO license applications for crops (e.g., wheat, canola and cotton) and certain virus for therapeutical purposes (e.g., vaccines).

A biotechnology code of ethics is in place in Queensland, which compliance is mandatory for biotechnology research (including gene technology) funded by the Queensland Government.

4.4. Administrative capacity

As explained above, several government agencies at federal and state levels are involved in the GBR permission system. Focus group participants expressed concern about the capacity of such system to deal with novel and more complex activities. Challenges exist around timing for decisions, which is driven by a range of factors including resources, competing priorities, and uncertainty about risks and how to manage them. Reef interventions in the context of RRAP (Table 1) will necessarily involve: (1) more permit applications to trial a range of technologies and methods leading to an associated increase in the volume of work for goverment agencies, (2) the introduction of emerging technologies, which will change the nature of assessments undertaken and the risks required to be considered during assessments, and (3) early support for work with Aboriginal and Torres Strait Islander Traditional Owners and the broader GBR community to understand the social acceptability of various types of reef interventions. Consequently, it is very likely that various relevant government agencies will need to adapt to maintain a strong regulatory and management oversight of the GBR. The scientific community will also need to understand the need for additional information and be prepared to be involved more in the risk assessment and community engagement aspects of the permitting processes.

Focus group participants also expressed concern about the need for different skills set for assessing the safety and feasibility of interventions based on emerging technologies. For example, skills relating to genetic engineering are yet to be included in GBRMPA's expertise. Similarly, the OGTR – responsible for administering the *Gene Technology Act* 2000 (Commonwealth) – does not have expertise in corals.

5. Discussion

This study explored the regulatory implications of reef interventions in the context of the GBR. It mapped the existing regulatory and governance landscape, established an approach to account for regulatory requirements of reef interventions, and interrogated different types of such interventions to underscore regulatory issues associated with their development and deployment. In this context, regulatory duplication and fragmentation, regulatory misfit and administrative capacity emerged as key issues requiring attention. These are discussed below.

5.1. Minimising regulatory duplication and fragmentation

The GBR regulatory system is remarkably complex, involving multiple federal and state government agencies, and a good deal of fragmentation and duplication. As a result, a single intervention may require several permits under different pieces of legislation – interventions involving genetic engineering illustrate well the case. Regulatory fragmentation and duplication may result in delays in the development and deployment of RRAP interventions.

Regulatory fragmentation and duplication are common features of multi-level governance, where decision-making is dispersed across various jurisdictions (Hooghe and Marks, 2010). Addressing fragmentation and duplication requires collaboration across relevant jurisdictions (Feiock, 2013; Fidelman et al., 2013; Swann and Kim, 2018). In fact, this study identified instances of collaboration between agencies to streamline the permission process for activities within the GBR. For example, GBRMPA and QPWS jointly assess permit applications for activities involving both jurisdictions (i.e., the Marine Park and Coast Marine Park). Likewise, GBRMPA and DEE developed arrangements to streamline assessments involving the EPBC Act. Developing similar arrangements across a wider range of government agencies will be critical for addressing fragmentation and duplication in the GBR. Facilitating interaction between agencies such as GBRMPA, OGTR, DEE, DES and, DAF may be a general first step in this regard. This may provide the opportunity for fostering reciprocal relations, crafting collaborative strategies, exploiting commonalities and developing collaborative capacity of agencies (see Swann and Kim, 2018).

5.2. Dealing with regulatory misfit

The GBR regulatory environment is yet to include provisions to specifically assess interventions based on emerging technologies. For example, neither the GBRMPA nor the OGTR have in place

arrangements to regulate interventions aiming to enhance heat tolerance in corals using genetic manipulation. These can be conceptualised as a "problem of fit" between the regulations and the nature of reef interventions (Galaz et al., 2008; Young, 2002). In other words, these regulations may not be entirely fit-for-purpose in relation to reef restoration and adaptation. Limited fit, in this case, is associated with both novel ecological states driven by climate change and the emerging nature of the proposed technological interventions. Regarding the latter, emerging technologies (e.g., genetic engineering and solar radiation management) challenges the existing regulatory system in an unprecedented fashion to address novel risks and impacts, high levels of uncertainty and untested mechanisms for observation and monitoring. This is compounded by the ever-increasing pace of development of these technologies (Linkov et al., 2018; Trump, 2018).

In the context above, concerted action will be needed to develop a more robust permission system that can timely and effectively assess the risks and impacts of emerging technologies. This should be underpinned by forms of governance that are inclusive of a range of Traditional Owners, stakeholders and adaptive and flexible in nature (Linkov et al., 2018; Stemerding et al., 2009; Tait, 2009; Trump, 2018). Inclusiveness of regulators, citizens, advocacy groups, scientists, decision-makers and industry helps align knowledge and capacities, counteracting the typical lack of large quantitative data and guidance for governing risks of emerging technologies (Linkov et al., 2018). Adaptation and flexibility are also important. They allow for the iterative review of risk assessment capacities and regulatory requirements as more information becomes available (Linkov et al., 2018; Trump, 2018). This, in turn, allow for keeping pace with the process of technological development and maturation (Trump, 2018). Further, adaptive and flexible governance should prevent unreasonable constrains to the development of innovative reef interventions (Tait, 2009).

5.3. Overcoming capacity issues

Reef interventions based in emerging technologies represent a major departure from traditional approaches to ecosystem restoration (van Oppen et al., 2017). GBR regulators are now confronted with unprecedented challenges (e.g., novel risks and impacts, high levels of uncertainty and untested mechanisms for observation and monitoring), which require additional capacities, including skills and information. Collaboration among regulators and inclusive forms of governance for risk assessment, discussed above, are also relevant to enhancing and leveraging their capacity. For instance, focus group participants suggested that GBRMPA's risk assessment of assisted gene flow would provide OGTR with useful insights into risk management for eventual field trials involving genetically manipulated corals. Information and skills capacities may also be addressed through the development of guidelines and training of regulators with expert input from RRAP scientists. Lastly, complementary financing strategies may be required if regulators are to meet an increasing demand from reef restoration. This would typically be addressed by increasing government funding of regulators. However, exploring opportunities for co-contributions from philanthropists and the private sector may prove beneficial.

6. Concluding remarks

The feasibility and viability of reef restoration and adaptation interventions currently being considered for the GBR will depend to a large extent on the regulatory environment in which they are developed and deployed. These interventions will have to navigate a complex regulatory environment featuring a good deal of fragmentation and duplication. Further such regulatory environment may not be entirely fit-for-purpose in relation to reef interventions based on emerging technologies. Addressing fragmentation and duplication will require collaboration across relevant jurisdictions. Inclusive, adaptive and flexible forms of governance will be required, if regulation is to keep pace with the process of technological development and maturation associated with the proposed reef interventions. Lastly, adequate levels of resources will also be required to address the range of challenges and demands associated with reef restoration.

Acknowledgement

This research was funded by the Australian Government through the Reef Restoration and Adaptation Program (GBRrestoration.org).

References

Anthony, K., Bay, L.K., Costanza, R., Firn, J., Gunn, J., Harrison, P., Heyward, A., Lundgren, P., Mead, D., Moore, T., Mumby, P.J., van Oppen, M.J.H., Robertson, J., Runge, M.C., Suggett, D.J., Schaffelke, B., Wachenfeld, D., Walshe, T., 2017. New interventions are needed to save coral reefs. Nat. Ecol. Evol. 1, 1420–1422.

Aronson, J., Brancalion, P.H.S., Durigan, G., Rodrigues, R.R., Engel, V.L., Tabarelli, M., Torezan, J.M.D., Gandolfi, S., de Melo, A.C.G., Kageyama, P.Y., Marques, M.C.M., Nave, A.G., Martins, S.V., Gandara, F.B., Reis, A., Barbosa, L.M., Scarano, F.R., 2011. What role should government regulation play in ecological restoration? Ongoing debate in São Paulo State, Brazil. Restorat. Ecol. 19, 690–695.

Bay, L.K., Rocker, M., Boström-Einarsson, L., Babcock, R., Buerger, P., Cleves, P., Harrison, D., Negri, A., Quigley, K., Randall, C.J., van Oppen, M.J.H., Webster, N., 2019. Reef Restoration and Adaptation Program: Intervention Technical Summary. A report provided to the Australian Government by the Reef Restoration and Adaptation Program.

Clement, S., Standish, R.J., 2018. Novel ecosystems: governance and conservation in the age of the Anthropocene. J. Environ. Manage. 208, 36–45.

Deloitte Access Economics, 2017. At What Price? The Economic, Social and Icon Value of the Great Barrier Reef. Deloitte Access Economics.

Ekstrom, J.A., Young, O.R., 2009. Evaluating functional fit between a set of institutions and an ecosystem. Ecol. Soc. 14, 16. [online] URL. http://www.ecologyandsociety.org/vol14/iss12/art16/.

Feiock, R.C., 2013. The institutional collective action framework. Policy Stud. J. 41, 397–425.

Fidelman, P., Ekstrom, J.A., 2012. Mapping seascapes of international environmental arrangements in the Coral Triangle. Mar. Policy 36, 993–1004.

Fidelman, P., Leitch, A., Nelson, D.R., 2013. Unpacking multilevel adaptaion in the Great Barrier Reef. Glob. Environ. Change 23, 800–812.

Galaz, V., Olsson, P., Hahn, T., Folke, C., Svedin, U., 2008. The problem of fit among biophysical systems, environmental and resource regimes, and broader governance systems: insights and emerging challenges. In: Young, O.R., King, L.A., Schroeder, H. (Eds.), Eds.), Institutions and Environmental Change: Principal Findings, Applications and Research Frontiers. MIT Press, Cambridge, Massachusetts, pp. 147–186.

GBRMPA, 2004. Great Barrier Reef Marine Park Zoning Plan 2003. Great Barrier Reef Marine Park Authority.

GBRMPA, 2014a. Great Barrier Reef Outlook Report 2014. Great Barrier Reef Marine Park Authority, Townsville.

GBRMPA, 2014b. Great Barrier Reef Region Strategic Assessment: Strategic Assessment Report. Great Barrier Reef Marine Park Authority, Townsville.

GBRMPA, 2016. No Structures Sub-Zones. Great Barrier Reef Marine Park Authority, Townsville.

GBRMPA, 2017. Assessment and Decisions Guidelines. Great Barrier Reef Marine Park Authority, Townsville.

GBRMPA, 2018. Permit Applications for Restoration/Adaptation Projects to Improve Resilience of Habitats in the Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority, Townsville.

Hooghe, L., Marks, G., 2010. Types of multi-level governance. In: Enderlein, H., Wälti, S., Zürn, M. (Eds.), Handbook on Multi-Level Governance. Edward Elgar, Cheltenham, pp. 17–31.

Hughes, T.P., Barnes, M.L., Bellwood, D.R., Cinner, J.E., Cumming, G.S., Jackson, J.B.C., Kleypas, J., Leemput, I.Avd., Lough, J.M., Morrison, T.H., Palumbi, S.R., Nes, E.H.V., Scheffer, M., 2017a. Coral reefs in the anthropocene. Nature 546, 82–90.

Hughes, T.P., Kerry, J., Álvarez-Noriega, M., Álvarez-Romero, J., Anderson, K., Baird, A., Babcock, R., Beger, M., Bellwood, D., Berkelmans, R., Bridge, T., Butler, I., Byrne, M., Cantin, N., Comeau, S., Connolly, S., Cumming, G., Dalton, S., Diaz-Pulido, G., Eakin, C.M., Figueira, W., Gilmour, J., Harrison, H., Heron, S., Hoey, A.S., Hobbs, J.-P., Hoogenboom, M., Kennedy, E., Kuo, C.-Y., Lough, J., Lowe, R., Liu, G., Malcolm McCulloch, H.M., McWilliam, M., Pandolfi, J., Pears, R., Pratchett, M., Schoepf, V., Simpson, T., Skirving, W., Sommer, B., Torda, G., Wachenfeld, D., Willis, B., Wilson, S., 2017b. Global warming and recurrent mass bleaching of corals. Nature 543, 373–377.

Hughes, T.P., Kerry, J.T., Baird, A.H., Connolly, S.R., Dietzel, A., Eakin, C.M., Heron, S.F., Hoey, A.S., Hoogenboom, M.O., Liu, G., McWilliam, M.J., Pears, R.J., Pratchett, M.S., Skirving, W.J., Stella, J.S., Torda, G., 2018. Global warming transforms coral reef assemblages. Nature 556, 492–496.

IPCC, 2018. Global Warming of 1.5°C. World Meteorological Organization, Geneva.

Linkov, I., Trump, B.D., Anklam, E., Berube, D., Boisseasu, P., Cummings, C., Ferson, S., 2018. Comparative, collaborative, and integrative risk governance for emerging technologies. Environ. Syst. Decis. 38, 170–176.

Mansourian, S., 2016. Understanding the relationship between governance and forest landscape restoration. Conserv. Soc. 14, 267–278.

Mansourian, S., 2017a. Governance and forest landscape restoration: a framework to support decision-making. J. Nat. Conserv. 37, 21–30.
Mansourian, S., 2017b. Governance and restoration. In: Allison, S.K., Murphy, S.D. (Eds.), Routledge Handbook of Ecological and Environmental Restoration. Routledge, London, pp. 401–413.
Miles, M.B., Huberman, A.M., 1994. Qualitative Data Analysis: An Expanded Source Book, 2nd ed. Sage Publications, Thousand Oaks, CA.
Patton, M.Q., 2002. Qualitative Research and Evaluation Methods, 3rd ed. Sage Publications, Thousand Oaks.
Redford, K.H., Adams, W., Carlson, R., Mace, G.M., Ceccarelli, B., 2014. Synthetic biology and the conservation of biodiversity. Oryx 48, 330–336.
Richardson, B.J., 2016. The Emerging Age of Ecological Restoration Law. Review of European 25. Comparative and International Environmental Law, pp. 277–290.
Smith, M., A. C, Milic-Frayling, N., Shneiderman, B., Mendes Rodrigues, E., Leskovec, J., Dunne, C., 2010. NodeXL: a free and open network overview, discovery and exploration add-in for Excel 2007/2010/2013/2016. Social Media Research Foundation.
Stemerding, D., De Vriend, H., Walhout, B., van Est, R., 2009. Synthetic biology and the role of civil society organizations: shaping the agenda and arena of the public debate. In: Schmidt, M., Kelle, A., Ganguli-Mitra, A., De Vriend, H. (Eds.), Synthetic Biology: The Technoscience and Its Societal Consequences. Springer, pp. 156–176.
Swann, W.L., Kim, S.Y., 2018. Practical prescriptions for governing fragmented governments. Policy Polit. 46, 273–292.
Tait, J., 2009. Governing synthetic biology: processes and outcomes. In: Schmidt, M., Kelle, A., Ganguli-Mitra, A., De Vriend, H. (Eds.), Synthetic Biology: The Technoscience and Its Societal Consequences. Springer, pp. 142–154.
Trump, B.D., 2018. Synthetic biology regulation and governance: lessons from TAPIC for the United States, European Union, and Singapore. Health Policy 121, 1139–1146.
UN, 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. United Nations, New York.
UNEP, 2018. The Emissions Gap Report 2018. United Nations Environment Programme, Nairobi.
UNESCO, 2017. Operational Guidelines for the Implementation of the World Heritage Convention. UNESCO World Heritage Centre, Paris.
van Oppen, M.J.H., Oliver, J.K., Putnam, H.M., Gates, R.D., 2015. Building coral reef resilience through assisted evolution. Proc. Natl. Acad. Sci. 112, 2307–2313.
van Oppen, M.J.H., Gates, R.D., Blackall, L.L., Cantin, N., Chakravarti, L.J., Chan, W.Y., Cormick, C., Crean, A., Damjanovic, K., Epstein, H., Harrison, P.L., Jones, T.A., Miller, M., Pears, R.J., Peplow, L.M., Raftos, D.A., Schaffelke, B., Stewart, K., Torda, G., Wachenfeld, D., Weeks, A.R., Putnam, H.M., 2017. Shifting paradigms in restoration of the world's coral reefs. Glob. Change Biol. 23, 3437–3448.
Young, O.R., 2002. The Institutional Dimensions of Global Environmental ChaGlobal Environmental Change: Fit, Interplay and Scale. MIT Press, Cambridge.