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PERSPECTIVES AND NOTES

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Restoring shellfish reefs: Global guidelines for practitioners and scientists

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Abstract

Widespread global declines in shellfish reefs (ecosystem-forming bivalves such as oysters and mussels) have led to growing interest in their restoration and protection. With restoration projects now occurring on four continents and in at least seven countries, global restoration guidelines for these ecosystems have been developed based on experience over the past two decades. The following key elements of the guidelines are outlined: (a) the case for shellfish reef restoration and securing financial resources; (b) planning, feasibility, and goal setting; (c) biosecurity and permitting; (d) restoration in practice; (e) scaling up from pilot to larger scale restoration, (f) monitoring, (g) restoration beyond oyster reefs (specifically mussels), and (h) successful communication for shellfish reef restoration projects.

KEYWORDS
ecosystem services, ecological restoration, marine ecosystem restoration, oyster reef, shellfish reef

1 | INTRODUCTION

The global *Shellfish Reefs at Risk* assessment (Beck et al., 2009; Beck et al., 2011) revealed steep and widespread declines in native populations of ecosystem-forming bivalves such as oysters and mussels (herein "shellfish reefs"), which was confirmed by subsequent and more detailed national and regional studies (e.g., Alleway & Connell, 2015; Ford & Hamer, 2016; Gillies et al., 2018, 2020; Pogoda, 2019). Acknowledgment of the loss of these ecosystems coupled with growing recognition of the valuable functional role shellfish reefs perform in coastal systems, including water filtration, coastal protection, and fish production (e.g., Coen et al., 2007; Grabowski et al., 2012), has led to widespread interest in their restoration and protection (Baggett et al., 2014, 2015; Gillies et al., 2015; Gillies, Crawford, & Hancock, 2017; Theuerkauf & Lipcius, 2016; zu Ermgassen et al., 2016). This growing scientific interest, coupled with expanding professional networks (e.g., http://shellfishrestoration.org.au, https://noraeurope.eu/) and public attention (including the recent announcement by the United Nations on the Decade on Ecosystem Restoration, see also Young & Schwartz, 2019; Waltham et al., 2020), provides a platform to review and revise restoration processes and experiences related to shellfish reef restoration.

The first *Practitioners Guide* for shellfish reef restoration (Brumbaugh, Beck, Coen, Craig, & Hicks, 2006) was primarily focused on supporting community-based restoration efforts for oyster reefs in the United States. There was a nascent and growing interest in reversing local losses of oyster reefs, frequently motivated by declines in local oyster fisheries. The motivations for undertaking restoration still include recovering oyster fisheries, and there is also growing interest and efforts to recover shellfish reefs for other benefits including threatened ecosystem recovery, biofiltration, coastal protection, fish production, and nutrient cycling. Since the first *Practitioners Guide*, shellfish restoration has also grown to encompass a number of different bivalve species (e.g., *Ostrea angasi*, *Ostrea edulis*, *Perna canaliculus*, and *Crassostrea hongkongensis*) and geographies (Australia, Europe, New Zealand, Asia) not included in the original guide.

A new set of restoration guidelines (Fitzsimons, Branigan, Brumbaugh, McDonald, & zu Ermgassen, 2019) were recently produced by and for practitioners, managers, and community members involved in shellfish restoration across the globe. These guidelines were produced with a key objective to simplify complex scientific principles and terminology into a resource that would be useful to a broad audience including community members, coastal managers, and scientists new to the field of restoration. The content of these guidelines was informed by a global survey of shellfish reef restoration practitioners and managers, which resulted in feedback from 76 respondents spanning four continents and six geographies (Box 1). The new guidelines provide support for decision-making related to where and how to establish restoration projects in addition to examples and case studies of how guidance can be applied in a range of different geographic, environmental, and social settings (Fitzsimons et al., 2019). Importantly, the guidelines also align shellfish reef restoration approaches with guidance provided by the International Principles and Standards for the Practice of Ecological Restoration (Gann et al., 2019) and incorporate advice for both smaller community projects and larger scale (>10 ha) projects.

2 | KEY ELEMENTS TO THE GUIDELINES

In the following, we provide a summary of key elements of the new guidelines as a quick reference for practitioners. These are built on our collective knowledge of how these ecosystems are structured and function, while encouraging continued science and monitoring to better inform increased success at both local and systems scale. For expanded guidance, see Fitzsimons et al. (2019). A checklist of key planning, design, implementation, and monitoring principles developed from the Guide is provided in Box 2.

2.1 | The case for shellfish reef restoration and securing financial resources

Shellfish reefs provide a wealth of benefits to ecosystems and people, including increasing biodiversity, enhancing water quality, providing a distinct fishery (bivalves), and an important habitat for other fishery species (e.g., finfish and crustaceans), reducing shoreline erosion, as well as providing significant cultural values. Beneficiaries of shellfish reef restoration may include the local community, through improvement of water quality or reduction in shoreline erosion, as well as anglers through enhancement of fish stocks and providing structure around which fish may aggregate. Many bivalve species have been harvested for millennia (McLeod, Gillies, Creighton, & Schmider, 2018). Although overharvest has been one of the key drivers of decline of this critical habitat, sustainable harvest and aquaculture can be economically valuable and the basis of a deep cultural bond between local communities and their environment in many parts of the world. Restoring habitat, creating larval spillover to harvest in unrestored areas, and supporting bivalve aquaculture are all important in forging, reviving, and sustaining a rich cultural association with these often edible species. For example, in the United Kingdom, oyster festivals are seeing a resurgence by bringing the community to the shore and raising awareness of the near-forgotten native European oyster (*O. edulis*).

Successful restoration projects rely on financing as much as good science and practice. Without adequate funding, projects can stall at the planning stage, partway through the implementation stage, or may not have sufficient resources to support the important work of monitoring for outcomes of the project. Restoration projects often rely on multiple sources of funding to complete all facets of a restoration project. Therefore, it is useful to identify sources of funding (or in-kind resources) early in the planning process and identify how different sources of funding can be leveraged to support the various elements of a project. Restoration often starts with small-scale "proof-of-concept" projects, which in some cases are community led and are designed to test methods and approaches for enhancing populations of target bivalve species and provide evidence of the value of restoration activities. Typical funders in these situations include those who provide community or environmental grants, such as governments, private trusts, or corporate philanthropy. Larger scale restoration efforts to date have resulted primarily from political commitments, often with an industry development or jobs incentive for funders (e.g., the US *American Recovery and Reinvestment Act of 2009* saw 50 coastal restoration projects, including many oyster reefs funded as part of an economic stimulus focusing on jobs: Conathan, Buchanan, & Polefka, 2014). Anticipated returns on investment from the ecosystem services returned from reef restoration can be strong incentive for funders. For example, the Glenmorangie Whisky Distillery has joined forces with Heriot-Watt University and Marine Conservation Society to form the Dornoch Environmental Enhancement Project (https://nativeoysternetwork.org/portfolio/deep/). The project aims to restore oyster reefs,

BOX 1 Global survey of practitioners and managers for an update of guidelines for shellfish reef restoration

One of the initial steps in updating the first *Practitioners Guide* (Brumbaugh et al., 2006) was to conduct a global survey of shellfish reef restoration practitioners and managers to seek their input and ensure their needs were best met. The survey questions covered topics such as their regional location; professional experience; awareness about the first *Practitioners Guide*; the main challenges faced in establishing and implementing projects; and suggested new content for the update. There were 76 survey participants in total with 78% from North America and the remaining from Europe (10%), Australia and New Zealand (5%), China and Hong Kong (3%), and elsewhere in the Asia Pacific (4%). The North American participants averaged ~6 plus years experience and the other regions 1–3 years experience, principally in research and project management.

More than half of the participants (68%) were aware of the first *Practitioners Guide*, with 90% of those finding it useful, but also recommending that all chapters needed an update. The main critiques were that the first publication was a beginner resource and needed more in-depth scientific evidence of restoration benefits. The primary challenges faced by practitioners and managers were feasibility assessments, addressing restoration key knowledge gaps, fundraising, and implementing restoration at scale. Many participants requested that the updated guidelines focus on ecosystem services—the "why" behind restoration projects and that a diversity of shellfish is represented—not just oysters. In addition, lessons learned and site selection processes from an international perspective were the other main suggestions for content.

The survey results, as well as the outcomes of a number of planning workshops, shaped the content direction for the updated guidelines and who was chosen as part of the global team of editors and authors. This team includes practitioners with experience in all facets of project implementation, with their collective knowledge, including lessons learnt, shaping the content of the updated guidelines.

BOX 2 Key guidelines for practitioners when undertaking shellfish reef restoration projects

Know the system you are working in

Become familiar with the ecosystem in its local setting (e.g., consider its historical distribution), causes for decline, current threats (including diseases), bivalve lifecycle and reproduction methods, and associated community assemblages. Gather evidence of recruitment strength and timing from previous research, observation, aquaculture operators, and settlement plates.

Develop a restoration concept and socialize with potential project stakeholders and supporters

Consider developing a short document that outlines project aspirations and potential approaches. Use this to receive feedback and support for establishing a more detailed feasibility plan and funding proposals. Include regulators in the outreach.

Establish a feasibility plan

Consider including the following in a feasibility plan:

- Identification of reference ecosystems or reference models and derived targets.
- Clearly defined S.M.A.R.T. (Specific, Measurable, Attainable, Relevant, and Time-bound) objectives.
- Identification of project stakeholders and supporters.
- Likely funding streams.
- Different restoration approaches.
- Availability and disease tolerance of broodstock and source of seed (if larvae limited).

Identify funding sources and secure funding

Consider linking ecosystem service outcomes to beneficiaries and targeting funding opportunities linked to ecosystem service outcomes. Explore opportunities to leverage and match initial support.

Establish project management systems

Establish detailed project and implementation plans, communication plans, volunteer management, legal framework and contracts, detailed risk assessments, site management plans, tenders and quotes, and so on.

Know biosecurity risks and permitting requirements

Identify biosecurity and disease risks to wild populations and to aquaculture and fishing industries. Understand requirements and development times to secure permits. Understand/address the potential threat of the harvest of shellfish from the restored reef.

Undertake habitat suitability assessments and pilot studies

Identify optimal places for restoration with the system using suitability assessments, history of the most recent shellfish reefs, and pilot studies.

Confirm technical approach(es) required to support recovery including reef designs

Does the ecosystem require reconstruction (e.g., addition of substrate and shellfish), assisted regeneration (e.g., addition of substrate or shellfish), or management to limit threats (e.g., sediment, disease, or predation)? What reef designs will be used to support these technical approaches?

Undertake restoration

Work with community volunteers, contractors, and third parties to mobilize and deploy substrate, shellfish, and reduce/remove threats.

Undertake monitoring, evaluation, and reporting

Measure progress against predefined restoration targets and reference ecosystems and models. Measure universal indicators.

Effectively communicate outcomes of your project to stakeholders, practitioners, and the research community

Plan for communication, do the basics, and target visual media and social media.

in part, to offset organic waste from the distillery. Restoration projects are also beginning to utilize a number of emerging and alternative (to traditional environmental funding) options including (a) linking to livelihoods (e.g., sustainable oyster harvesting), (b) biodiversity and nutrient offsets, (c) payment for ecosystem services, and (d) blue bonds.

2.2 | Planning, feasibility, and goal setting

Considering the multiple benefits provided by shellfish reef restoration, every restoration project should be guided by a clear set of restoration goals that describe what the project is setting out to achieve. These can include ecological goals (e.g., restoration toward the target ecosystem), social and economic goals (e.g., engage volunteers, provide employment), and project efficiency goals (e.g., undertake work within allocated budget and time). Ecological goal setting can sometimes be difficult, especially when different stakeholders may have different views on what they would like from the project. For instance, a goal could be to "By X date, restore the ecosystem to improve marine biodiversity" or to "restore the ecosystem to support recreational fishing." Both goals require the ecosystem to be restored, yet the latter places more emphasis on a specific type of biodiversity (recreationally important fish species) and a particular type of ecosystem service (provision of fishing opportunity) in addition to the ecosystem being restored. Although this might seem like a trivial difference given both scenarios seek to restore the ecosystem, understanding the primary motivator for restoration will help shape how a project is sited, designed, constructed, and monitored, selection of the ecosystem target or model, and ultimately determine whether project stakeholders consider the project a success. Examples of resources that are designed to assist in conservation and restoration planning include the Open Standards for the Practice of Conservation (CMP, 2013), Conservation by Design (TNC, 2016), and from the Society for Ecological Restoration (Gann et al., 2019).

Methods to understand whether restoration is possible within an estuary or coastal system can range from a simple summary of available information to more sophisticated, restoration suitability models and Geographic Information System spatial analysis (see also Puckett et al., 2018; Sarkar et al., 2006; Schwartz et al., 2018). Answering questions such as (a) Have the threats that caused the initial degradation of the ecosystem been removed or sufficiently managed to allow the ecosystem to be restored?, (b) Are the environmental and physical parameters of the area (e.g., salinity, pH, dissolved oxygen, wave energy, bottom condition) within the biological tolerances of the primary habitat-forming bivalve and the associated ecological community?, (c) Are the logistical and regulatory requirements available and within budgetary scope to support the restoration activities?

Stakeholder analysis can be performed to identify who should be involved in the project and how they should be engaged prior to starting the project. Start by listing all relevant stakeholders according to categories or like-minded groups and then make an assessment on their likely needs and involvement in the project. This will help determine and prioritize groups to consult during project planning and implementation. Example categories/groups could include (a) estuary or coastal zone users (recreational, industry, cultural), (b) land and sea managers and regulators, title holders, neighbors, (c) potential project funders, (d) project supports and volunteers, (e) subject matter experts (e.g., marine ecologists, oyster and mussel biologists, resource managers, oyster fishers), and (f) project detractors.

The Society for Ecological Restoration recommends the use of a reference ecosystem (which is synthesized from information from a number of reference "sites" to act as a model ecosystem as a fundamental requirement of restoration projects. A reference ecosystem or model helps guide the project design, sets ecological targets, and supports monitoring (Gann et al., 2019). A reference ecosystem or reference model describes what is known about the ecosystem's ecological and physical characteristics and can be considered analogous to the detailed engineering plans required by a builder to replicate an existing house. These can be developed by either conducting detailed ecological surveys on references site to ascertain structural (e.g., reef size, height), community and population information (e.g., oyster density, associated communities), and species relationships (e.g., grazing, predatory forces), or where reference sites are absent by building a reference model of the ecosystem through information sourced from the scientific literature (Gann et al., 2019). For further information about synthesizing and incorporating a model ecosystem into restoration plans for a modelled shellfish reef ecosystem, see Gillies et al. (2017).

2.3 | Biosecurity and permitting

The transfer of aquatic species, such as shellfish, among water bodies has been a major cause of the spread of invasive species, parasites, diseases, bacteria, and viruses. The spread of these harmful organisms can have damaging and irreversible ecological impacts, especially where they become serious pests in their new environment. Therefore, taking biosecurity precautions is an obligatory aspect of all shellfish reef restoration where it involves the transfer of shellfish species (or their shells). Where translocations of shellfish are allowed, dipping or spraying shellfish with freshwater or weak acetic acid (vinegar solution) has been used to destroy biofouling pest species, such as invasive sea squirts, seaweeds, and fan worms, to prevent their transfer among locations (e.g., Dunphy, Wells, & Jeffs, 2005; Forrest, Hopkins, Dodgshun, & Gardner, 2007). Although there are standard industry approaches to chemical treatments, their efficacy is not reported in the scientific literature. In any case, even if efficacy has been tested previously, it is necessary for each batch of shellfish to be screened before translocation takes place, in order to ensure that unwanted organisms are not being introduced unintentionally. The movement and placement of shell-based cultch material bears some similar risks to those associated with the movement of live shellfish. Untreated shell material, collected as part of shell recycling initiatives, may contain living pests or spores and should therefore also be subject to biocontrol measures before being deployed.

Of the many components of a successful restoration project, it is the time and diligence involved in permitting that often tends to be underestimated. Permits in many jurisdictions are provided by natural resource management agencies who are charged with protecting the resource on behalf of the public and considering all possible interactions resulting from the restoration. Navigating the permitting process requires a thorough understanding of the project and the restoration process for both the applicants and the permit reviewers. Useful guides for navigating the permitting process are available in some jurisdictions (e.g., Mississippi-Alabama Sea Grant Legal Program and National Sea Grant Law Center, 2014). In jurisdictions where shellfish reef restoration is a new and unfamiliar activity, it is beneficial to involve staff of the regulatory agencies in the restoration project, along with other stakeholders, from the outset with the initial planning and concept development phase. Being aware of national or subnational jurisdictional standards for the safe and sanitary control of the growing, processing, and shipping of shellfish for human consumption (e.g., US Food and Drug Administration, 2017) will be important for shellfish reef restoration projects if they are located near sites where shellfish are being grown for consumption, as will be consideration of international protocols around reintroductions and conservation translocations (e.g., IUCN/SSC, 2013).

2.4 | Restoration in practice

Approaches to successful restoration vary with species, scale, and local biological, ecological, and physical conditions. Local regulatory and social factors are important as well. Although it is useful to learn from national and international examples, it is also critical to consider how these may need to be adapted for application to a particular region or site. Understanding the physical attributes and basic functions of your local reference ecosystem (e.g., patch size, reef height, spawning time, larval dispersal and local hydrodynamics, oyster density, disease resistance, fish and invertebrate assemblages) will help to determine which technical approaches may need to be applied to restore the ecosystem. These can range from (a) natural regeneration (recovery after the cessation of the degrading practices alone), (b) assisted regeneration (recovery at sites of intermediate or high degradation needing both removal of causes of degradation and further active interventions to correct abiotic damage and trigger biotic recovery), and (c) reconstruction approaches (where damage is high, all causes of degradation need to be removed or reversed and all biotic and abiotic damage corrected to suit the identified local native reference ecosystem, with all or a major proportion of its desirable biota needing to be reintroduced wherever possible). These different approaches can be largely summarized into whether absences of suitable reef substrate, absence of recruitment, disease, or a combination of these are preventing the natural recovery of the shellfish reefs (e.g., Brumbaugh & Coen, 2009).

Typically, an area in need of restoration is either "recruitment limited," "substrate limited," or both (Brumbaugh & Coen, 2009), and assisted regeneration or reconstruction methods would be required (Gann et al., 2019). Recruitment-limited environments lack sufficient nearby broodstock (mature, reproductively capable shellfish of the target species) to naturally populate existing reef structure. Substrate-limited environments lack reef structure to which shellfish larvae can attach. The presence of abundant wild shellfish attached to docks, piers, pilings, seawalls, and so on near the proposed restoration site is a good indication that an area may be substrate limited but not recruitment limited. It is quite common for restoration sites to be both recruitment and substrate limited. Understanding whether the localized limitation is recruitment, substrate, or both will inform decisions on what restoration treatment should be applied.

In a recruitment-limited area, practitioners will need to add the target shellfish species to the reef. These can be adult animals, but more typically juvenile animals (often referred to as "seed") are added. Juvenile shellfish tend to be more readily available in large quantities than adult broodstock; this is particularly true of the quantities required for large-scale restoration (i.e., 0.5 ha or larger). Sources for seed include hatcheries (juvenile shellfish production facilities), pond systems, and collection of wild spat on cultch (placing cultch in high-recruitment areas and transporting to the restoration site). Relocation of natural (sometimes called "wild") shellfish seed is another option for seeding reefs and may be more feasible, cost effective, and scalable than hatcheries (Southworth & Mann, 1998). Shellfish gardening programs (where community members grow shellfish off docks in floats or cages for planting onto restoration areas) can also be a source of adult broodstock for small-scale restoration projects. Oyster gardening can increase local broodstock, which may provide a larval supply in otherwise recruitment-limited systems (Brumbaugh et al. 2000b). A further advantage of oyster gardening is that it engages the local community in reef restoration and can provide hands-on educational experience. In areas where reefs are largely subtidal, such as Europe, this can be one of the few ways in which the community can engage with the target restoration species.

In substrate-limited areas, practitioners will need to construct reefs from some type of appropriate substrate. If the area is both substrate and recruitment limited, practitioners will need to construct reefs and then seed them with juvenile shellfish. Selecting reef-building substrate requires careful consideration of the local biotic and abiotic environment, social factors, and material availability. Factors to consider when selecting reef material include recruitment suitability (e.g. chemical, surface roughness), wave energy, water depth, benthic characteristics, purpose of the reef project, sedimentation, sanctuary (nonharvest) status and public health, fishing gear restrictions, conservation status of the restoration site, public and regulatory acceptance of the material, user group conflicts, reef material acquisition and placement, and cost.

2.5 | Scaling up from pilot to larger scale restoration

Shellfish restoration often starts from small-scale, community-based projects that commonly ranged from only a few square meters to a few hundreds of square meters in size. These projects can provide "proof of concept" for large-scale projects, yet the restoration methods and approaches for larger scale restoration (>1,000 m^2) can often be very different from those deployed at smaller scales. Larger scale projects not only increase the level of the services provided (Bersoza Hernández et al., 2018), which makes it easier to appreciate and measure the benefits of restoration. With larger and more costly projects come more complex legal considerations, tendering, contracting and project management systems, contractor management, detailed financial reporting mechanisms, labor laws, health and environmental safety considerations. The task of scaling shellfish reef restoration is one of combining project management expertise with an understanding of the biology involved and the essential components of the project, from hatchery production to managing marine contractors and developing outreach, public awareness and opportunities for community members, government, industry, and corporate partners to be involved in the project. Examples of this broader involvement from Port Phillip Bay in Australia include: through the Shuck Don't Chuck project, where shells are recycled from restaurants and seafood wholesalers to use in the restoration process (see https://www.natureaustralia.org.au/what-we-do/our-priorities/provide-food-and-water-sustainably/food-and-water-stories/shuck-don-t-chuck–shell-recycling-project/) and through citizen science and volunteering activities, including OysterWatch (i.e., deploying and monitoring settlement plates), shell cleaning for the Victorian Shellfish Hatchery to produce cultched seed, and measuring individual shellfish.

Timelines for completing projects of course vary depending on the funding, political, and project setting. However, 6–12 months for project funding and initial concept, 1–3 years for pilot development and monitoring, and 2–10 years to establish and deliver larger projects would not be unusual, particularly where shellfish restoration is a novel or emerging management tool for the region.

Consideration of lessons from the broader scaling literature may be of assistance. For example, Battista, Tourgee, Wu, and Fujita (2017) identified a number of factors for scaling to be successful, including (a) scaling must be considered at all stages of a project; (b) the context must be managed and barriers to scaling must be identified and removed; and (c) deliberate attention must be paid to scaling methods, marketing and dissemination efforts, and long-term monitoring of scaling progress.

2.6 | Monitoring

Restoration projects should generally be monitored to evaluate outcomes at the project level, as well as monitored in a way that allows for comparison of results across projects (e.g., Lindenmayer & Likens, 2010; McDonald-Madden et al., 2010; Sanchirico, Springborn, Schwartz, & Doerr, 2013). The type of monitoring performed should inform one or more of the following monitoring types. Firstly, implementation monitoring assesses whether the management actions for restoration were implemented as designed and planned. It is a straightforward assessment of whether the designed and planned restoration was carried out and accomplished. Secondly, performance monitoring determines whether the restoration activities activate the desired habitat response, such as increasing shellfish recruitment, biomass, or other population-level parameters toward the trajectory of the respective reference ecosystem or model. There may also be ecosystem functions and services intended by a project such as increases in biodiversity, fish biomass, or water quality. Performance monitoring requires development of clearly articulated objectives and identification of informative indicators. Finally, adaptive management monitoring will inform restoration management and improve the design of future restoration efforts. Systematic monitoring using standardized and comparable methods is critical when accomplishing these last two forms of monitoring to facilitate the comparison of results across projects and programs and eliminates the potential for observed changes across projects to be the result of procedural differences in the monitoring.

A set of minimum universal metrics and environmental variables that have been created for oysters in the United States should be measured on every project, regardless of restoration objectives (Baggett et al., 2014, 2015; The National Academies of Sciences, Engineering, and Medicine, 2017). The minimum universal metrics aim to provide all projects with the data they need to assess their progress and possible causes of any failure. These can serve as guides for other reef-forming shellfish reef restoration projects. Further monitoring methods are proposed for goal-based (ecosystem service) monitoring. Although such monitoring is often more difficult to implement, it can allow for better communication with stakeholders, can inform monitoring for adaptive management where the goal is ecosystem service delivery, and can inform other predictive ecosystem service models. Another important consideration in evaluating project outcomes is to involve citizen-scientists in monitoring, as these individuals often possess both the interest and technical capabilities to undertake the activities.

2.7 | Restoration beyond oyster reefs (specifically mussels)

Most shellfish reef restoration projects to date have focused on oysters. However, there is growing interest and activity around restoring mussels and other reef- or bed-forming shellfish. These species deliver many of the same ecosystem services as restored oyster reefs, but they often differ from oysters with regard to their life history, especially in terms of varying habitat requirements throughout their development. Consequently, these reef-building shellfish species often require different approaches from those used for oysters to achieve successful restoration. In particular, the relative locations of nursery and adult habitats may need to be taken into account in restoration planning—many mussel species have larval settlement and juvenile phases with different habitat requirements to the adult phase. Mussel larvae frequently have a strong preference to settle on filamentous organisms, such as seaweeds, hydroids, and seagrasses, which initially keeps the early juvenile mussels off the seafloor while they become established (Seed & Suchanek, 1992). In contrast, adult mussels frequently prefer to aggregate on the seafloor to form reef structures. The need for a nursery habitat that is distinct from that of the adults is in marked contrast to larval oysters, which seek out hard substrate, particularly adult oyster shells, on which to settle and attach permanently, remaining in the same position as they grow to adults.

Although these guidelines focus specifically on the restoration of shellfish reefs, it is recognized that coastal habitats do not function in isolation, and that location of restoration activities of shellfish reefs can yield positive benefits for the recovery of other habitats, such as seagrass and saltmarshes (Chowdhury et al., 2019). Although there may be some redundancy in benefits arising from multiple colocated structured coastal habitats (Grabowski, Hughes, Kimbro, & Dolan, 2005), colocation may also increase benefits associated with some services (e.g., carbon sequestration, Ridge, Rodriguez, & Fodrie, 2017).

2.8 | Successful communication for shellfish reef restoration projects

Effective communication with a variety of stakeholders is essential for the success of shellfish reef restoration projects. It is most often a permitting and funding requirement and, when done well, helps people feel connected to and excited about the project. In contrast, if communication and engagement are not done early and well, this can lead to misunderstanding and mistrust, causing problems and delays. A good strategy for successful communication makes the most out of limited resources and will likely lead to greater project support and funding (Olsen, 2009). It can also provide clarity about a project's mission and goals. Communication planning includes "building a team" (identify the people involved in your project who can assist with communication activities), "define the audience" (document the most important people for the success of the project and make sure these people are prioritized in your communication strategy), "determine key messages" (start with the vision for the project and clearly articulate the problems the project is trying to overcome, and the benefits envisaged), "determine the best methods to communicate with the project's target audience" (the best communication methods will be a compromise between the communication methods that are used by your audience, what your team is comfortable using and what is possible considering the project's time and financial budget), "keep track of the strategy" (document objectives and track the project's success), and "review the strategy" (projects change so ensure the communications strategy is reviewed and consider what has and has not worked well) (see also Enquist et al., 2017).

3 | CONCLUSIONS

In summary, our collective reflections developed during the production of the new guidelines are as follows:

1 Restoration now encompasses a wide variety of species (including *Crassostrea*, *Ostrea*, and *Mytilus* genera), geographies (including the United States, New Zealand, Australia, China/Hong Kong, Germany, Netherlands, and United Kingdom) and positions in the seascape (including intertidal, low intertidal, and fully subtidal).
2 There are a variety of different approaches and methods, including reducing external threats, partial reconstruction, and full reconstruction, but projects often include addition of reef substrate and/or oysters.
3 The International Principles and Standards for the Practice of Ecological Restoration (Gann et al., 2019) can be applied to shellfish reef restoration and provide a useful framework, which allows comparable approaches, terminology, and monitoring methods with terrestrial ecosystems.
4 There are a number of online decision-support tools, financial approaches, and planning tools available that can help guide practitioner decision-making (e.g., coastalresilience.org restoration decision support tools, others listed in Fitzsimons et al., 2019).
5 Although much of the shellfish reef restoration activity to date has been focused on oysters, there is rapidly growing activity around restoring mussels and other habitat-building shellfish. These species deliver many of the same ecosystem services as restored oyster reefs.

Our experiences developing the new guidelines (and the many contributions from practitioners and researchers across four continents who provided us with thoughtful suggestions, examples, and experiences) have provided strong evidence that shellfish reef ecosystems can be restored, at scale, in varied geographies, using a range of approaches. With ever-increasing knowledge on the science of restoration and the benefits it provides to both coastal communities and industries combined with greater international attention on the need for restoration (i.e., UN Decade on Ecosystem Restoration), the recovery of shellfish reefs could provide a global bright spot in ecosystem recovery and road map for how other marine ecosystems could be similarly restored.

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CONFLICTS OF INTEREST

The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed to writing and/or editing the guidelines from which this paper was based.

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