RESTORATION GUIDELINES FOR SHELLFISH REEFS

Editors: James Fitzsimons, Simon Branigan, Robert D. Brumbaugh, Tein McDonald and Philine S.E. zu Ermgassen

SER SOCIETY FOR ECOLOGICAL RESTORATION

The Nature Conservancy

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The restoration of habitat has become a priority for many citizens and governments as the ecological and societal benefits of these habitats have been become more widely recognised.

Black pygmy mussels. Photo: Alan Cottingham, Murdoch University

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PRACTITIONERS' CHECKLIST

This table provides a high-level checklist for practitioners to help guide the establishment and delivery of shellfish restoration projects.

Know the system you are working in *(Chapters 1 and 2)*	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 socialise with potential project stakeholders and supporters *(Chapters 1 and 2)*	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 *(Chapter 3)*	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. 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 *(Chapter 2)*	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 *(Chapters 3, 4 and 5)*	Establish detailed project and implementation plans, communication plans, volunteer management, legal framework and contracts, detailed risk assessments, site management plans, tenders and quotes, etc.
Know biosecurity risks and permitting requirements *(Chapter 4)*	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 *(Chapters 3 and 5)*	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 *(Chapter 5, 6, 7 and 8)*	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 *(Chapter 5 and 6)*	Work with community volunteers, contractors and third parties to mobilise and deploy substrate, shellfish and reduce/remove threats.
Undertake monitoring, evaluation and reporting *(Chapter 7)*	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 *(Chapter 9)*	Plan for communication, do the basics and target visual mediums and social media.

*Documenting the historical ecology of shellfish reefs in the area can be important to support the planned restoration.

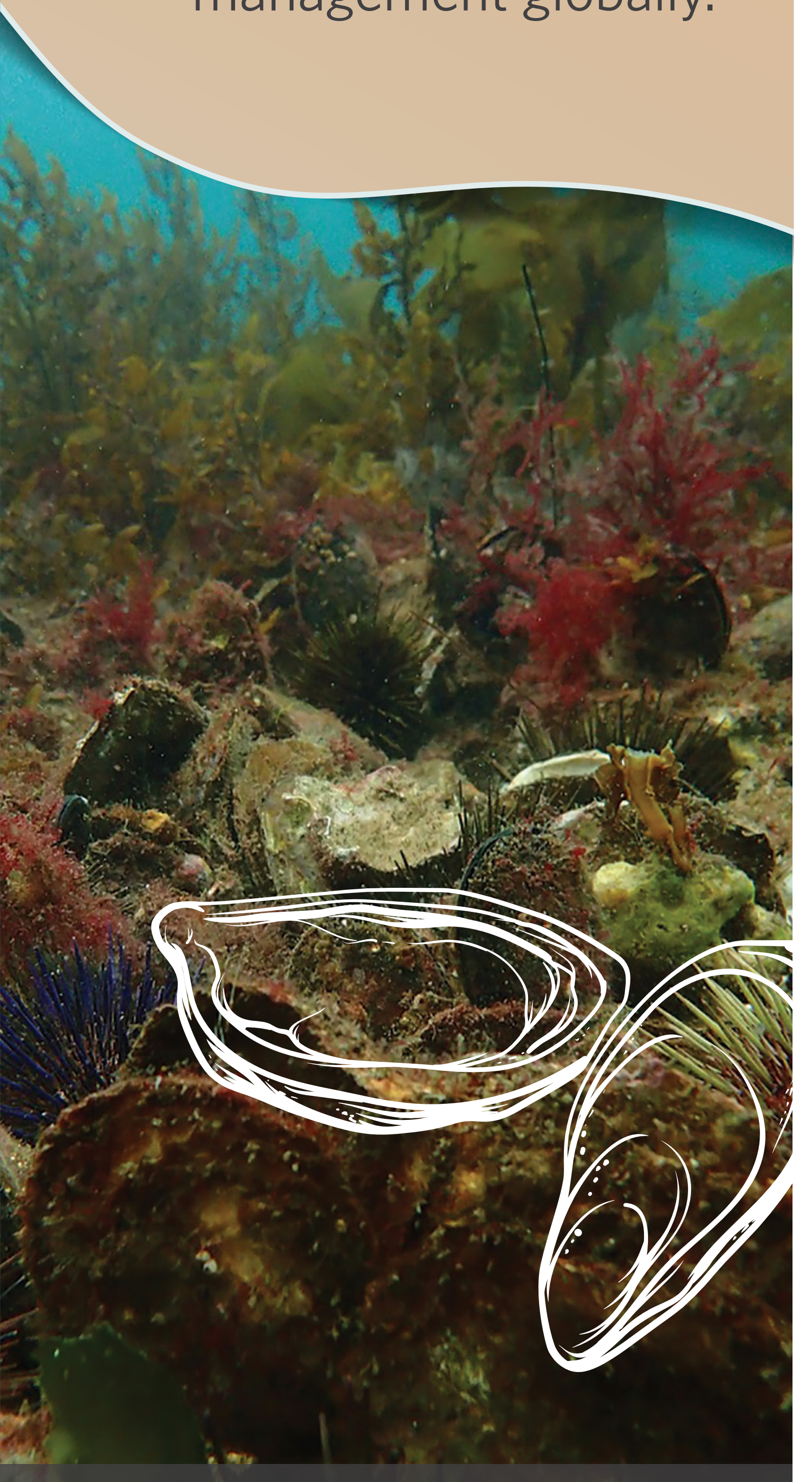
This publication is intended to provide foundational information to serve as a useful starting point for shellfish reef restoration.

Margaret's Rock, Port Phillip Bay, Australia. Photo: Paul Hamer.

GLOSSARY

- **Adaptive management:** a structured decision-making process that incorporates learning by doing and a monitoring program that incorporates learnings into future decision-making.
- **Assisted regeneration:** recovery at sites of intermediate (or even high) degradation. Need both removal of causes of degradation and further active interventions to correct abiotic damage and trigger biotic recovery.
- **Bins:** are in a histogram chart and are the entire range of values divided into a series of intervals. Then, how many values that fall into each interval are counted. The bins are usually specified as consecutive, non-overlapping intervals of a variable.
- **Bivalves:** aquatic molluscs which has its body enclosed within two hinged shells, such as oysters, clams, mussels, and scallops.
- **Cultch:** any substrate to which a juvenile shellfish is attached or may attach.
- **Cultched seed:** juvenile shellfish attached to any type of substrate, natural or artificial.
- **Cultchless seed:** juvenile shellfish attached to very small pieces of cultch, such as a grain of sand or tiny shard of shell, so as it grows it appears that it is not attached to any substrate.
- **Implementation monitoring:** a straightforward assessment of whether the restoration that was designed and planned was carried-out and accomplished as intended.
- **Monitoring for adaptive management:** monitoring to inform subsequent restoration management so as to improve the design of future restoration efforts.
- **Natural regeneration:** where damage is relatively low (or where sufficient time frames and nearby populations exist to allow recolonization), plants and animals may be able to recover after the cessation of the degrading practices alone.
- **Performance criteria:** tangible, measurable objectives to be accomplished within a proposed timeframe that indicate progress toward meeting the project goals. The criteria should include metrics, target values, and timeframes. Performance criteria may represent conditions at a reference site, and/or they may represent target conditions considering the surrounding land use or other local conditions.
- **Performance monitoring:** monitoring to determine whether the restoration activities are having the desired habitat response, such as a change in overall shellfish recruitment, biomass, or other population-level parameters.
- **Reconstruction:** where damage is high, not only do 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, but also all or a major proportion of its desirable biota need to be reintroduced wherever possible.
- **Recruitment-limited environment:** can be due to the lack of sufficient nearby broodstock (mature, reproductively capable shellfish of the target species) to naturally populate existing reef structure.
- **Reference ecosystem:** a model adopted to identify the particular ecosystem that is the target of the restoration project. This involves describing the specific compositional, structural and functional ecosystem attributes requiring reinstatement before the desired outcome (the restored state) can be said to have been achieved.
- **Restorable bottom:** a defined area of the seafloor where restoration is feasible based on available knowledge and present-day limiting factors.
- **Restoration goal-based metrics:** a set of measurable restoration goals that can be monitored to assess the delivery of shellfish reef restoration projects benefits for nature and people.
- **Restoration goals and objectives:** restoration goals describe the desired future condition of a site. These long-term goals are supported with more short-term objectives. Restoration objectives should be explicit about the scale and time-frame for restoration and be measurable so that progress towards the goals can be assessed.
- **Seed:** commonly used fishing industry term for juvenile shellfish.
- **SER:** Society for Ecological Restoration.
- **Shell budget:** balance between shell loss and accretion.
- **Shellfish gardening:** program where citizens grow shellfish off docks in floats or cages for planting onto restoration areas.
- **Shellfish reefs:** structural features in coastal waters created through the aggregation and accumulation of bivalve molluscs, such as oysters and mussels.
- **Spat:** common term for post-larval juvenile oysters or mussels, after they have attached to hard substrate.
- **Spat-on-shell:** juvenile oyster attached to empty shells of the same or another shellfish species.
- **Substrate-limited environment:** an area of potential shellfish habitat which lacks reef structure to which shellfish larvae can attach.
- **Universal metrics and universal environmental variables:** set of standard metrics and environmental variables that should be measured on all projects, regardless of restoration objectives. The universal metrics allows for the basic performance of each reef to be assessed through time, while also allowing for comparisons with other projects. Sampling of universal environmental variables also provides valuable information that can aid in the interpretation of data collected during reef monitoring activities.

Restoration is increasingly viewed as an integral part of ocean and coastal management globally.



Ostrea angasi oyster reef, Georges Bay, Tasmania, Australia. Photo: Chris Gillies.

CONTENTS

CHAPTER 1
SHELLFISH REEF RESTORATION: AN INTRODUCTION

Robert D. Brumbaugh and Boze Hancock

The field of marine habitat restoration has accelerated dramatically in the past decade, partly in response to a growing awareness of the degradation of marine habitats around the world and partly in response to an increased ability to quantify the economic value of habitat benefits.

The restoration of habitat has become a priority for many citizens and governments as the ecological and societal benefits of these habitats have been better characterised. Accompanying this scientific characterisation comes the broad understanding that there is insufficient habitat remaining in many parts of the world to deliver services and benefits at a level necessary to sustain the socio-environmental systems. At this point, restoration is a necessary management intervention in addition to conservation of remaining habitat. Once the 'last frontier' on earth, there are now massive expectations that the ocean will be a critical driver for human well-being. Indeed, nations around the world are counting on the 'Blue Economy' to drive economic growth, and the United Nations' Sustainable Development Goals for 2030 bring the ocean's importance into sharp focus. The provision of food for a growing population, support for economic growth and prosperity, and adaptation to, and mitigation of, climate change are expectations woven throughout the United Nation's Sustainable Development Goals. Accordingly, restoration is increasingly viewed as an integral part of ocean and coastal management globally.

SOME IMPORTANT CONTEXT

'Shellfish reefs' is a term used throughout this publication and refers to structural features in coastal waters created through the aggregation and accumulation of bivalve molluscs, such as oysters and mussels. These structural features can vary in height depending on the species, as well as the depth of water and other physical attributes of the local bay, estuary or inlet in which they occur (Figure 1.1). Where the aggregations form a single layer and do not clump on top of each other they are often called 'beds' (but are considered a 'shellfish reef' for the purposes of this document). In essence, shellfish reefs are analogous to the more familiar reefs formed by tropical corals, and we are attempting to convey an important idea in this terminology: the restorative actions being taken are typically aimed at achieving both a population-level outcome (more bivalves in the system) and a structural outcome (a physical attribute of the bay, estuary or inlet itself). Although the term '*shellfish*' can have a rather broad definition in some countries and contexts, throughout this guide we are using it synonymously with '*bivalves*'.

Oysters and **mussels** are both bivalves that like to live in aggregations, resulting in structure-forming populations or shellfish reefs. Both types of bivalves have suffered similar fates of over-exploitation and habitat degradation, and both are the subject of restoration in various places around the world. Their life histories, habitat requirements and other ecological attributes may differ, and to be successful, restoration projects need to consider the biology of the species. Even within oyster species there are differences that can be important for the design and implementation of restoration projects. For example, cupped oysters in the genus *Crassostrea* are broadcast-spawners with free-swimming larvae, whereas flat oysters in the genus *Ostrea* brood their offspring within the mantle cavity (Figure 1.2). This difference in reproductive biology has implications for the siting of restoration projects, among other things. Where possible, we have tried to be explicit about the type of bivalves being discussed in each chapter, and whether there are important considerations for a given type of shellfish restoration project.

Figure 1.1: Example of intertidal oyster reef in Jiangsu Province, China. Photo: Qing Liu.

The global *Shellfish Reefs at Risk* assessment (Beck *et al*. 2009, 2011), revealed steep and widespread declines in native populations of habitat-forming bivalves. Findings of this loss were presented at the Society for Ecological Restoration International conference in 2011, raising both a local and global challenge. Subsequently in 2012 shellfish reefs were added to the list of wetland types eligible for designation for protection under the Ramsar Convention on Wetlands. Since 2012, shellfish reef restoration has become a global practice conducted at increasing scales from the Asia-Pacific region, through Europe and the UK to the Americas.

The first Practitioners Guide for shellfish reef restoration (Brumbaugh *et al*. 2006) was primarily focused on supporting community-based restoration efforts in the USA. There was a nascent and growing interest in addressing local loss of oyster reefs, frequently motivated by declines in local oyster fisheries. As potential ecological benefits produced by intact shellfish reefs such as clearer water and reef habitat for associated fish and crustaceans were revealed by scientific studies, this became a primary motivation for many restoration projects. Regardless of the motivation(s), there was a sufficient base of knowledge and experience to compile some fundamental guidance around design and monitoring of projects taking shape in the USA.

The purpose of this new guide is to provide both guidance in decision-making for establishing shellfish reef restoration projects and examples of different approaches undertaken by experienced practitioners in a variety of geographic, environmental and social settings. The new guide both updates and expands on the original *Practitioners Guide*, capitalising on the improvements in knowledge around the ecological function of bivalves in their coastal environments as well as on the depth and breadth of experience that now exists globally. Importantly, many of the restoration efforts are reaching scales that vastly eclipse the projects that were reflected in the first iteration. This publication is intended to provide, as the first one did, foundational information to serve as a useful starting point. By capitalising on novel techniques applied in different countries, management frameworks reflecting different social and political settings, and relatively new monitoring guidance, this publication should have application globally.

Ecological restoration in the marine realm has developed rapidly as a discipline that extends well beyond shellfish reef habitats. In the marine realm, many other critical coastal habitats are now the focus of habitat restoration, including coral reefs, kelp forests, mangroves, salt marsh and seagrass habitats. While terrestrial restoration is arguably more advanced and firmly established as a management intervention than marine restoration, the trajectories are converging rapidly and opportunities for additional collaboration are increasingly apparent. While terrestrial and marine restoration are each responding to some challenges that are unique, the conceptual framework that has been developed to guide the application of ecological restoration can be applied to both.

Moreover, adopting a common framework to describe ecological restoration, and the use of a common language among networks of practitioners focused on the different marine habitat types, as well as the terrestrial and freshwater realms, will strengthen the discipline of ecological restoration and make it easier to compare projects and share lessons learned. That common framework and language is best developed and articulated in the Society for Ecological Restoration's *International Principles and Standards for the Practice of Ecological Restoration* (Gann *et al*. 2019) (SER Standards). The process of undertaking restoration and terminology used to describe shellfish reef restoration in this guide adopts the SER Standards where possible.

A useful communication tool from the SER Standards is the 'Recovery Wheel', used to document progress toward the recovery of an ecosystem toward a reference condition (Figure 1.3). This has been successfully adapted for use in marine habitat restoration and offers opportunity for further use. The Recovery Wheel identifies six key ecosystem attributes, or broad functional and structural categories of ecosystems which include the more specific and measurable goals and objectives defined for each project.

While this reporting structure is nested under characteristics such as the scale, the strategic importance of a project and the level of social engagement that are critical higher-level features, considering these ecosystem attributes will help place an individual project within the broader ecological context when reporting on progress. The five levels represented as concentric rings in the recovery wheel relate to the degree of progress toward matching the conditions of a native 'reference' ecosystem, ranging from level one where ongoing deterioration has been prevented to level five where a characteristic assemblage of biota has been established to a point where structural and trophic complexity is likely to develop without further intervention (Gann *et al*. 2019).

Example of intertidal oyster reef in Jiangsu Province, China. Photo: Jun Cheng.

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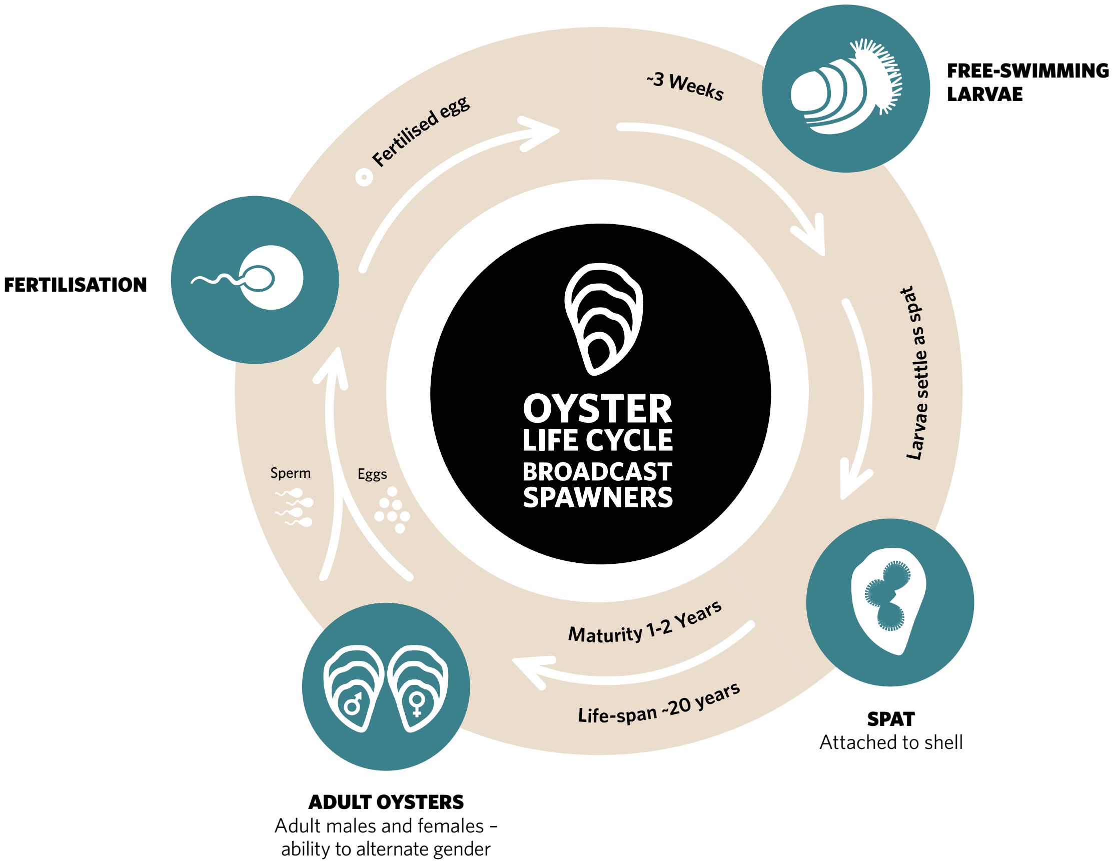

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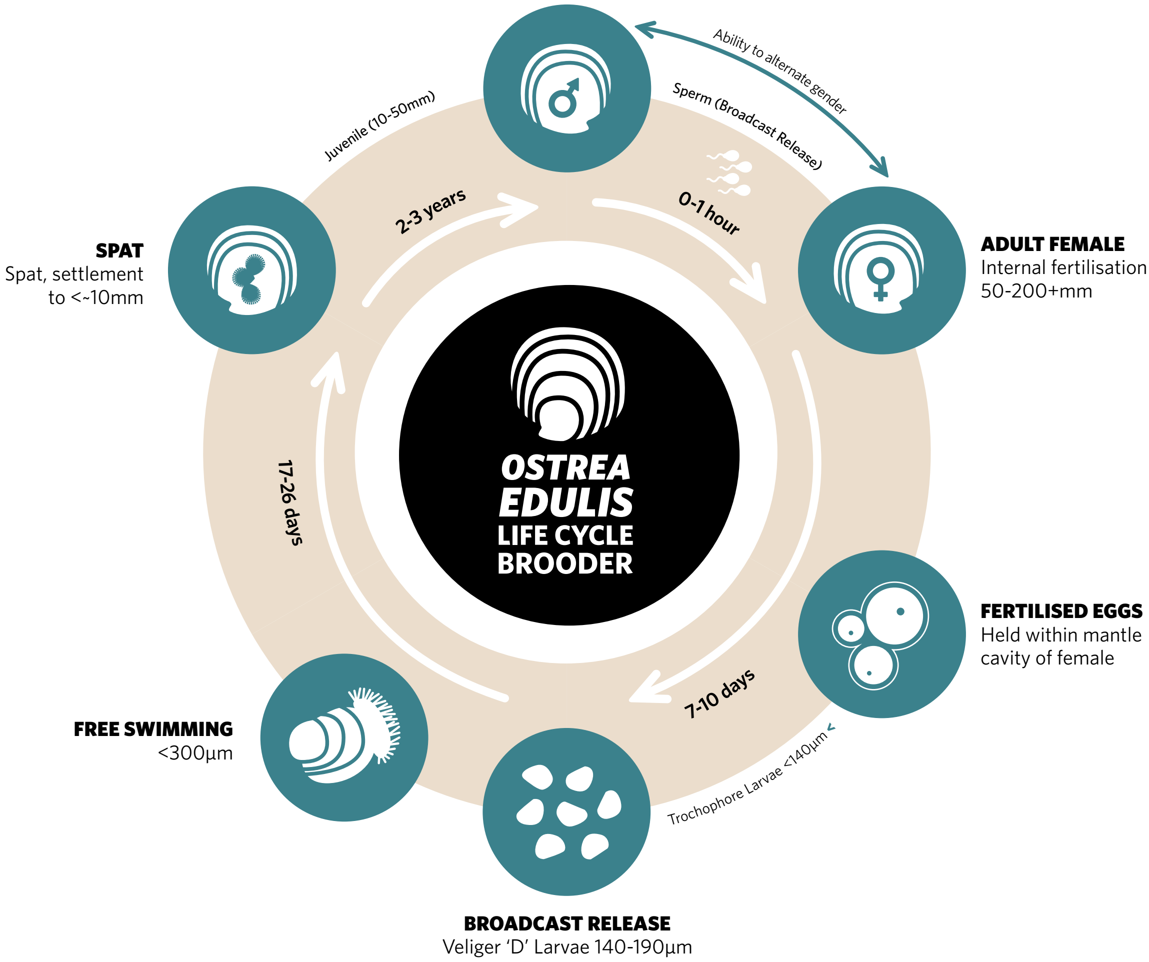


Figure 1.2: Lifecycle of ***a)*** *Crassostrea virginica* and ***b)*** *Ostrea edulis*. The life cycle of oysters differs by genus, with some having free swimming larvae and others brooding eggs and larvae within the mantle cavity of adults. These diagrams illustrate some of the differences that are important considerations for restoration project design and implementation.

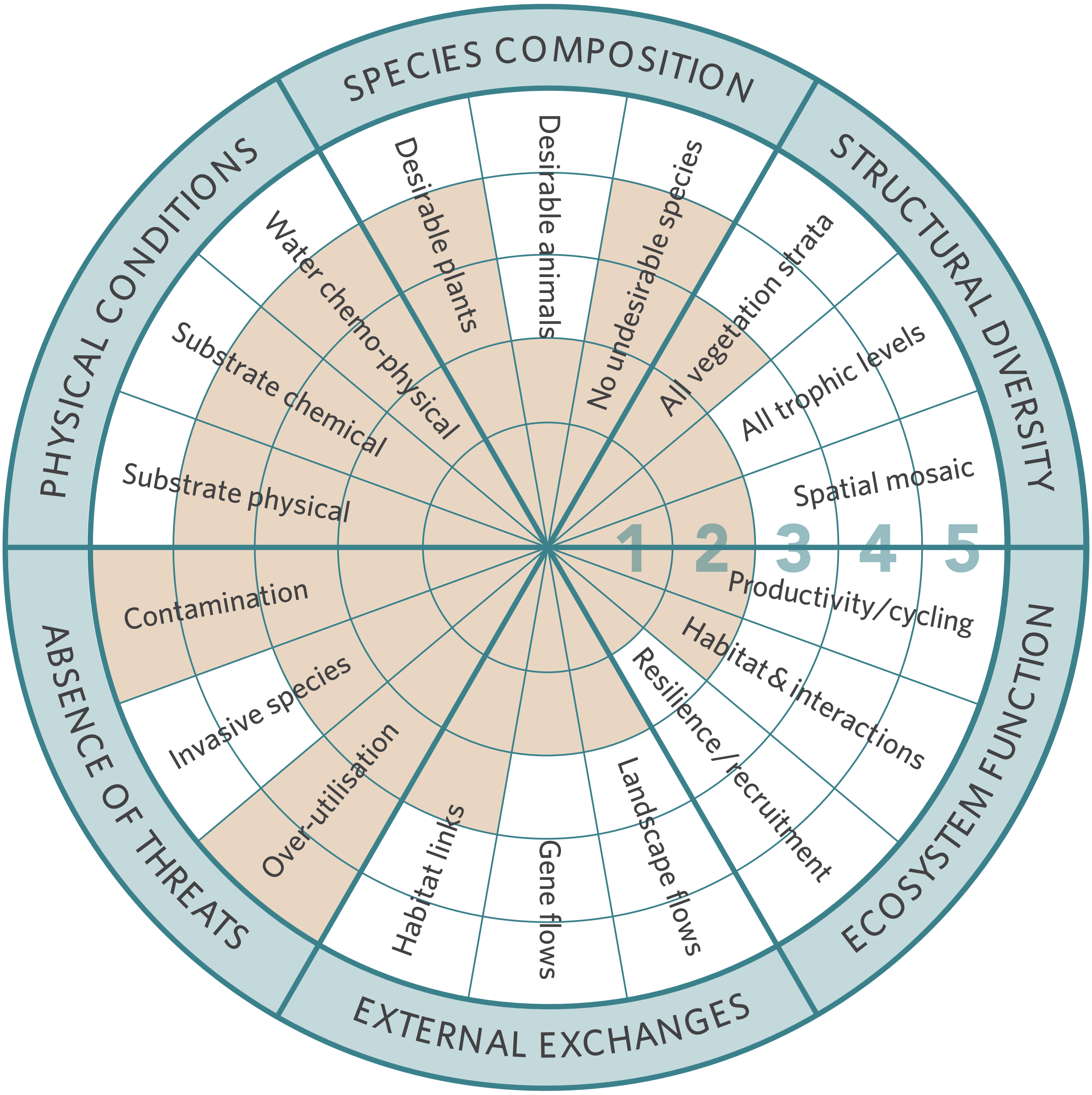


Figure 1.3: The 'Recovery Wheel' allows a project manager to illustrate the degree to which the ecosystem under treatment is recovering over time. A practitioner with a high level of familiarity with the goals, objectives and site-specific indicators set for the project and the recovery levels achieved to date can shade the segments for each sub-attribute after formal or informal evaluation. Blank templates for the diagram and its accompanying proforma are available in Gann *et al.* (2019).

CHAPTER 2
THE CASE FOR SHELLFISH REEF RESTORATION AND FINANCE

Philine zu Ermgassen and Rob D. Brumbaugh

KEY POINTS

- **Shellfish reef ecosystems are threatened but have a high biodiversity value, both locally and globally.**
- **Shellfish reef ecosystems have 'something for everyone'. The value realised from fisheries is just one part of a much larger total value of the ecosystem that provides a plethora of other societal benefits.**
- **Restoration is often financed through public grants or philanthropic support, but new funding streams such as impact investing and corporate sustainability investment is likely to play an increasing role.**

THE BENEFITS OF SHELLFISH REEF RESTORATION – SOMETHING FOR EVERYONE

Shellfish reefs and beds are among the most threatened marine habitats globally (Beck *et al.* 2011). These ecosystems also provide a wealth of benefits to people, including increasing biodiversity, enhancing water quality, being a distinct fishery (bivalves) and an important habitat for other fisheries species (e.g. finfish and crustaceans), reducing shore line erosion, as well as providing significant cultural values. Over the past decade, remarkable progress has been made in the uptake and success of shellfish restoration efforts globally.

Restoration of shellfish reef ecosystems not only benefits those ecosystems and associated species and those people who rely directly on shellfish harvesting for their livelihoods, but has far reaching, tangible, benefits for many parts of society (Figure 2.1). 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. A large number of ecosystem services are now well recognised as being generated by shellfish reefs (Table 2.1). The recovery of these valuable ecosystems is linked not only to these ecosystem services that provide benefits to people, but also to economic gains through increased angler spending, increased recreational and commercial fisheries catch, and reduced nitrate concentrations in the water (Grabowski *et al.* 2012).

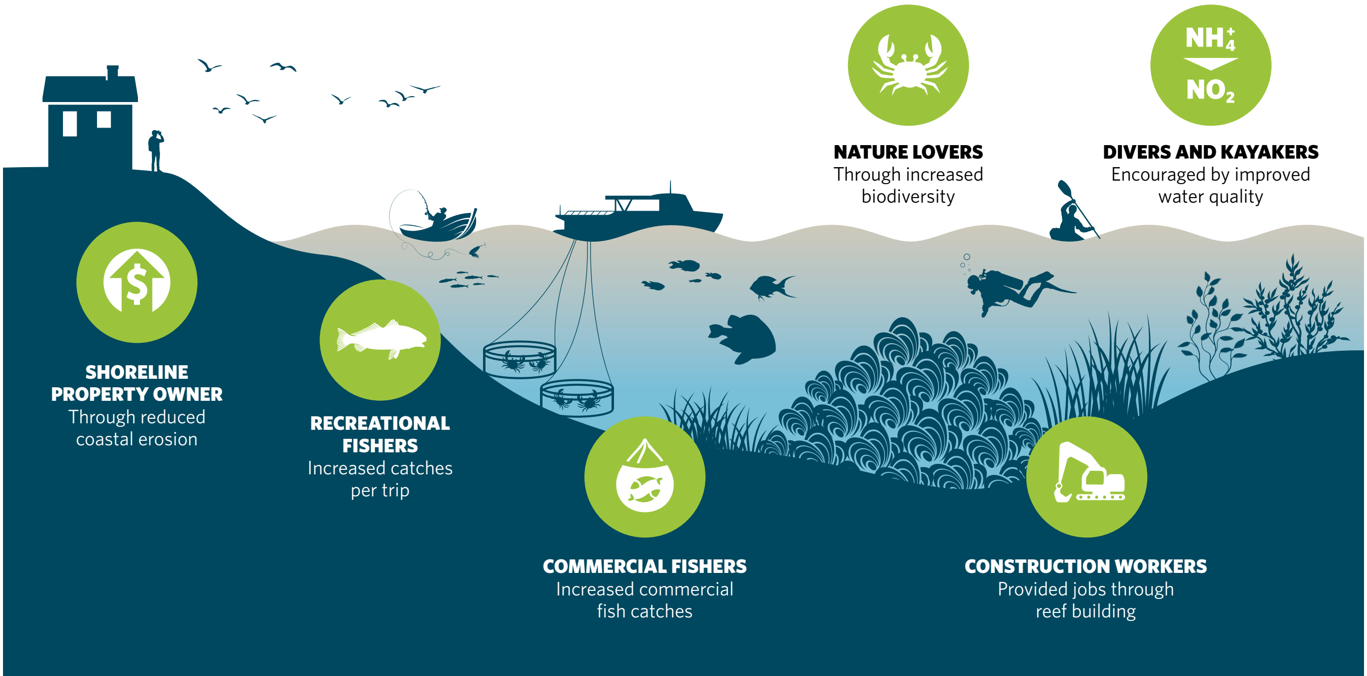


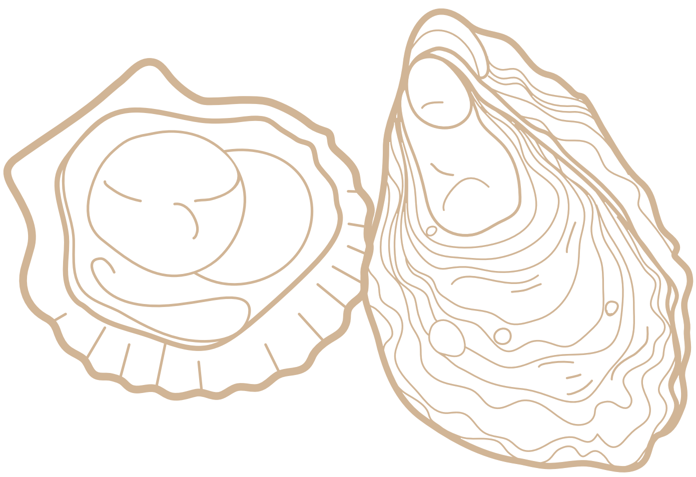
Figure 2.1: Beneficiaries of shellfish reef ecosystems

Shellfish reefs provide a diversity of benefits to people (Figure 2.1). While these ecosystem services have been quantified for only a handful of species, the mechanisms which result in these habitats providing value are a natural consequence of the bivalve species themselves (Figure 2.2). Bivalves are filter feeders, which means that they draw particles from the water column and deposit both digested and inedible material onto the sea floor. This acts to clear particles from the water column, which increases water clarity. The deposition of material onto the sea floor also acts to stimulate the bacterial community in converting nitrate pollution to inert nitrogen gas through a process termed denitrification (Figure 2.2).

Deposition of sediments can also result in the increased burial of carbon over time, which could contribute positively to carbon sequestration, as has been recently measured around the horse mussel (*Modiolus modiolus*) beds in Scotland (Kent *et al*. 2017). Reef building shellfish such as oysters require hard surfaces or at least some form of consolidated substrate to which they can attach. Oysters tend to prefer settling onto other living oysters and shell material and in this way build their own reef systems.

The fact that reef or bed building bivalves are habitat creators by nature is key in their provision of ecosystem services. These complex three-dimensional structures provide refuge to other associated species through creation of microhabitats (Figure 2.3). The number and abundance of other species found on shellfish reefs tends to far exceed those found in the soft sediment habitats that degraded reefs ultimately become.

The complex three-dimensional structure supports other species by providing a site for settlement for sessile animals, and crevices for small individuals to hide from predation. This, combined with the greater food availability resulting from the deposition of particles, make shellfish reefs an ideal home for many juvenile fish, crustaceans and other organisms (Figure 2.2). A thorough review of the mechanisms and quantification of some services provided by shellfish reefs in the USA can be found in *Setting objectives for oyster habitat restoration using ecosystem services: A manager's guide* (zu Ermgassen *et al*. 2016).



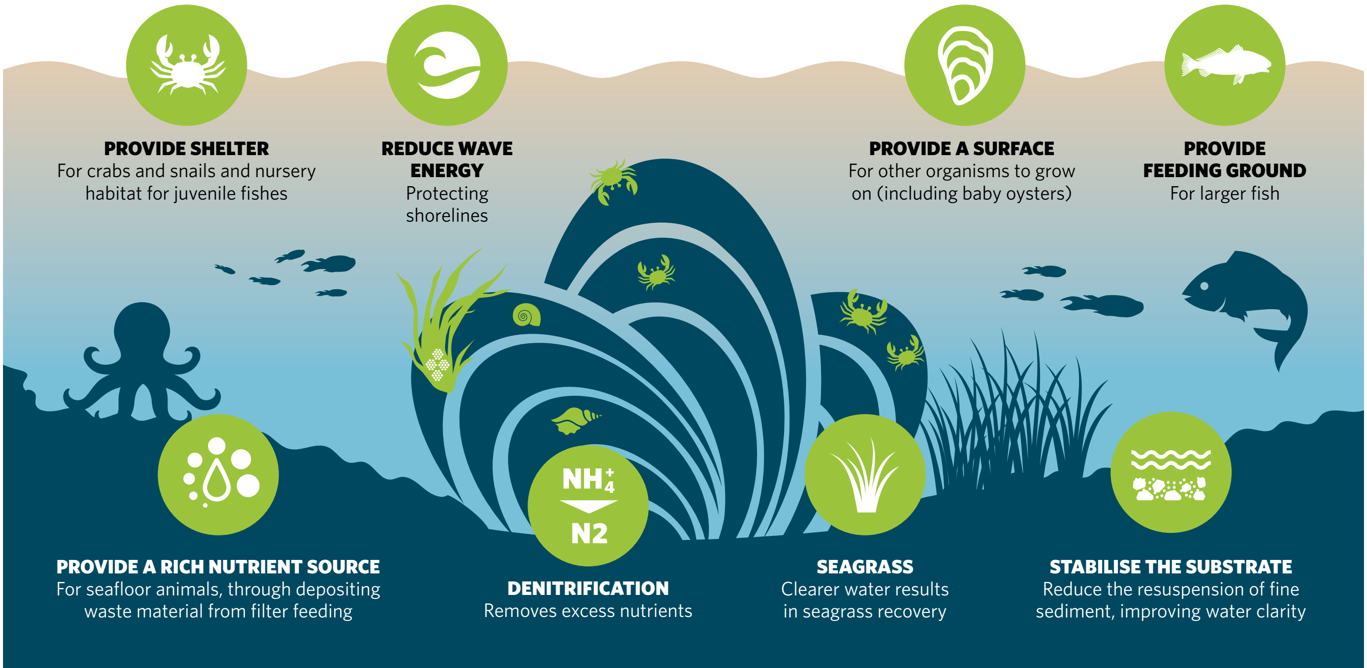


Figure 2.2: Ecosystem services provided by shellfish reef ecosystems

Figure 2.3: Epifauna microhabitats, North Sea, German Bight, Germany. Photo: Verena Merk.

Restoring shellfish reefs can 'pay for itself' – or at least provide a good return on the investment from a societal standpoint – through the many ecosystem services the habitat provides (Grabowski *et al.* 2012). This is not necessarily the case if the restored reef is subjected to harvesting of its bivalves, as this has been historically depleted the natural capital of the reef and failed to maintain a sustainable return over time. Shellfish reef restoration can nevertheless benefit the local bivalve fisheries through 'spill-over' effects. This is especially important where the bivalve species in question is at a fraction of its historical level. In such situations the bivalves may be struggling to reproduce effectively due to low numbers. Simply put, when bivalves are far apart, there is a smaller chance that the eggs and sperm will meet. Habitat restoration can address this by providing areas where the bivalves are found at higher densities and therefore may have greater breeding success. As the larvae all have a planktonic phase, they may settle outside of the restoration area and supplement surrounding areas that are open to harvest. Ecosystem restoration can also benefit non-bivalve fisheries through providing habitat for key fished species such as crabs and fish during their sensitive juvenile life phase (zu Ermgassen *et al.* 2016).

Many bivalve species have been harvested for millennia. While 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 spill-over 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 UK, oyster festivals are seeing a resurgence, by bringing the community to the shore and raising awareness of the near-forgotten native European oyster (*Ostrea edulis*) (Figure 2.4).

Figure 2.4: Traditional oyster smacks dredging by sail at the annual Mersea Oyster Dredging Match at Mersea, Essex, UK. Locals gather on boats and on the shore to watch the smacks hand dredging and then being judged for their technique and total catch (and to eat some local grown oysters). Mersea is also home to a Marine Conservation Zone for the native oyster, and active restoration is ongoing in part of the estuary closed to dredging. Photo: Philine zu Ermgassen.

Table 2.1: Ecosystem services derived from shellfish reef ecosystems, the beneficiaries of the service, and how this service is provided. NB: Not all shellfish reefs provide all services. The services provided will be both location and species specific.

ECOSYSTEM SERVICE	BENEFICIARIES	MECHANISM
Finfish and crustacean enhancement	Commercial and recreational fishers, Indigenous communities, coastal culture	By providing refuge and high prey abundance in the 3D reef structure
Reduced shoreline erosion	Shore front land owners and local community, governments	By dissipating wave energy and acting as a breakwater, and consolidating water channels
Increased water clarity	Local community and recreational visitors	By drawing sediment and algae to the seafloor through their filter feeding
Reduced water pollution	Local community and communities downstream, recreational visitors, commercial fishers, governments	By enhancing nitrogen removal in coastal waters (i.e., denitrification by bacteria in surrounding sediments)
Carbon burial	Governments and global population	By drawing sediment to the seafloor and stabilising it at a higher rate than surrounding areas
Oyster/mussel fishery enhancement	Commercial and recreational fishers, Indigenous communities	Through over spill of larvae from the restored to surrounding areas
Cultural value	Indigenous communities, local community, recreational visitors	Supporting a centuries old cultural way of life and associated sense of community
Biodiversity enhancement and ecosystem stability	Local people to global citizens	By providing a complex 3D habitat, clarifying water and drawing particles to the seafloor a multitude of species are enhanced locally and globally. Enhanced biodiversity results in enhanced ecosystem stability. Additionally, a global bivalve restoration movement ensures the diversity of habitat-forming bivalves themselves are conserved at both the local and global scale.

FINANCING SHELLFISH REEF RESTORATION AND CONSERVATION

Successful implementation of restoration projects is as much about the financing as the science and practice of restoring the shellfish reefs themselves. 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.

Quite often, multiple sources of funding need to be accessed to assemble the total resources needed to complete all facets of a restoration project, and it is useful to identify sources of funding (or in-kind resources) that can be leveraged for additional funds to support the various elements of a project.

For example, some funding entities support science, some support community engagement and outreach, and some may support only the deployment of material used in the restoration project itself.

Understanding where funder priorities lie is a good first step toward building a sufficient level of funding for the entire project.

COMMUNITY-LED PILOT PROJECTS

Restoration often starts with small-scale 'proof of concept' projects designed to test methods and approaches for enhancing populations of target bivalve species, usually in response to a documented decline in harvest, habitat extent, or both. While ecosystem services may be a long-term goal of restoration, restoration at this scale usually focusses solely on the bivalves themselves; how well they survive and grow, and how conditions for them can be improved to maximise success in these metrics. In most places around the world, these initial forays are supported through philanthropic funds or targeted public grants. Improving the condition of the coastal system and addressing the historical loss of bivalves from the system are often the motivation for funders at this scale. Typical funders therefore include those who provide community or environmental grants such as governments, private trusts or corporate philanthropy. For example, pilot work in the Blackwater, Roach, Crouch and Colne Marine Conservation Zone in Essex, UK, is being funded through a combination of private donations, and corporate donations (Selfridges) as well as direct investment in time and resources by stakeholders such as oystermen, nature conservation organisations and universities (Figure 2.5). The pilot work undertaken supported the development of a management plan and provisional costings, which were pivotal in underpinning subsequent successful bids for larger grants from EU and UK government sources.

Supporting the monitoring of community-led projects is often challenging, given the short-term nature of the grants which typically support pilot projects and the need to design and carrying out scientific monitoring that is both informative and rigorous. Monitoring whenever possible is, however, critical for building evidence of restoration outcomes. This evidence is crucial to maintaining stakeholder interest and support for the projects (see Chapter 7) and for supporting adaptive management of the restoration effort. In some instances, the funds necessary to support monitoring can be integrated into grants but it is worth noting the value of 'citizen-scientists', who possess both the interest and technical capabilities needed to undertake such monitoring (Figure 2.6). The oyster restoration monitoring guide produced by The Nature Conservancy and NOAA can be referred to for advice on monitoring (Baggett *et al*. 2014).

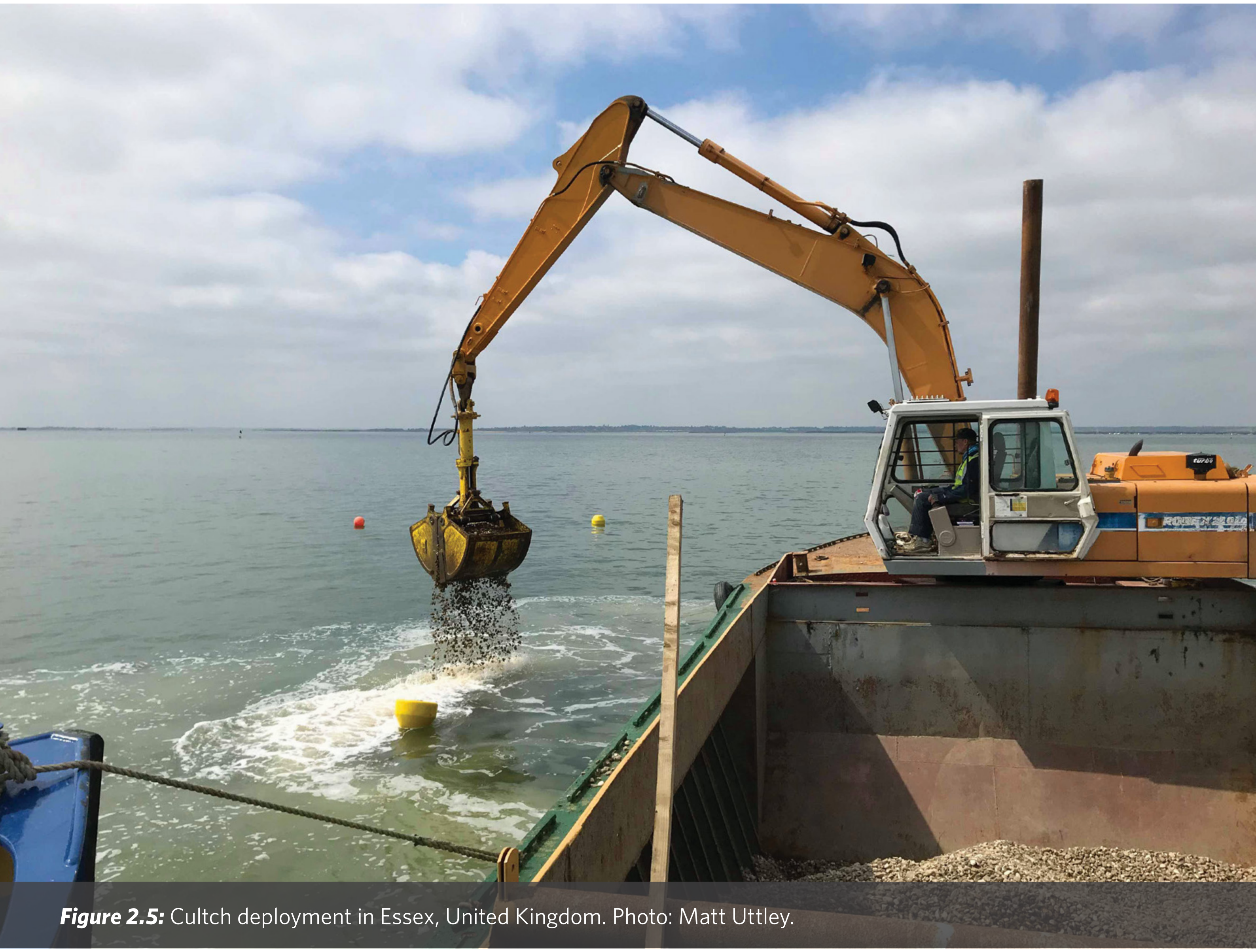


Figure 2.5: Cultch deployment in Essex, United Kingdom. Photo: Matt Uttley.

Figure 2.6: Volunteers monitoring shellfish reefs in Charlotte Harbour, Florida, USA. Photo: Anne Birch.

LARGER-SCALE PROJECTS

Once the feasibility of shellfish reef restoration has been demonstrated, often through community-led initiatives, the next challenge is to scale up efforts. Public funds deployed for small- and mid-scale projects often require match funding, and private funds are invaluable for leveraging such funds. Sources of this 'match' funding can be industry and corporate sector, philanthropic including private trusts and foundations. Some funders allow 'in-kind' support of materials, staff and volunteer time, and provision of equipment such as barges, cranes and boats. Relevant government funds at this stage may include large programmatic grant schemes, such as regional development grants. The added challenges of navigating potentially complex reporting requirements, and accounting for multiple sources of funding throughout a project's life can pose challenges for smaller organisations, and collaborations that bring in organisations with such capabilities and experience can be helpful. Where the aims of restoration fall within the realm of achieving compliance to international biodiversity commitments (e.g. RESTORE in Germany, https://www.awi.de/en/science/biosciences/shelf-sea-system-ecology/main-research-focus/european-oyster.html), funding for scaling up may be provided entirely by government.

In the Chesapeake Bay, USA, early (pilot) restoration work was designed to evaluate the importance of reef structure and whether localised stock enhancement was a potential strategy for increasing recruitment. Projects were supported through modest (US$50,00-$100,000) grants from habitat-focused funders such as the Chesapeake Bay Foundation, Fish America Foundation, National Fish and Wildlife Foundation, and the U.S. Environmental Protection Agency. As knowledge increased and more experience was gained, public support increased as well. This led to much larger infusions of public funds – primarily federal government – to support restoration that ultimately saw the recovery of an historic public oyster fishery.

The largest scale restoration efforts to date have resulted primarily from political commitments, often with an industry development or jobs incentive component. Anticipated returns on investment from the ecosystem services restored are often similarly a strong incentive for funders. For example, in Matagorda Bay, Texas, an estuary adjacent to the Gulf of Mexico in the USA, large-scale restoration has been undertaken using federal funds channelled through the *Estuary Restoration Act of 2000.* This federal legislation aimed to restore 1 million acres of degraded habitat in estuaries, with oyster reefs among the targeted habitat types. Texas possesses a strong recreational fishing economy and the anticipated production of recreationally important fish species provided much of the impetus for restoration in Matagorda Bay.

An economic study conducted by The Nature Conservancy and Texas Sea Grant revealed an impressive return on investment just from the enhancement of local fishing opportunities (Carlton *et al.* 2016).

Grants at this scale typically require a significant (and potentially burdensome) evidence base. Even before grants at this scale can be accessed it may be necessary to fund economic analysis, assess possible return on investment, or cost other ecosystem benefits such as tourism, in order to demonstrate that the project will achieve co-benefits beyond the known environmental benefits.

Reporting back on the social, economic and environmental benefits are typically deliverables of a grant. This therefore requires an additional level of investment and expertise to ensure that the correct metrics are collected, analysed and reported back to the funder in a timely manner. Where biodiversity conservation is a primary goal, e.g. resulting from international commitments, demonstrating biodiversity targets are met is similarly important. A case study of successful leveraging of funds for large scale restoration is described in Box 2.2.

Ostrea angasi oysters growing on Pinna, Windara Reef, South Australia. Photo: The Nature Conservancy.

BOX 2.2: WINDARA REEF: CASE STUDY ON FINANCIAL LEVERAGING FOR REEF RESTORATION

CHRIS GILLIES

In 2014, the South Australian Government committed AU$600,000 towards artificial reefs (typically concrete blocks) as an 'offset' to the loss of recreational fishing grounds with the introduction of a number of new marine protected areas across that State. Public consultation was conducted as part of the project and The Nature Conservancy, amongst others, was invited to present at public forums to discuss the fish benefits of restoring shellfish reefs as an alternative to artificial reefs. As a result of this consultation, the public nominated shellfish reef restoration over artificial reefs and in early 2015, the South Australian Government allocated the full AU$600,000 towards oyster reef restoration. During the same period, The Nature Conservancy and the South Australian Government jointly commissioned an economic study and business case on the social and economic benefits of restoring oyster reefs en masse across the State. The economic study, business case and South Australian Government's financial commitment, were key components in an application to the Australian (Federal) Government's regional development program, National Stronger Regions Fund (NSRF). The NSRF provided a further AU$1M in funding which was matched with: the initial AU$600,000 from the South Australian Government, AU$1.39M from The Nature Conservancy, AU$100,000 from Yorke Peninsula Council (local government) and a further South Australian Government contribution of AU$610,000 from two separate agencies (environment and fisheries). A private foundation, The Ian Potter Foundation, provided further resource to support the University of Adelaide in undertaking supporting research, with the total financial resource pool totalling approximately AUD$4.2M. Key success factors included: 1) Using case studies of the environmental and social benefits of shellfish reef restoration (particularly from the USA) to help educate the community and government stakeholders on the benefits of natural habitat restoration compared to artificial reefs, 2) Identifying a clear social beneficiary stakeholder (i.e. recreational fishers), and economic beneficiary stakeholder (i.e. local service businesses that financially benefit from the predicted increase in recreational fishers in the region), and 3) Successfully articulating marine ecosystems as natural infrastructure which is synonymous to built infrastructure in terms of providing a beneficial service to communities and which can be quantified like other types of infrastructure.

Linking to livelihoods

As many of the bivalves targeted for restoration are also harvested for consumption, there is potential to fund restoration work alongside developing sustainable livelihoods. One such example is the EU-funded 'Our Seas Our Life' project managed by Zoological Society of London (https://www.zsl.org/conservation/regions/africa/our-sea-our-life).

The project is working to establish community-based oyster farms in Cabo Delgado Province, Mozambique. The aim is to develop an economically viable and environmentally friendly alternative to unsustainable harvesting of marine resources and at the same time provide women in the community with livelihood opportunities (Figure 2.7).

Funding in support of developing livelihoods are also a potential funding source in more economically developed nations. For example, the European Maritime Fisheries Fund is funding a number of oyster restoration projects in the UK, with the aim of supporting associated fisheries, biodiversity and of developing associated aquaculture.

Figure 2.7: Community-based oyster farm in Cabo Delgado Province, Mozambique. Photo: Zoological Society of London.

Biodiversity offsetting

The restoration of habitats to mitigate losses from habitat conversion by industries is commonplace in terrestrial systems. Biodiversity offsetting is considered part of the mitigation hierarchy in combating negative impacts of development on biodiversity and is incorporated in government policies in a number of countries. The implementation of biodiversity offsetting in marine environments is currently rare, but there is an increasing interest, both from policy makers and from businesses seeking to achieve a high level of corporate responsibility. The implementation of biodiversity offsetting actions for shellfish reef restoration requires close partnership with, or leadership by, the industries well in advance of the point at which tenders are developed. This early involvement is important to ensure the costs of biodiversity offsetting are included in project planning, and the benefits correctly recognised. Governments also need to recognise the value this provides when assessing tenders. Education, policy and regulation will therefore play a significant role in progressing the potential for biodiversity offsetting in marine environments to fund shellfish reef restoration.

Payment for ecosystem services

Payments for Ecosystem Services (PES) are another potential pathway for securing long term funding streams for management and maintenance of shellfish reefs. PES approaches have been used to conserve mangroves, with local fishers providing financial support for conservation of nearby mangroves; similar arrangements for shellfish reefs have yet to emerge but should be possible as additional data on non-bivalve fishery benefits and nutrient removal data are generated. For example, should the science provide a robust case for these values, there is the potential for the nutrient removal by bivalve restoration to be included in nutrient reduction targets (see also Box 2.3). Recommendations for doing so are already being drafted for the Chesapeake Bay (Malmquist 2018).

Blue bonds and impact investing

As the science improves around shellfish reef restoration, there is growing interest in developing financing models that are aimed at long term funding sustainability. Increasingly, governments and multi-lateral funders are exploring the potential of 'blue bonds' to raise funding for environmental initiatives that have monetised ecosystem benefits as a core output.

A further emerging area of financing for conservation is through 'impact investing' which seeks to match private capital investors with initiatives that return socially- and/or environmentally-significant benefits along with the eventual return of the initial investment (with or without a significant additional level of interest on the principal). This type of funding is most likely to become available when restoration can be incorporated into initiatives that produce discrete marketable benefits such as nitrogen credits, increased fishery yields or mitigation of storm impacts.

BOX 2.3: GLENMORANGIE AND THE DORNOCH ENVIRONMENTAL ENHANCEMENT PROJECT: CASE STUDY ON INDUSTRY PARTNERSHIPS

The Dornoch Environmental Enhancement Project (DEEP) aims to restore native European oysters to the protected area of the Dornoch Firth in the Scottish Highlands. The project is a partnership between The Glenmorangie Company, Heriot-Watt University and the Marine Conservation Society (Figures 2.8 and 2.9).

The Glenmorangie Company Distillery has been in the Scottish Highlands on the banks of the Dornoch Firth since 1843, and therefore has a strong sense of place, as well as a long term view of the role of the distillery in the local community and environment. Furthermore, the consumer-base for luxury whisky is increasingly ethically-demanding, therefore good stewardship can even have a return on investment in terms of brand-value. The restoration of long-lost oyster reefs will enhance biodiversity and act in tandem with Glenmorangie's new (2017) anaerobic digestion plant to purify the by-products from the distillation process – an environmental first for a distillery. The anaerobic digestion plant is expected to remove up to 95% of the waste water with the remaining 5% of the organic waste accounted for by the oysters.

Overall the aim is for DEEP to contribute to the distillery going beyond discharge compliance to achieve an unusually high environmental standard.

Figure 2.8: Glenmorangie's Hamish Torrie and Dr Bill Sanderson of Heriot-Watt University inspect some of the Native European Oysters before they take up residence in their newly created home in the Dornoch Firth.
Photo: Rich Shucksmith.

Figure 2.9: Scientists lay Native European Oysters on the recreated reef in the Dornoch Firth as part of Glenmorangie's DEEP project. Photo: Rich Shucksmith.

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CHAPTER 3
GETTING STARTED: PLANNING, GOAL SETTING, AND FEASIBILITY FOR SHELLFISH REEF RESTORATION

Chris L. Gillies

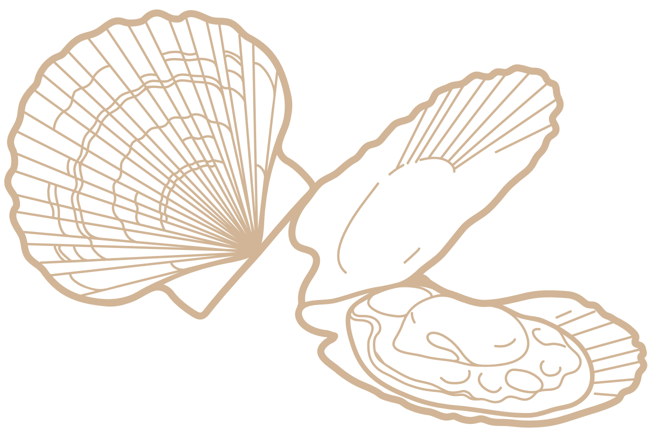
KEY POINTS

- **Consideration of the primary and secondary motivating factors behind restoration is important to clarify stakeholder expectations, set goals and objectives and to help guide the detailed design and implementation of projects.**
- **Developing a plan on paper and undertaking a feasibility study is the easiest and most cost-effective way to consider different options and their outcomes, identify the risks and challenges of a particular course of action, and understand the situation before committing significant time and resources in the field.**
- **Reference ecosystems or models, as ecological targets for restoration, are required to guide project design, set ecological targets and support monitoring.**

INTRODUCTION

The first stage of any restoration project should be to consider and develop a plan on paper that clearly describes the project's goals, rationale, key strategies or activities and expected outcomes. Developing a plan on paper is the easiest and most cost-effective way to consider different options and their outcomes, identify the risks and challenges of a particular course of action, and understand the situation before committing significant time and resources in the field. Planning is not, however, a guarantee that all the project's potential problems will be identified or solved but it will help project proponents to 'think through' decisions that are logical, structured and based on evidence or collective knowledge.

There are many guides and resources freely available that can help to plan a restoration project. Some of these have been specifically developed to support conservation and restoration projects, for example this guide, the Open Standards for the Practice of Conservation (CMP 2013), Conservation by Design (TNC 2016), and the *International Principles and Standards for the Practice of Ecological Restoration* (Gann *et al.* 2019).



A typical project plan includes:

- Description of the target ecosystem or reference model, which identifies the primary structural components, biological community, important species interactions and functional processes (i.e. ecosystem services) as described in the 'feasibility study' section of this chapter
- The range of project goals describing what the project ultimately seeks to achieve
- Project objectives (these should be Specific, Measurable, Attainable, Relevant and Time-bound, known as S.M.A.R.T. objectives) which describe discrete bodies of work within the project (e.g. community engagement, reef restoration, project governance, monitoring)
- Summary of strategies (also called activities or actions) and their timelines. Each strategy describes the main tasks associated with delivering each project objective
- The duration, outputs (deliverables resulting from each objective) and ultimate outcome(s) of the project
- A list of who will undertake and support the work and their roles and responsibilities
- Summary of the initial feasibility analysis undertaken and any gaps or limitations in knowledge/information
- Risk assessment and permit requirements
- Budget
- Monitoring evaluation and reporting framework (how you will measure the success of your project against the stated objectives)
- Communication framework (how you will talk about your project).

Because restoration occurs over long timeframes, it is important that any planning process uses adaptive management principles. In its simplest form, adaptive management incorporates *learning by doing* and having a process(es) in place (like monitoring, pilot studies, research) which you can learn from and incorporate past learning into future decision-making. Adaptive management is particularly important for shellfish restoration because each project is unique, i.e. no two locations, ecological communities or start points in time are the same.

SETTING RESTORATION GOALS

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 towards 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. Whilst 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 designed, constructed and monitored, selection of the ecosystem target or model (see below) and ultimately determine whether project stakeholders consider the project a success (for an example of how different objectives influence project design: see Table 3.1). For these reasons it is important to spend time thinking through a project's real motivations and how these may influence the feasibility and method of restoration undertaken.

If project proponents desire multiple outcomes from a single project, it is important to clearly articulate a primary goal (or motivation) that all stakeholders can agree on. This helps to ensure that there is one primary goal that can guide decision-making throughout the project. Additional desired outcomes such as multiple ecosystem services (e.g. fish for recreational fishing, coastal protection, water filtration) need to be clearly identified as secondary outcomes or motivations because in some circumstances, these may need to be 'traded off' against each other when not mutually supportive. For instance, it may be impossible to optimally design a restoration project that achieves both fishing opportunities *and* coastal protection benefits equally, so one may need to be prioritised during the design phase over the other.

Further guidance on appropriate goal setting for shellfish ecosystem restoration and on how to engage with stakeholders during goal setting can be found in Chapters 3 and 4 (and zu Ermgassen *et al.* 2016). After deciding on the goal(s) of the project and developing a number of specific objectives that will deliver the project goal(s), the next stage should be to assess whether the project is likely to be feasible.

Table 3.1: Example of how similar goals with slightly different motivations or desired outcomes can influence decision-making throughout a restoration project.

	ALTERNATIVE DESIGN CONSIDERATIONS	
	Primary purpose is to restore the ecosystem for biodiversity equally	**Primary purpose is to restore the ecosystem for a particular ecosystem services (e.g. fish productivity)**
Location	Consider proximity to other reef ecosystems to maximise species pool available for colonisation.	Consider proximity of reefs to populations of target fish species and their connectivity with other habitats utlised.
Restoration design	Optimised design to maximise the variety of different niche spaces available (e.g. small and large interstitial spaces, different patch sizes, high rugosity).	Optimise design for fish recruitment, protection and growth (e.g. reef height extends to reduce current velocities, substrate material selected to support fish-friendly interstitial spaces).
Monitoring	Incorporate general biodiversity monitoring with primary focus on species richness (or target indicators). No species is ranked more valuable than another.	Focus on measuring fish recruitment, biomass and abundance as primary biodiversity targets.
Financing	Target general environmental funding, community-based funding.	Target recreational and commercial fishers, fishing licence fees, fishing clubs, fishery management agencies.
Stakeholder support	Involve groups which do not require a tangible return on investment other than to see a restored ecosystem.	Involve recreational and commercial fishers, fishing and aquaculture research groups, and fishery management agencies.
Measure of success	Seek increase in biodiversity towards reference ecosystem or model.	Seek increase in recreationally or commercially important fish biomass towards reference ecosystem or model.

WHY DO A FEASIBILITY STUDY?

The purpose of a feasibility study is to develop an understanding of what is known (and not known) about the shellfish reef ecosystem in the intended restoration location and to assess whether the project goal is achievable within the project's environmental, social and economic context. Feasibility studies need not be difficult, but should include a few simple steps:

1. Determine whether ecosystem restoration is possible within the desired location(s)
2. Understand who should be involved in the project and in what context and stage
3. Understand the local reference ecosystem or the ecological target that will be used to guide the restoration process (known as the ecosystem target).

A focus on addressing these issues will help guide the development of a project plan, including: identifying the main physical and biological attributes and positive species interactions which support and sustain the ecosystem (usually obtained from a similar reference ecosystem often called an ecological target), setting S.M.A.R.T objectives, determining the amount of restorable area and likely restoration sites within the focus geography, identifying the specific method of restoration or construction, identifying risks to restoration efforts (and ways to mitigate those risks) and identifying key metrics for monitoring and evaluation. A feasibility assessment can also help formulate a project proposal and demonstrate to stakeholders, regulatory agencies and potential project funders that due diligence has been conducted on the project.

A feasibility study does not always need to be a lengthy document but it should be sufficiently detailed to help answer the basic questions of what, where, when and how a project can be managed.

METHODS AND SOURCES OF INFORMATION TO DEVELOP A FEASIBILITY STUDY

There are many sources of information that can be used to identify the ecological reference or target ecosystem to be restored and to undertake a feasibility study. These include:

- *Scientific journal articles* (often accessed for free via Google Scholar or ResearchGate, or contact the author/s of those article directly)
- *Historical newspaper articles, photos, maps and books* (form local libraries, online library databases, local historical societies)
- *Community and traditional ecological knowledge* (obtained from interviews and surveys of local residents, traditional owners, local environmental groups, fishers, divers, teachers)
- *Shellfish aquaculture and shellfish fishery industries, shellfish farmers/fishers*
- *Malacological societies, geographic societies, science societies, universities*
- *Government reports and surveys* (historical and current)
- *Direct observation and experimentation*

Teaming up with a local university, historical society or friendly librarian can help with accessing information that may be restricted or difficult to find and understanding rules on conducting scientific research and observation. Using key words consistently such as 'oysters' 'oyster fishing', 'mussel ecosystem' and restricting searches to discrete geographic areas are important tips for helping to systematically search through information. Keeping a record of search terms and methods will make it easier to come back to research in the future and for others to assist in the process.

STEP 1: DETERMINE WHETHER ECOSYSTEM RESTORATION IS POSSIBLE WITHIN THE DESIRED LOCATION(S)

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 (GIS) spatial analysis (Box 3.1). All methods are based on a series of basic questions designed to identify areas were restoration is feasible based on the biological and physical requirements of the ecosystem. A detailed list of questions that can help form the basis of a feasibility study are presented in Appendix 3.1. These questions can be generally grouped into three themes:

1. **Have the threats (that caused the initial degradation of the ecosystem) been removed, or, sufficiently managed to allow the ecosystem to be restored?** Answers to this question may consider an assessment of: past and present fishing pressure, status of pollution and water quality, disease prevalence and disease transfer risk, sedimentation and predation.
2. **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?** If not, can they be easily modified or managed through *active restoration* (e.g. addition of substrate to improve bottom condition, selection of disease tolerant shellfish, restricted site selection)?
3. **Are the logistical and regulatory requirements available and within budgetary scope to support the restoration activities?** (this includes access to maritime loading facilities, oyster hatcheries, shell cultch, substrate, necessary permits, need for development applications, etc.).

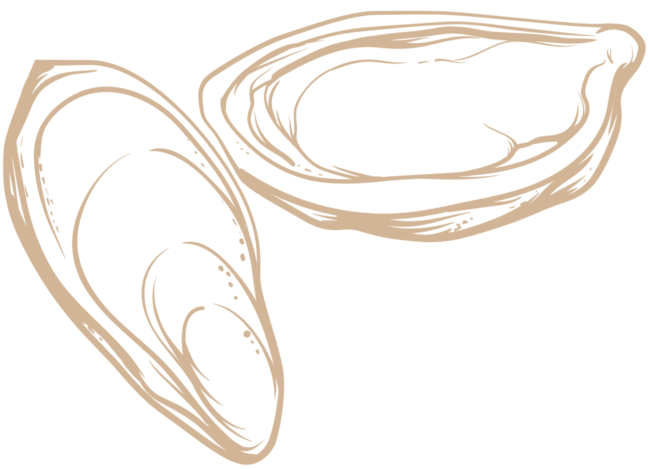
Restored mussel reef, Port Phillip Bay, Australia. Photo: Jarrod Boord.

Evidence for or against each criterion should be provided by way of direct observation, scientific studies, anecdotal and traditional knowledge or government reports. Other factors to consider also include:

- Proximity to high use or culturally sensitive areas (e.g. aquaculture zones, marine protected areas, boating channels, recreational areas, traditional fishing areas, cultural sites). Where such uses exist, the suitability of the site and the restoration project should be considered in that context and relevant stakeholders should be involved
- Areas where the ecosystem historically occurred, where remnant reefs or beds remain or where there is a high density of oyster or mussel biomass that may support natural recruitment
- Proximity to other structured ecosystems (to assist with ecosystem connectivity and available species pools)
- Priority areas for conservation identified by external agencies
- Potential perverse outcomes for other ecosystems or threatened species of establishing shellfish reefs (see Box 3.2).

A simple map displaying these areas or a more sophisticated GIS analysis or model (Box 3.1) will help to identify: 1) The total potential restorable bottom in which is it theoretically feasible to undertake ecosystem restoration (this can be used to set long-term planning and goal setting), 2) Preferred sites for initial restoration trials or more in depth, field-based investigations, and 3) Risks that should be addressed during initial trials/pilot projects and full-scale restoration.

Finally, changes to local conditions that are attributable to climate change or anticipated future uses should also be considered. Climate change, for example, can introduce new threats such as invasive species, sea level rise, ocean acidification, changes in local salinity and temperature.



STEP 2: UNDERSTAND WHO SHOULD BE INVOLVED IN THE PROJECT AND IN WHAT CONTEXT AND STAGE

Stakeholder analysis and mapping is the simplest method that can be used to identify who should be involved in the project and how they should be engaged. 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 prioritise groups to consult during project planning and implementation.

Example categories/groups include:

- Estuary or coastal zone users (recreational, industry, cultural)
- Land and sea managers and regulators, title holders, neighbours
- Potential project funders
- Project supports and volunteers
- Subject matter experts (e.g. marine ecologists, oyster and mussel biologists, resource managers, oyster fishers)
- Project detractors.

A decision can then be made on whether each stakeholder should be informed, involved or consulted and at which stage this should occur (i.e. feasibility, planning, implementation, monitoring). Understanding who has the most to gain (or lose) from the restoration project will help to inform who could be a project partner, project supporter, project funder and where collaboration and engagement efforts should be concentrated.

STEP 3: UNDERSTANDING THE LOCAL REFERENCE ECOSYSTEM OR ECOLOGICAL TARGET USED TO GUIDE RESTORATION

The Society for Ecological Restoration recommends the use of a reference ecosystem (which can be composite reference 'sites' or a modelled ecosystem) as a fundamental requirement of restoration projects. A reference ecosystem or model helps guide the project design, set 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 (see Gillies *et al.* 2016 for a shellfish example of a modelled ecosystem) and can be considered analogous to a builder obtaining the detailed engineering plans required to replicate an existing house. The reference site or model provides information on key species, physical, structural and biological attributes, functional processes and characteristic fauna.

This information is then used to:

1. Compare between the restoration site and reference ecosystem, to identify the main structural and biological components and species interactions that need to be reinstated during restoration (e.g. addition of substrate, oyster spat, grazing species)
2. Identify whether adjacent existing ecosystems can be linked to restoration sites to expediate flow of species and genes
3. Set specific biological targets for the restoration site such as oyster (or other bivalve species) density, biodiversity, functional groups and ecosystem services or to help identify indicator, keystone species or positive species interactions
4. Assess progress of restoration in 'real time' (when using a reference ecosystem as opposed to a model). The reference ecosystem can be used as a present day baseline that incorporates current macro influences such as climate change, when using a Before-After-Control-Impact-Reference monitoring design (see Baggett *et al.* 2014).

Conceptual diagrams or recovery wheels can be a useful means of summarising what is known about some of the key processes governing the ecosystem (Figure 1.3) and to help develop an understanding of the key processes and biological and physical attributes that support the existence of the ecosystem.

WHAT IF THE ANSWERS TO SOME OF THESE QUESTIONS CANNOT BE FOUND?

It is rare that any assessment, no matter how detailed, will identify all the answers about project feasibility with absolute certainty. The conclusions of the feasibility study, based on the evidence available at the time should therefore be used as a means to justify (or not) proceeding to the next stage of the project (often small scale trials – see Chapters 5 and 6). Some questions identified from the feasibility assessment may still need to be answered before full-scale restoration, and these should be the focus of pilot studies and/or further research. Other data gaps can be managed through the use of adaptive management principles or incorporated into the project design.

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BOX 3.1: SITING SHELLFISH ECOSYSTEM RESTORATION: THE VALUE OF GEOSPATIAL DECISION SUPPORT TOOLS

SETH THEUERKAUF

Where shellfish reef restoration is conducted often determines how successful an effort is. For example, if located in an area with poor larval recruitment or that experiences periodic low dissolved oxygen events, a restored reef may never establish or may experience episodic mortality. Maps of historic distribution of oyster reefs have often been used as a tool to guide restoration efforts, however the usefulness of these maps may be limited where they are unavailable or within urbanised estuaries where environmental conditions have changed. Within the past decade, geospatial decision support tools for oyster restoration, often termed habitat suitability indices (hereafter 'HSI'), have emerged as powerful resources to synthesise a broad set of spatial data – including environmental, biological, and logistical criteria – to guide oyster restoration efforts.

Multiple examples of successfully designed and implemented HSIs for oyster restoration exist in the peer-reviewed literature, and their frameworks can provide the basis for development of new HSIs. Theuerkauf and Lipcius (2016) provide a modern review of these tools and the spatial criteria considered within each HSI. Given the well-defined and replicable nature of technical approaches to HSI development for oyster restoration, development of new HSIs generally only requires determination of key spatial criteria to incorporate from stakeholder input and subsequent assembly of suitable spatial datasets (e.g. derived from government natural resource departments or remotely-sensed sources). Importantly, despite the relative simplicity of their development, multiple assessment methods are necessary to ensure the reliability of HSIs to inform oyster restoration (e.g. sensitivity analysis, validation of output using independent oyster density data). Furthermore, web-based mapping tools, such as The Nature Conservancy's Restoration Explorer for the USA, provide examples of how easily-accessible platforms can be developed for practitioners to better tailor results to their restoration planning needs (Figure 3.1).

Deployment of Sanmen shellfish reef, China. Photo: Dazheng Dong.

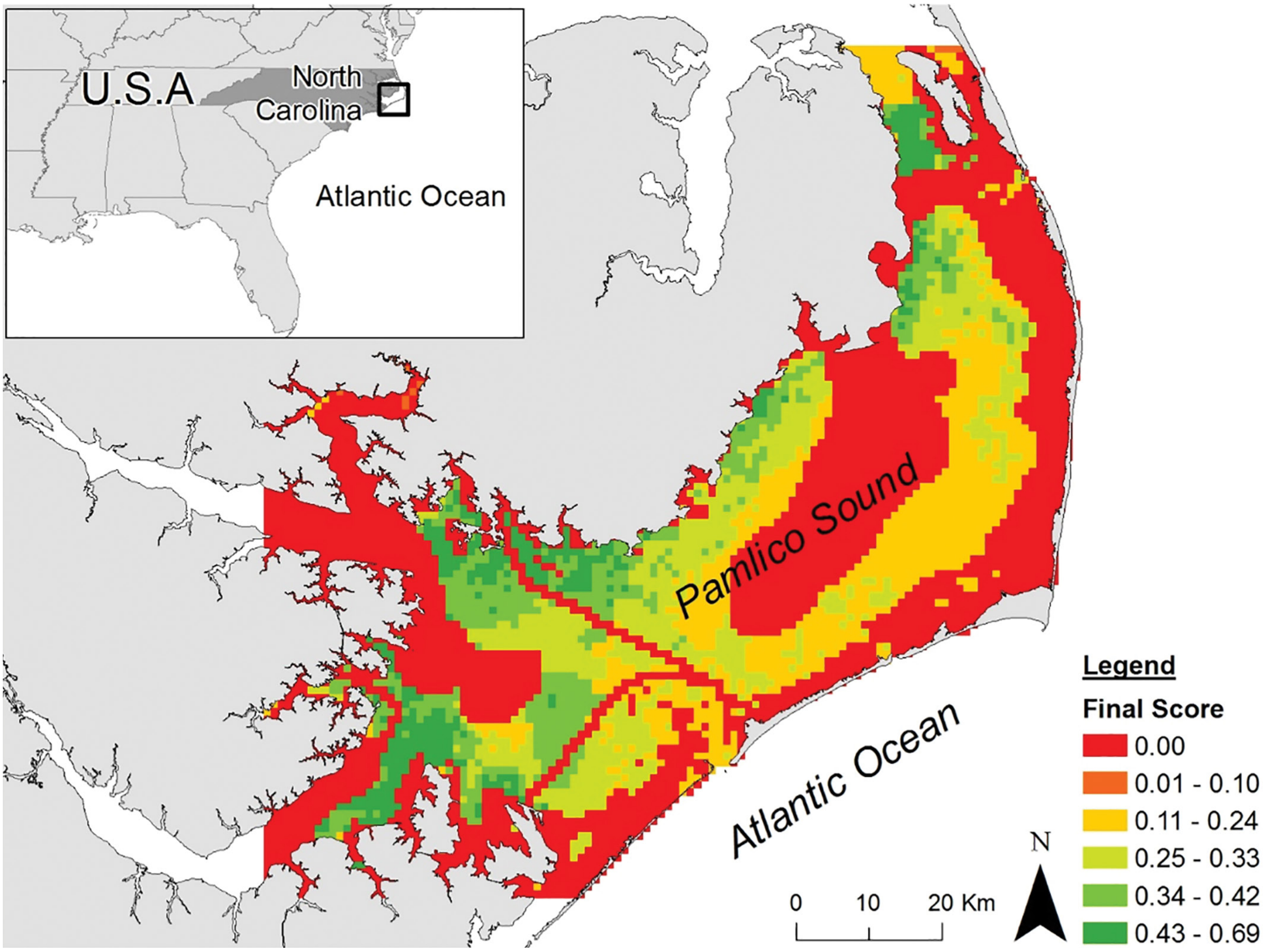

Figure 3.1a: Example output from an oyster restoration habitat suitability index developed for oyster restoration in North Carolina, USA that integrates multiple key environmental, biological, and logistical criteria (adapted from Puckett et al. 2018). Suitability for restoration increases from low (red) to high (green).

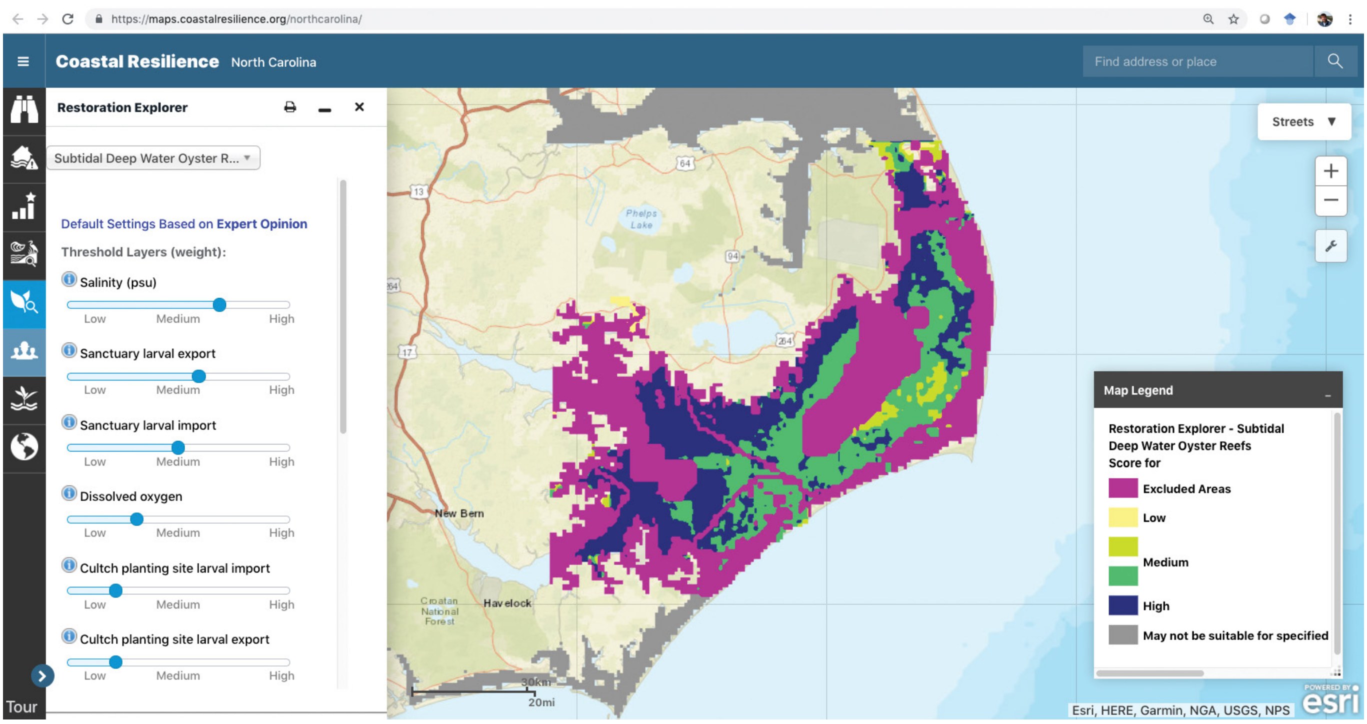

Figure 3.1b: Integration of oyster restoration habitat suitability index for North Carolina within The Nature Conservancy's Restoration Explorer, a web-based mapping platform that allows for dynamic adjustment of model parameters.

BOX 3.2: CASE STUDY: THE CHALLENGE OF WORKING IN AREAS WITH THREATENED SPECIES

MARINE THOMAS

The Hong Kong side of Shenzhen Bay houses important nursery sites for two endangered species of horseshoe crab, *Tachypleus tridentatus* and *Carcinoscorpius rotundicauda*. While native oysters are also naturally present in the ecosystem, there is no baseline data on the historical range of natural oyster habitats. This is because traditional cultivation methods involving the deployment of hard structures (stones and concrete poles) have been modifying the landscape for over 700 years. Today, this cultivation practice is dying out and vast areas of abandoned oyster clutches now take up the shoreline (Figure 3.2). These farms differ from natural oyster beds in that clutches are sparsely distributed over large areas, whereas oysters in a natural setting form smaller, more concentrated patches of habitat.

In early 2018, The Nature Conservancy was invited to carry out a small-scale restoration pilot near an important nursery site for horseshoe crabs. The project aimed to transform an abandoned oyster farm into smaller patches of oyster bed. Shortly before the work began, horseshoe crab conservationists voiced concerns on the potential negative impacts that oyster structures could have on the endangered species (Kwan *et al*. 2017), advocating the removal of oysters from the area altogether. There are knowledge gaps on the ecological consequences of both approaches (habitat modification vs. complete removal) and no consensus was reached. As such, the project was withdrawn, and months of planning and already deployed resources were lost.

Useful considerations and best practices for working in areas with threatened species (adapted from Cassazza *et al*. 2016):

- Ecosystem restoration and species conservation usually have compatible goals but do consider habitat from different perspectives: restoration tends to prioritise broader ecosystem functions, while species management focuses on conserving specific habitat conditions.
- The merits of ecosystem-based conservation approaches are increasingly recognised but this field remains relatively new. Environments that have been degraded over time will inherently have knowledge gaps around the ecosystem processes that underpin them. Restoration projects can be controversial or rejected if the effects of habitat manipulation on individual species are difficult to predict.
- Sensitivities around threatened species are likely to spark delays, confusion, debates and ultimately influence project objectives. Early identification of potential issues, active stakeholder engagement and a flexible planning process are critical for success. To that end, a functioning adaptive management framework should include:
  - › Research on sensitive species and relevant stakeholders in assessing site suitability
    for the work;
  - › Actively engaging stakeholders on a desired vision, perceived conflicts and how restoration fits into a site's management plan;
  - › Consensus on existing baseline conditions and knowledge gaps;
  - › Collaborative monitoring, data sharing, interpretation and consensus-driven implication of findings;
  - › Quantifying both negative effects and benefits to other ecosystem components when evaluating impact;
  - › Clearly agreed-upon thresholds that trigger alternative management plans (e.g. increased mortality of individuals of the threatened species);
  - › Alternative approaches that could take longer and require further research and resources.

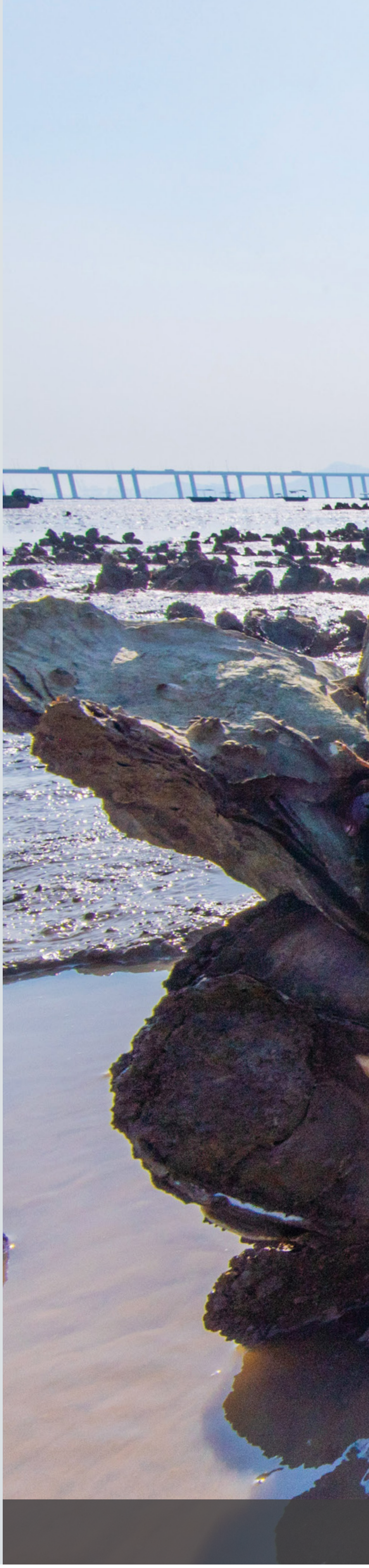

Figure 3.2: Abandoned oyster farm on Hong Kong shoreline, Shenzhen in the distance. Photo: Kyle Obermann.

Appendix 3.1: Restoration Feasibility Checklist. These questions are meant to act as a guide to help undertake a feasibility study for shellfish reef restoration.

	EXAMPLE QUESTIONS	NOTES
Goal and objective setting	• What is the primary restoration goal? • What are the desired project outcomes? • Are the project objectives S.M.A.R.T. (Specific, Measurable, Attainable, Relevant, Time-bound)?	Consider, for example: recovery of degraded ecosystem, increase local biodiversity, improve oyster fisheries, increase fish habitat, improve water quality, remove nitrogen, provide local jobs, provide volunteering opportunities
Historical reefs	• Is there evidence of current or historical shellfish reef and bed ecosystems?	Evidence of existing or historical reefs and beds can help inform which sites within a region could be suitable for restoration and can also help build the case for why intervention should be undertaken in a specific location
Physico-chemical parameters and threats	• Is the site's physical characteristics within the tolerance levels of the main bivalve species and ecological community?	Consider: wave exposure, currents/tidal movements, sedimentation levels, sediment quality and dynamics, dissolved oxygen, water pollution, pH, salinity, sun exposure, temperature, settlement substrate availability
Ecological parameters and threats	• Are the site ecological characteristics within the tolerance levels of the ecosystem engineer (oyster or mussel)?	Consider: connection to other ecosystems, food availability, existing reproductive capacity/oyster biomass, distance from other (oyster/mussel) reefs, disease prevalence, predators
Stakeholder engagement	• Which groups/individuals would support restoration and why? • Which groups would be against restoration and why? • Will you need volunteers, and if so, who could volunteer? • Will the neighbours/land owners be supportive?	An assessment of stakeholder supporters and potential detractors will help inform potential project partners and collaboration strategies

	EXAMPLE QUESTIONS	NOTES
Logistical parameters	• What approvals and permits will you need to undertake restoration? • Do you need approvals for site access? • Where will the reef materials come from? • What equipment will you need to construct reefs? • Where will you stage equipment/construction activities on shore? • Is the site free from major traffic areas or other use areas (e.g. industry, aquaculture) or can these be managed?	You may need permits/approvals such as: scientific collection, development application, translocation, biosecurity Reef materials include: substrate, shell, live oysters/mussels Equipment includes: barges, boats, dive equipment, sampling equipment, cameras Try to place restoration sites away from high use areas (e.g. shipping channels) unless this is part of your objective (e.g. shoreline stabilisation)
Reference ecosystems and restoration targets	• Where is the nearest reference sites? • Have the physical/ecological characteristics been mapped (and can you access the information)? • Can you gain access to the reference sites? • Will they be suitable 'ecological guides' for your project?	For more information on reference ecosystems and restoration targets see Gann *et al.* (2019)
Funding	• Who will financially support your project? • Why would they financially support your project?	Understanding project funders and key messages early on may help secure project resources and tailor proposals to specific audiences
Project risks	• What are the social, ecological and economic risks to the project and how will you manage these?	Detailed risk assessments are generally included in project management plans but an early assessment will help identify major threats to the project
Monitoring, evaluation and reporting	• Who will conduct the monitoring, analysis and reporting? • What methods will they use and are these financially sustainable? • Have you consulted relevant monitoring guides?	You should identify who will conduct monitoring and evaluation of the project early on and ensure they are involved in helping to establish the project objectives and deliverables

CHAPTER 4
BIOSECURITY AND PERMITTING IN SHELLFISH REEF RESTORATION

Andrew Jeffs, Boze Hancock, Philine zu Ermgassen and Bernadette Pogoda

KEY POINTS

- **Transfers of shellfish is a major cause of the spread of invasive species and diseases and should be avoided between ecologically different water bodies.**
- **Invasive organisms may result in unpredictable ecosystem alterations in the new environment and may cause negative ecological and economic effects.**
- **The restoration of shellfish reefs has numerous positive ecological benefits, which should not be put at risk from poor biosecurity practices for transfers of shellfish and shell material.**
- **The introduction of non-native species for habitat restoration should be avoided.**
- **Basic rules for successful permitting are: (1) start early, (2) communicate often, (3) involve relevant stakeholders, (4) seek help from experienced shellfish restoration networks.**

Figure 4.1: American slipper limpet (*Crepidula fornicata*). Photo: D.J. McGlashan.

BIOSECURITY

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).

A wide range of naturally-occurring pathogens and parasites are associated with marine shellfish, especially with species of oysters and mussels (Bower *et al.* 1994). Such parasites and pathogens are often at low levels and inconspicuous within a native (donor) population of shellfish, making them difficult to detect with confidence, but capable of causing severe effects once transferred into new environments.

In the past, aquaculture and restocking of fisheries was a major source of introductions of aquatic species into new areas. Shellfish reef restoration efforts can now benefit from this past experience and should always strive to apply the best environmental practices and techniques to ensure high biosecurity standards.

INVASIVE SPECIES

Besides parasites and pathogens, there is also a real risk of accidentally introducing other species into new locations when transferring live shellfish and associated material for restoration purposes. The greatest risk of this occurring is from biofouling species catching a ride on the outside of the shells of transferred shellfish. An example of this, is the American slipper limpet (*Crepidula fornicata*) which was unintentionally introduced to Europe in the late 1800s with the import of the American oyster (*Crassostrea virginica*). Today, in parts of Europe the slipper limpet reaches extremely high densities, often smothering the native seafloor community with the large quantities of waste it produces. These limpets may further negatively impact shellfish reef restoration through competition for food and their incidental consumption of shellfish larvae (Figure 4.1).

If the shellfish species intended for transfer is not already present and was not present historically in the proposed restoration site, there is the potential for the introduction of the shellfish to cause unintended ecological disruption. For example, the Pacific oyster (*Crassostrea gigas*) was introduced to Europe for aquaculture in the 1970s and has now established problematic wild populations at various locations throughout Europe. For this reason, the introduction of a shellfish species to an area outside of its natural range should not be considered (Bartley and Minchin 1996).

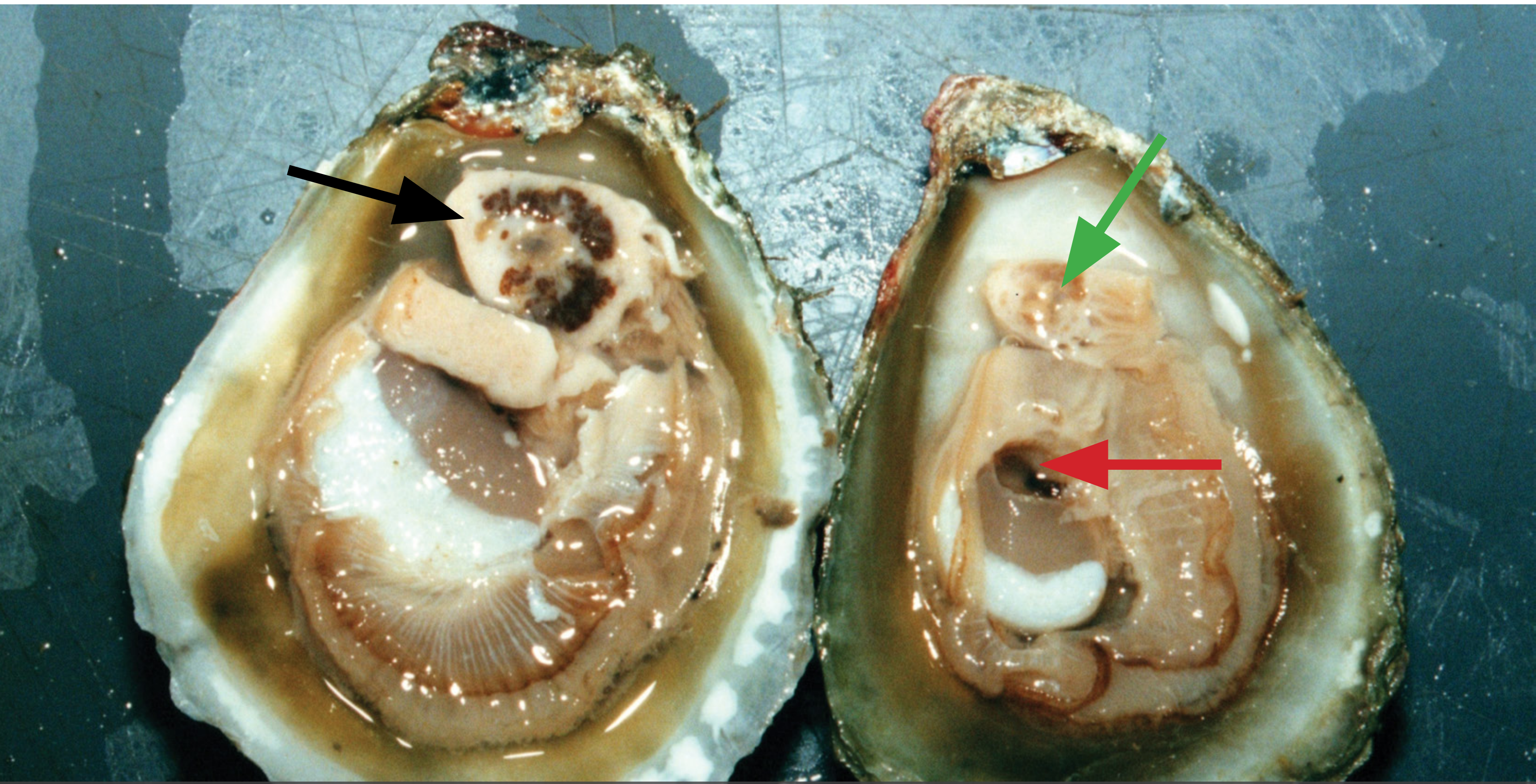

Figure 4.2: Bonamiosis in Bluff Oysters (*Ostrea chilensis*). The oyster on the left appears healthy with a dark digestive gland and normal sized gonad (black arrow). The oyster on the right is infected with *Bonamia exitiosus*. It has a gonad and digestive gland which are comparatively small and pale (green arrow), and an enlarged heart (red arrow). Photo: Ben Diggles.

PARASITES AND DISEASES

Historically the accidental introductions of shellfish parasites and pathogens have occurred in concert with the transfer of shellfish or shell material deployed in efforts to improve shellfish harvests. This has frequently caused massive financial losses from damage to commercially important shellfish populations across large areas.

For example, a virulent microbial parasite of flat oysters, *Bonamia ostreae*, was transferred with oysters from the Pacific Coast of North America to France, resulting in widespread and ongoing losses of farmed oysters, especially in northern Europe. Initial losses in some oyster populations due to the introduced disease were almost 80%, indicating the vulnerability of shellfish to pests for which they have no natural resistance. Similar impacts have been observed in *Ostrea chilensis* in New Zealand (Figure 4.2).

Similarly, a virulent herpes virus is the cause of Pacific oyster mortality syndrome (POMS) which caused significant losses in the Pacific oyster aquaculture industry after it first appeared in New South Wales, Australia, in 2010. The viral disease was subsequently transferred to the island state of Tasmania in 2015, causing mass Pacific oyster mortalities (>60%) and closing down the export of seed oysters from the state, which supported the oyster aquaculture industry in other regions of Australia.

Once a pest species is introduced into a new location in the marine environment it is extremely difficult, if not impossible, to eradicate.

Therefore, preventing introductions of pest species when transferring shellfish and other material, such as shell cultch, among locations is vitally important.

In areas targeted for restoration that may already have shellfish diseases or parasites present, it is important to identify populations of shellfish for sourcing broodstock or for transfer that are resistant to these pests to help ensure the survival of the shellfish following their transfer, if at all possible. Surviving shellfish in areas that have displayed the highest disease loads, for the longest period, are most likely to have developed the greatest tolerance to the disease. However, it is also important to avoid transporting the pathogens responsible for the disease to new areas. Producing disease-free stock that carry the available genetic tolerance, but are free of pathogens, is an important consideration for shellfish transfers in areas affected by diseases.

Increasingly, shellfish hatcheries are playing a role in developing and producing certified disease-free stock that is particularly effective for reducing the risk of spreading shellfish diseases.

Transferring large numbers of the shellfish species targeted for reef restoration into new areas has the potential to alter the genetic diversity and local adaptation of the existing native population in the receiving areas. Subsequent genetic mixing of the two groups may decrease the fitness of the genetically mixed population.

For example, strains of the American oyster that have been selectively bred for disease resistance have been found to have the highest growth and survival in their natal region. These benefits tend to decrease with increasing distance from that natal region. Transferring these oysters into more distant locations where they can interbreed with an existing resident population of oysters may ultimately result in the dilution of the local adaptation among the resulting oysters to the environmental conditions in the area.

In some areas, e.g. southern Australia and Europe, the native population of shellfish has been driven to local extinction, so sourcing locally-adapted broodstock is not an option.

Where possible, it is always preferable to work with local shellfish populations as the basis for restoration because it eliminates the risk of accidental introductions of shellfish pests and genetic interference. High resolution scientific studies of the genetic structure of shellfish populations are the best guide to determining possible differences between the intended source and receiving populations for shellfish reef restoration. In the absence of information on population genetics, wild shellfish populations from the same geographic region and connected by an immediately contiguous water body should be used where possible. If the transfer of shellfish between more distant locations is required for restoration, it needs to be carefully assessed before proceeding.

In some jurisdictions this careful assessment is a mandated requirement, which may also entail formal permitting considerations by a managing agency or assessment by a regional biosecurity agency. Even if it is not a mandated requirement, an assessment is advisable to avoid the risk of the shellfish transfers doing more environmental harm than good through accidental introductions of parasites or diseases.

Typically, such an assessment will involve an expert appraisal of any potential risks of negative effects of a transfer of shellfish, usually involving a comparison between the profiles of the presence of parasites and diseases at the source and receiving locations for the planned transfer of shellfish for the restoration. Finding suitable expertise in shellfish diseases and parasites, especially for community-driven shellfish restoration initiatives, may be challenging, however, such people are often found in regulatory agencies, universities, and other aquatic research institutions. If regulatory agencies are unable to provide guidance, then asking around among aquatic researchers will often provide direction to appropriate expertise that can be of help.

An assessment may result in protocols for shellfish transfers that are aimed at minimising any associated risks due to shellfish transfers (e.g., ICES 2008; CEFAS 2009). Protocols used in assessment may involve prior testing of shellfish to confirm pest-free status, treatment of transferred shellfish prior to their release into their destination location (to destroy organisms living on or in the shells of shellfish), or the banning of movements of shellfish from known disease regions to currently disease-free areas.

This is currently the situation with restrictions on movement of oysters across regions of Europe and parts of Australasia where the flat oyster parasite *Bonamia* is known to be present.

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.

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.

While regulations vary, heat treatment, chlorine treatment, immersing in freshwater for extended periods or weathering outdoors for a period to ensure all hitch-hiker species and pathogens on shell material have been destroyed or reduced to acceptable levels, greatly reduces the risk of inadvertently transferring pest species. Where large volumes of shell are involved, weathering at an inland site may be the only cost effective approach unless the shell is a by-product of shellfish processing involving sufficient heat treatment. For shell weathering, six months is a commonly used minimum weathering time. For example, the Rhode Island Biosecurity Board stipulates six months weathering of shell material with turning of the pile every second month for a thin layer of shell material (<6 inches, 15 cm) and up to twice a month for a deeper layer of shell material (Figure 4.3). The requirement to turn the pile would be less frequent in warm climates.

Whilst complying with such measures may appear to create additional complexities or hurdles for shellfish restoration they should not be overlooked because the long-term ecological and reputational consequences of an accidental introduction may greatly outweigh the benefits of local shellfish reef restoration.

PERMITTING

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.

Complications can arise in the permitting process. While those in the restoration community are often immersed in the process and in quantifying the benefits of the restored habitat, those in the regulatory agencies may have little familiarity with marine habitat restoration. In this situation, completing an application with tables of information is likely to be insufficient and consideration should be given to communicating specific restoration aims and benefits in greater detail to the regulators.

Figure 4.3: Community members preparing a pile of cured recycled shells for deployment in Rhode Island, USA. Photo: John Torgan.

Involving overarching restoration networks with prior experience of dealing with regulatory agencies and the concerns these agencies may have, can help to facilitate the regulatory acceptance of restoration.

Frequently, in areas where shellfish reef restoration has not previously been undertaken, there may be uncertainty among regulatory agencies regarding who has the authority to grant a permit, or even how many agencies will need to provide their permission. Jurisdiction generally depends on the category of the selected restoration site and the existing management regime within the site (e.g., coastal waters, offshore waters, marine protected areas, multi-use areas, and fishing grounds).

There is rarely a category of 'restoration' permit available because this type of activity has only emerged in relatively recent times. This means that, at least initially, restoration is likely to be permitted under an existing category that is considered similar or that deals with different aspects of the proposed restoration activity. These permitting processes tend to relate to other activities such as aquaculture, fisheries, biosecurity or marine construction.

In the USA, with a longer history of shellfish reef restoration projects, the permitting process was sufficiently complex and varied across the country that The Nature Conservancy commissioned an inventory of shellfish restoration permitting for the 21 coastal states (Mississippi-Alabama Sea Grant Legal Program and National Sea Grant Law Center 2014). This inventory describes the regulatory environment that may affect shellfish reef restoration in each state, under five broad categories and encompassing 18 different sub-categories – indicating the extent of differences in the regulatory regimes affecting shellfish reef restoration activities across the USA.

Practitioners must endeavour to educate themselves about the regulatory process and educate regulators in the history and benefits of shellfish reef restoration, as well as the project to be permitted. In the absence of familiarity with the permitting environment the basic rules are:

1. Start early
2. Communicate often
3. Involve relevant stakeholders
4. Seek help from experienced shellfish restoration networks.

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. Providing a clear picture of the reference ecosystem or model for which the restoration project is working towards (see Chapter 3) may assist with communicating to regulators what the future intended state of the restoration site(s) will look like.

One consideration that routinely arises in the design and permitting stages is whether subsequent harvest of the shellfish will be allowed within the restoration area. Overharvest of shellfish has been the primary threat leading to the drastic decline of shellfish populations, and yet many jurisdictions often do not have the legislative framework to close off a restoration site to subsequent harvest, even where an objective of shellfish reef restoration is to provide an increased supply of larvae to enhance recruitment to nearby fishery resources. It is important to determine the legal and social frameworks for managing fishing within the restoration project's boundaries so that the integrity of the shellfish restoration effort can be maintained.

In some jurisdictions there will be groups or individuals from which additional approvals may need to be sought, and the process may not be as straightforward as filing a written application with a government agency. For example, indigenous stakeholders in many regions of the world maintain both historical and/or legally mandated jurisdiction over coastal resources, which may include customary title or preferential access rights to tidal lands and shellfish. Due to strong historical association with coastal resources, indigenous stakeholders frequently have a high degree of knowledge of shellfish resources and are often valuable sources of information and can be strong allies in support of restoration efforts. Consulting with indigenous stakeholders early and maintaining dialogue and engagement throughout coastal restoration initiatives is often a key to success.

Other groups in the community that may be affected by a restoration initiative also need to be identified early and consulted. This may include commercial and recreational fishers, tidal land owners or leaseholders, or aquaculture operators. Promoting open dialogue with all interested groups in the community will often strengthen support for the restoration initiative, improve its design and acceptance, while also raising public awareness and promoting more active engagement around tackling threats to our coastal environments.

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CHAPTER 5
SHELLFISH REEF RESTORATION IN PRACTICE

Stephanie Westby, Laura Geselbracht and Bernadette Pogoda

KEY POINTS

- **It is critical to understand whether the planned reef location is recruitment limited, substrate limited, or both. This will guide selection of restoration methods.**
- **Shellfish for planting onto restoration reefs may come from hatcheries, ponds, or local broodstock.**
- **Restored reefs can be constructed from various substrates. Choosing among these requires understanding local physical conditions as well as social and regulatory factors.**
- **Disease may be a factor in shellfish reef restoration, and should be understood prior to undertaking restoration.**

INTRODUCTION

Approaches to successful restoration vary with species, scale, and local biological, ecological, and physical conditions. Local regulatory and social factors are important as well. While it is useful to learn from national and international examples, it is also critical to think about 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, 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 natural regeneration, through assisted regeneration to reconstruction approaches; all of which are preceded by the removal or mitigation of causal factors or threats. These different approaches can be largely summarised into whether a lack of reef substrate, lack of recruitment, disease, or a combination of these are preventing the natural recovery of the shellfish reefs.

IDENTIFYING THE APPROPRIATE RESTORATION ACTION

Typically, an area in need of restoration is either 'recruitment limited', 'substrate limited', or both (Brumbaugh and 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, etc. 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 localised limitation is recruitment, substrate, or both will inform decisions on what restoration treatment should be applied.

Figure 5.1: Settlement plates deployed in Yung Shue O, Tolo Harbor, Hong Kong. Photo: Lori Cheung.

TECHNIQUES FOR ADDRESSING RECRUITMENT LIMITATIONS

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 hectares or larger). If unsure whether your area is recruitment limited, one method of determining this is to collect data on spat settlement plates. Someone may have already done this, check with local academics, researchers or resource managers. If no information exists, the restoration practitioner can deploy settlement plates at a range of tidal elevations and check them monthly (Figure 5.1). This is best done for 1 or more years to understand seasonal peaks, but if time or resources are limited, at least put the settlement plates out during the anticipated spawning season (typically spring through late summer).

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).

Hatcheries may produce either 'cultchless' seed (attached to very small pieces of cultch, such as a grain of sand or tiny shard of shell), or 'cultched' seed (seed – or several seed – attached to a larger piece of cultch, such as an empty shell). Cultched seed is most often used for restoration, as it tends to mimic the reef's natural structure, where larvae attach to shells produced by previous generations. Seed attached to larger cultch may also be less vulnerable to predation than small, cultchless seed. Cultchless seed is most often produced for shellfish farming, particularly where the animals will be grown in cages or bags and can be managed more easily as single oysters. A common type of cultched seed is 'spat-on-shell', where one or several juveniles are attached to a single, empty shell of the same species (Figure 5.2). Shell material may be obtained from commercial shellfish processing facilities or restaurants as part of shell recycling initiatives, but should be 'aged' in the sun for at least six months to ensure that pathogens are eliminated (see Chapter 4).

Hatcheries typically produce shellfish larvae, then place them in large tanks with water and cultch to allow the larvae to 'set' (attach) to the cultch. Some hatcheries may sell unset larvae. Unset larvae is far easier to transport than spat-on-shell (i.e., only a lime-sized ball of eastern oyster (*Crassostrea virginica*) larvae is required to set a 11,400-litre tank of spat-on-shell). Practitioners may be able to purchase the larvae directly from the hatchery, and set up a small remote setting facility to set the larvae onto cultch (Congrove *et al.* 2009). Remote setting techniques may vary by species. For example, mortalities have been 100% to date when attempting to transport European flat oyster (*Ostrea edulis*) larvae. Another promising technique is to release shellfish larvae to set directly onto a restoration site, where appropriate substrate is in place (Leverone *et al.* 2010; Fredriksson *et al.* 2016).

Annual production capacity at local hatcheries is another factor to consider. Hatcheries are typically structured to produce a set amount of product annually (seed, larvae, or a combination). They may have trouble meeting an increased demand with little or no advance notice. It is important to discuss project plans with the hatchery manager to determine the feasibility and timing of producing the required amount of product.

In Europe, pond systems are traditionally used to produce shellfish seed (Figure 5.3). Broodstock is placed in shallow, enclosed ponds, where temperatures rise sufficiently high for successful reproduction and natural phytoplankton supply. Cultch is placed in the ponds, and the broodstock produces larvae that set onto the cultch. Various cultch types, including artificial substrates and pre-fabricated reef structures, can be seeded in ponds. The cultched seed is then removed and transported to the restoration site.

Figure 5.2: Hatchery produced *Crassostrea virginica*, with spat on shell cultch in the front (red arrow) and mature oysters on shell cultch after a period of grow out. Photo: University of Maryland Center for Environmental Science, Horn Point Hatchery.

Figure 5.3: Ponds for seed production of *Ostrea edulis* in Cork, Ireland. Photo: Shmuel Yozari.

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 and Mann 1998). In this traditional technique, practitioners place cultch in a nearby area of high recruitment to catch naturally occurring larvae. The cultched seed is then relocated onto the restoration site. This technique works with the area's local broodstock and takes advantage of natural larvae. This method is used in many areas to populate private shellfish beds. It may be wise to consult with a local aquaculture specialist or shellfish biologist to find appropriate cultch placement locations and to understand local permitting issues.

Whether stocking from hatcheries, ponds, or relocation of natural seed, very high mortalities should be anticipated. This is the nature of placing very small animals onto a reef environment, and transportation and handling may increase mortality (see also Box 5.1). One large-scale restoration plan projected 85% mortality of hatchery-produced spat-on-shell in the first year, and 30% annual mortality thereafter (Maryland Oyster Restoration Interagency Workgroup 2013).

See Table 5.1 for examples of seeding densities on restoration reefs.

BOX 5.1: SHELLFISH REEF RESTORATION IN COLDER CLIMATES

If you are working where winter air temperatures drop below freezing (even only occasionally), and in a recruitment-limited area, be cautious about constructing intertidal restoration projects. Many shellfish species will freeze and die if exposed to freezing air temperatures. Mortalities will likely be near 100% with only one freezing incident (for example, an extreme low tide combined with freezing air temperatures).

As long as the structure persists, and there is sufficient local recruitment, this loss may be only short term as the reef can repopulate itself (Figure 5.4). However, if the area is recruitment limited, be aware that intertidal reefs may require constant re-seeding with the target species after each freezing to support a shellfish population.

Figure 5.4: Intertidal oyster reef in the southern Chesapeake Bay built from reef balls, pictured at mid tide level. Although winter temperatures here occasionally reach freezing, there is sufficient natural oyster recruitment to re-populate the reef when it experiences temperature-related oyster mortality. Photo: Stephanie Westby.

Table 5.1: Examples of seeding densities on shellfish restoration reefs in recruitment-limited areas.

REGION (REEF NAME)	SPECIES	JUVENILE OR ADULT ANIMALS?	INITIAL SEEDING DENSITY OF OYSTERS	TARGET OYSTER DENSITY POST RESTORATION
U.S. mid Atlantic coast (Chesapeake Bay, Harris Creek)	*Crassostrea virginica*	Juvenile	12.5 million per hectare	15-50 per m^2
Essex, UK	*Ostrea edulis*	Adult	3 per m^2	5 per m^2
North Sea, Netherlands	*Ostrea edulis*	Adult	10 per m^2	unknown
North Sea, Germany	*Ostrea edulis*	Juvenile	1 million per hectare	15-50 per m^2
Victoria, Australia (Port Phillip Bay)	*Ostrea angasi*	Juvenile	750,000 per hectare	50 per m^2
South Australia, Australia (Windara Reef)	*Ostrea angasi*	Juvenile	350,000 per hectare	50 per m^2

Shellfish gardening programs (where individuals grow shellfish off docks in floats or cages for planting onto restoration areas) can be a source of adult broodstock for small-scale restoration projects (Figure 5.5). If such programs already exist locally, check with program operators about obtaining animals for the planned reef. If no program exists, practitioners can start one, recognising that the shellfish for the gardens still needs to come from hatcheries, ponds, or relocation of natural seed.

Oyster gardening can increase local broodstock, which may provide a larval supply in otherwise recruitment-limited systems (Brumbaugh *et al.* 2000a,b).

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.

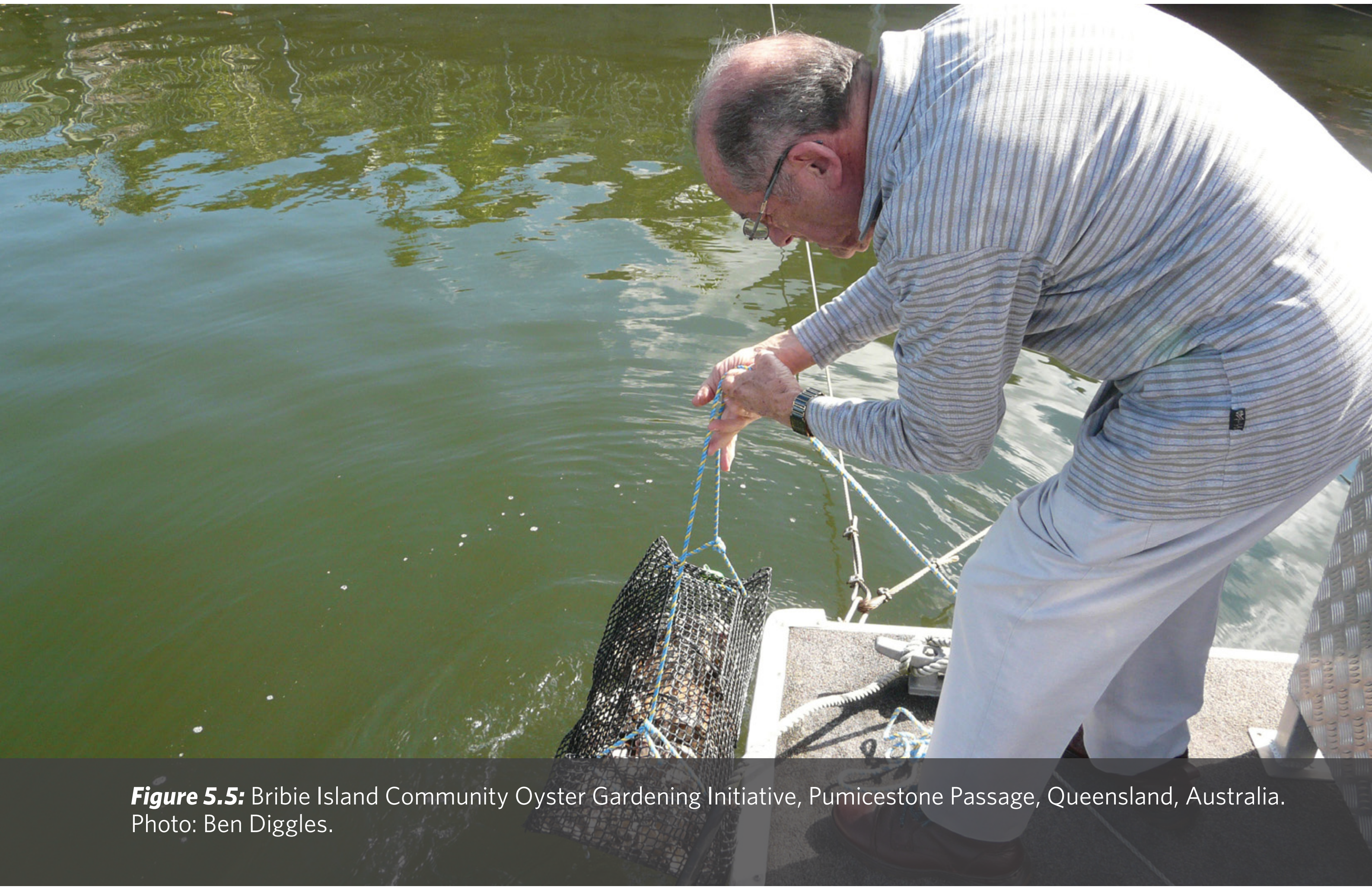

Figure 5.5: Bribie Island Community Oyster Gardening Initiative, Pumicestone Passage, Queensland, Australia. Photo: Ben Diggles.

TECHNIQUES FOR ADDRESSING SUBSTRATE LIMITATION

In substrate-limited areas, practitioners will need to construct reefs from some type of appropriate substrate (Figure 5.6). (If the area is both substrate- and recruitment-limited, practitioners will need to construct reefs, then seed them with juvenile oysters, as described above).

Selecting reef-building substrate requires careful consideration of the local biotic and abiotic environment, social factors, and material availability. A literature review is available on substrate materials used in the USA including porcelain, concrete, stablised coal ash, stone, shell, and engineered structures (NOAA 2017). Table 5.2 lists costs for some materials that have been used for projects in the USA, Europe, Hong Kong, China and Australia.

Figure 5.6: Barge deploying shell and stone to restore shellfish reefs as part of the Elizabeth River Project, Chesapeake Bay, USA. Photo: Joe Rieger.

Factors to consider when selecting reef material include:

- **Recruitment:** Will the target shellfish species set on the selected reef material?
- **Wave energy:** Higher-wave-energy areas typically require larger, more durable, heavier reef-building substrate to ensure durability.
- **Water depth:** Will the shellfish reef be subtidal (submerged at all times, even at extreme low tides), or intertidal? Intertidal reefs may be affected by even low amounts of surface wave energy, and must be constructed to withstand it. Shallow subtidal reefs may also be affected by surface wave energy. Reefs constructed from lightweight materials (shell, small stone) may spread out and lose three-dimensionality or disappear entirely.
- **Benthic characteristics:** Heavy reefs may sink in soft mud, whereas shell or other hard bottom substrate may be able to support the weight of the reef.
- **Purpose of the reef project:** For example, if the reef is to provide shoreline erosion protection, it needs to be constructed from materials that can serve that function.
- **Sedimentation:** If the reef is in a high sediment accumulation area, it should be constructed with greater relief to withstand those conditions. Ideally select a low sediment accumulation area instead.
- **Sanctuary status and public health:** Is shellfish harvest allowed in the area? Does the selected reef material allow for harvest, or prevent it? If the area is closed to shellfish harvest due to human health concerns, will the material help protect it from illegal harvest?
- **Fishing gear restrictions:** Is bottom trawling allowed in the area? Does the selected material harm fishing gear, or prevent fishing?
- **Conservation status of the restoration site:** Does the selected reef material and reef design comply with conservation designations (e.g. marine protected area; sanctuary status; historic designation)? It may be wise to consider potential natural movement of reef material, and how that might affect nearby protected areas or features.
- **Public and regulatory acceptance of the material:** Materials considered natural (e.g. shell, stone, clay) may have greater public and regulatory acceptance than others (e.g. slag, concrete, recycled porcelain, plastic), but local opinions can vary widely. It is critical to consult with the regulatory agencies, local community, and stakeholders to determine preference.
- **User group conflicts:** Will the reef material interfere with (or enhance) recreational or commercial fishing – either for the target species or other species? Will it interfere with boating or the view from shore? Even if the shellfish reefs once occurred there, current users may be accustomed to or prefer the way the ecosystem looks or functions now.
- **Reef material acquisition and placement:** A particular material may be well suited for a site, but locally unavailable. Material costs, transportation costs, and logistics must be considered. Substrate may be placed by hand (where safe) for small amounts of lightweight material in shallow water, or require cranes and barges for large amounts of heavy material in deep water.
- **Material cost:** material cost can vary widely (see Table 5.2 for examples).

There may be a strong seasonal component to addressing both recruitment and substrate limitations: hatcheries and ponds may only produce seasonally; natural set may only occur seasonally; and substrate reefs designed to catch naturally occurring larvae may become fouled with non-target species if placed out of sync with the target species' spawning cycle. It may be useful to consult on seasonality with a local fisher, or a shellfish biologist from an agency, non-government organisation, or academic institution.

Deployment of Lau Fau Shan shellfish reef, Hong Kong. Photo: Kyle Obermann.

Table 5.2: Costs for recent shellfish reef restoration projects. These costs are for reef material (substrate) purchase and placement only; they exclude costs for planning, design, permits, and cost for planting seed onto the reef.

SPECIES	PROJECT NAME AND REGION	REEF SIZE (HECTARES)	REEF HEIGHT (M)
Crassostrea virginica	Harris Creek, Chesapeake Bay, US East Coast	Various, 0.4 to 4.8 per reef; total of 30 hectares (additional reefs were built in Harris Creek using other materials)	0.3
Crassostrea virginica	Piankatank River, Chesapeake Bay, US East Coast	10	0.46
Crassostrea virginica	Piankatank River, Chesapeake Bay, US East Coast	6	0.15
Crassostrea virginica	Biloxi Bay, US Gulf of Mexico	0.01	1.1
Ostrea edulis	Blackwater, Crouch, Roach and Colne Estuaries, Essex, UK	0.12	0.3
Ostrea edulis	Borkum Reefground, German Bight, North Sea	0.04	0.3-1
Ostrea angasi	Margaret's Reef and Wilson Spit, Port Phillip Bay, Victoria, Australia	2.5	0.3-1
Ostrea angasi	Windara Reef, Gulf St Vincent, South Australia, Australia	20	0.7-1
Crassostrea ariakensis, Crassostrea sikamea	Sanmen Reef, Zhejiang, China	1	1
Crassostrea honkongensis	Lau Fau Shan Reef, Deep Bay, Hong Kong	0.06	0.3
Mixed shellfish that will recruit naturally (likely *Crassostrea bilineata* and *Perna viridis*)	Yung Shue O Reef, Tolo Harbor, Hong Kong	0.0015	6

* A collaboration between the Zoological Society of London, The Nature Conservancy, University of Essex, University of Edinburgh, Natural England, Cefas, Environment Agency, Tollesbury and Mersea Oyster Company, Colchester Oyster Fishery, Kent and Essex Inshore Fisheries and Conservation Authority, Essex Wildlife Trust, River Roach Oyster Company and Blue Marine Foundation.

REEF MATERIAL	REEF LOCATION (NEARSHORE/ ESTUARINE; OFFSHORE)	US$ PER HECTARE (MATERIAL COST + PLACEMENT COST)	ACTUAL REEF FOOTPRINT** POST RESTORATION (PER HECTARE)	REEF CONSTRUCTED BY
Stone, 7 cm to 15 cm diameter, and conch, clam and scallop shell	Nearshore/ estuarine	$235,000	100%	U.S. Army Corps of Engineers (federal agency)
Stone, ave 30 cm diameter	Nearshore/ estuarine	$200,000	40%	U.S. Army Corps of Engineers (federal agency)
Stone, ave 5 cm diameter	Nearshore/ estuarine	$37,500	100%	The Nature Conservancy and Virginia Marine Resources Commission (state government)
Oyster Castles (pre-fabricated concrete structures)	Nearshore/ estuarine	$2,400,000	33%	The Nature Conservancy
Mix of stone and shell (scallop and cockle)	Nearshore/ estuarine	$217,235	100%	Essex Native Oyster Initiative
stone, mixed shell, 3D-printed sandstone	Offshore	$570,000	75%	Alfred Wegener Institute, Federal Agency for Nature Conservation*
Limestone, ave 40 to 50 cm diameter and mixed shell	Nearshore/ estuarine	$85,000	15%	The Nature Conservancy
Limestone, ave 20 cm diameter	Nearshore/ estuarine	$123,700	6%	The Nature Conservancy
Stone, 10 to 40 cm in diameter	Nearshore/ estuarine	$8,555	0.8%	The Nature Conservancy, and East China Sea Fisheries Research Institute
Rough concrete posts	Nearshore/ estuarine	$85,690	10%	The Nature Conservancy
Recycled shell	Nearshore/ estuarine	$3,427,000	100%	The Nature Conservancy

** Some reefs were constructed by completely covering the reef footprint with substrate. These are denoted by '100%' in this column. Other reefs were constructed by placing reef material over a certain percentage of the reef footprint, for example in a striped configuration. These reefs are denoted in this column by a percentage less than 100.

TECHNIQUES FOR ADDRESSING SITE SELECTION

Practitioners should keep in mind that a successful reef location is one that meets *both* the biological needs of the target species *and* the interests of the local human community (e.g. acceptability of reef material, user group conflicts, regulatory compliance). Siting a reef based on only one or the other may reduce the potential for project success. The parameters used to determine reef site overlap with those used to determine reef material (see bulleted list above, 'Factors to consider when selecting reef material').

Additional parameters to consider when siting a shellfish restoration project include:

- **Historic presence of the target shellfish species:** seek evidence that the target shellfish species existed in the area historically. This can be historic maps or data sets, or evidence of shell substrate at or near the site.
- **Water quality:** determine if the area has suitable dissolved oxygen, temperature and salinity to support the target species. This information may be available from local academics, watershed groups or government.
- **Water depth:** carefully determine whether an intertidal or subtidal location is preferable, particularly in areas where air temperatures can fall below freezing (see Box 5.1). This may also influence reef material selection. Consider potential conflicts with local navigational channels and boat traffic when determining where and how tall to build the reef.
- **Biotic factors:** seek information from researchers or resource managers regarding food availability for the target species and predation issues.
- **Overall feasibility:** consider reef material availability, transportation, logistics, public acceptance, regulatory framework, harvest status for the target species and other species, and user group conflicts.

PILOT PROJECT

Once the site has been selected, the next stage of restoration can involve a pilot or proof of concept project, to learn empirically if a shellfish restoration project will work in a given location. Pilots are small-scale projects (typically from 10s of square meters to 0.5 hectare), with scale being the main difference between these and full-size projects. A pilot should go through the same feasibility, design, planning, public consultation, permitting, construction, and monitoring as a larger project. The pilot should be monitored to determine not only the health of the reef and target species, but for any additional services that are stated as goal of the larger restoration effort.

TECHNIQUES FOR ADDRESSING SHELLFISH DISEASE

In this section we discuss diseases that affect the health and survival of shellfish. These diseases may not be harmful to humans consuming them. However, some infections carried by shellfish (e.g. *Vibrio vulnificus*, toxic microalgae, Salmonella, Shigella, and toxin-forming bacteria) may not harm shellfish, but are harmful to humans consuming them, especially raw. Certain diseases can cause substantial mortality in shellfish populations, including those inhabiting restoration projects. Some common shellfish diseases include *Bonamia*, *Marteilia*, dermo, Herpes, Winter Mortality Disease, Queensland Unknown (QX), Juvenile Oyster Disease and Multinucleated Sphere Unknown (MSX). They are induced by protozoans, bacteria, or viruses, and may affect different life stages of shellfish. The movement of shell or living shellfish for restoration purposes should therefore consider this potential threat (see Chapter 4 on biosecurity for more guidance). There are no examples of diseases being eliminated once they are present in a system. Therefore, where diseases are already present in the restoration area, restoration can take either a passive or an active approach as described below.

LIVING WITH DISEASE

One approach to disease is to simply 'let nature take its course'. That is, proceed apace with restoration work, with the understanding that some, many, or even most, of the individuals on the site may succumb to disease. The theory behind this is that: a) it may not be possible, with existing knowledge and practices, to reduce disease pressure, and b) the disease may cause the weaker, less-tolerant individuals to die off, leaving the more-disease-tolerant individuals to produce future (hopefully more disease-resistant) generations. This approach also allows for selection of other traits which may afford increased growth or survival on the basis of local conditions. Under this scenario it is preferable to use local, previously exposed broodstock in restoration activities (see Chapter 4). Although this idea is theoretical, supporters in the scientific community believe that the shellfish that do not succumb to disease – even if there are very few – are actually the most valuable in terms of developing population-wide disease tolerance.

A further consideration when choosing the approach of 'living with disease' is to consider the other stressors that may impact on the shellfish population. For example, while the disease *Bonamia* can result in significant mortalities, the prevalence of the disease in an infected population appears to vary greatly with stress (van Banning 1991; Lynch *et al.* 2005).

Stressors may include: transplanting/handling; suboptimal salinity or temperature; low food availability; or high oyster density. Considering how these stressors can be reduced and hence allow the oyster population to recover despite the presence of disease is a further theoretical consideration, and not sufficiently understood so far.

DISEASE RESISTANCE

A tremendous amount of work in disease-prone but important oyster growing areas has been done to develop genetic lines that are resistant to disease (Dégremont *et al.* 2015). Most of this work has focused on improving industry productivity, but restoration practitioners can also take advantage of these improvements. Use of disease-resistant strains, however, would require practitioners to use hatchery-bred spat. There are several important factors to consider regarding use of disease-resistant spat. The most disease-resistant genotypes in one environment will not necessarily be the most resistant to the same disease in another environment. Developing a genotype resistant to one disease is not likely to confer resistance to other diseases; however, it is possible to simultaneously select for resistance to two diseases. Development of disease-resistant strains requires a dedicated program with facilities and a consistent level of support. Disease-resistant native oyster genotypes have been developed for restoration areas along the East Coast of the USA and in Australia (Dégremont *et al.* 2015).

Macroparasites in shellfish (e.g. copepods and trematodes) may not always cause epidemic diseases or severe threats to the population. They can be undesirable in aquaculture for aesthetic reasons, but if not harmful to the target species they can be considered as part of the natural ecological species community in restoration. In other cases, trematodes have been documented to cause substantial oyster mortality (Hine and Jones 1994).

TECHNIQUES FOR ADDRESSING SPECIFIC ECOSYSTEM SERVICES

Ecosystem services can often be used to set restoration objectives. If restoration projects address a specific set of ecosystem services, the approach, technique and scale need to be adapted accordingly, for example for:

- **Shoreline protection/living shoreline:** Reefs are constructed in intertidal areas. Ideally, they enforce marsh grass habitats, are a link to sublittoral habitats and will grow with sea-level rise. Construction needs to withstand higher wave energy compared to sublittoral sites. Shellfish/target species needs to be adapted to the intertidal areas.
- **Filtration capacity/water quality:** For maximum filtration rates, reefs are constructed in sublittoral areas. The volume of water cleared per oyster depends on species, size, sediment load, temperature, salinity and time submerged (zu Ermgassen *et al.* 2016). Nitrogen removal and carbon sequestration are additional gains. For further information see https://oceanwealth.org/tools/oyster-calculator.
- **Biodiversity/fish enhancement:** Reefs are constructed as complex three-dimensional habitats to maximise structure and area for invertebrates and fish to settle, to hide, to find food, and to spawn. For further information on quantities of fish increase per area of restored reef in the USA, see https://oceanwealth.org/tools/oyster-calculator.
- **Oyster fishery/harvesting:** Reefs are constructed in substrate-limited areas, e.g. by providing suitable substrate/cultch for successful recruitment. Oyster harvesting will mean substrate/cultch has to be renewed on a regular basis.

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CHAPTER 6
SCALING UP SHELLFISH REEF RESTORATION

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KEY POINTS

- **Scaling from a proof-of-concept and testing scale requires increased attention to all facets of the project.**
- **The project management process will likely start with developing a system-wide restoration plan.**
- **Restoration plans should include both social and ecological mapping with site suitability assessments, area targets and social license required to proceed.**
- **Logistics and mechanisation to operate at scale need to be considered, and include: increasing hatchery capacity, identifying, sourcing and transporting substrate for reef base construction, and deployment of both reef material and seed.**
- **Project management capacity becomes increasingly critical with scale and includes logistics oversight, legal review, contracting, outreach and communication and public engagement.**
- **The restoration plan should lead to a monitoring plan.**
- **It is also beneficial for large-scale projects to include an economic analysis to demonstrate the return on the investment in restoration.**
- **Opportunities need to be created for community members, government, industry and corporate partners to be involved in projects.**

INTRODUCTION

Shellfish restoration has grown from small-scale, often community-based, projects that commonly ranged from only a few square meters to operations a few hundred square meters in size. Smaller scale projects were critical for providing 'proof of concept' experiments to test methods and approaches for restoration, and still have their place in new geographies and where new species or methods are being tested, as described in previous chapters (see also zu Ermgassen *et al.* 2016). These projects are important precursors to larger-scale projects that are needed to respond to the scale of loss documented in many parts of the world. The reduction of shellfish reefs has been among the most extreme of any habitat type with remaining shellfish reef ecosystems generally below 10%, and all too commonly below 1%, of historic levels (e.g. Beck *et al.* 2011). Whatever the specific aims of the restoration project (ecosystem services or biodiversity) it is likely that, to be impactful at a system wide level, the restoration will need to be scaled to more realistically match the level of habitat loss. Larger scale projects not only increase the level of the services provided (Bersoza Hernández *et al.* 2018), but the greater the change in the service provided the easier it is to measure and to generate an appreciation for the benefits gained through the restoration.

Previous chapters have outlined the critical early considerations of making the case for restoration, attracting finance, and undertaking the pre-planning and feasibility assessments. Such assessments include the critical component of identifying conflicts, partners and their roles, biosecurity and permitting and addressing the key threats and knowledge gaps. While these are considerations common to all restoration projects, the preliminary work becomes a critical foundation as larger projects become increasingly more complicated and expensive, and demanding of coordination, attention to project logistics and general project management. There are inevitably many tasks to be undertaken, often by contractors and partners, that all need to be coordinated and appropriately sequenced, within strict timeframes. Delays can mean equipment is lying idle, an expensive proposition if that equipment is a barge that costs several thousand dollars, pounds or euros per day.

With larger and more costly projects come more complex legal considerations, including appropriate contracting and financial reporting mechanisms, labour laws, health and environmental safety considerations. Even in the USA, where restoration of shellfish habitat has a longer history, restoring at scales of tens to hundreds of hectares is still uncommon in most jurisdictions. While this means that there is likely to be little experience readily available for this scale of shellfish restoration, considerable experience in the management of other types of large and complex projects is nearly always available and transferable.

The task of scaling shellfish reef restoration is one of marrying 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 and public awareness. Large-scale projects of around 20 ha from Port Phillip Bay and Gulf St Vincent, Australia, and over 100 ha in Harris Creek in the Chesapeake Bay, USA, highlight many of these foundational elements and the following case studies are used to illustrate their application.

Importantly in recent years, practitioners have learnt that having clear project goals, a monitoring program and a reference ecosystems or models from which understanding of ecosystem attributes and function can be derived and physical targets set are critical factors of large-scale success. Throughout this guide, we reference the SER Guidelines (Gann *et al.* 2019) as providing the underlying principles on which to model large-scale restoration.

Deployment of Wilson Spit shellfish reef, Port Phillip Bay, Australia. Photo: Simon Branigan.

CASE STUDY: PORT PHILLIP BAY, AUSTRALIA

BACKGROUND

Port Phillip Bay is a large marine bay situated in the state of Victoria, southern Australia and covers an area of 1,950 km^2, with the cities of Melbourne and Geelong fringing a large part of the shoreline (Figure 6.1). Subtidal flat oyster (*Ostrea angasi*) and blue mussel (*Mytilus edulis galloprovinicialis*) reefs were once a dominant feature of Port Phillip Bay's marine environment, however, historical overfishing, compounded by poor water quality and increased sedimentation, has led to the collapse of these reefs (Ford and Hamer 2016). Port Phillip Bay is now both substrate and recruitment limited but still supports low populations of native oysters and mussels.

All these ecological characteristics contribute to a reconstruction approach being required in Port Phillip Bay (see Chapter 5 and below).

In 2014, a long-term project to restore the lost shellfish reefs of Port Phillip Bay was launched, bringing together a unique foundation partnership between The Nature Conservancy, the Victorian Government and Albert Park Yachting and Angling Club (APYAC) and has grown to include many other partners (see also Box 6.1). This project was initiated because APYAC members experienced a marked decline in the catch of their favourite target fish species, snapper (*Chrysophrys auratus*), at their local shellfish reefs, one of which was Margaret's Reef, through the 1980s and 1990s.

Alarmed by the loss of Margaret's and many other reefs through overharvesting and the implications for the wider health of the bay, club members initiated a feasibility study, which was led by the Victorian fisheries department (Hamer *et al.* 2013). This study assessed the historical loss and previous extent of shellfish reefs in Port Phillip Bay through a literature review, fishery catch records and interviews with fishers. The study also appraised the key threats to restoration, the level of support amongst fishers, permitting requirements and site selection.

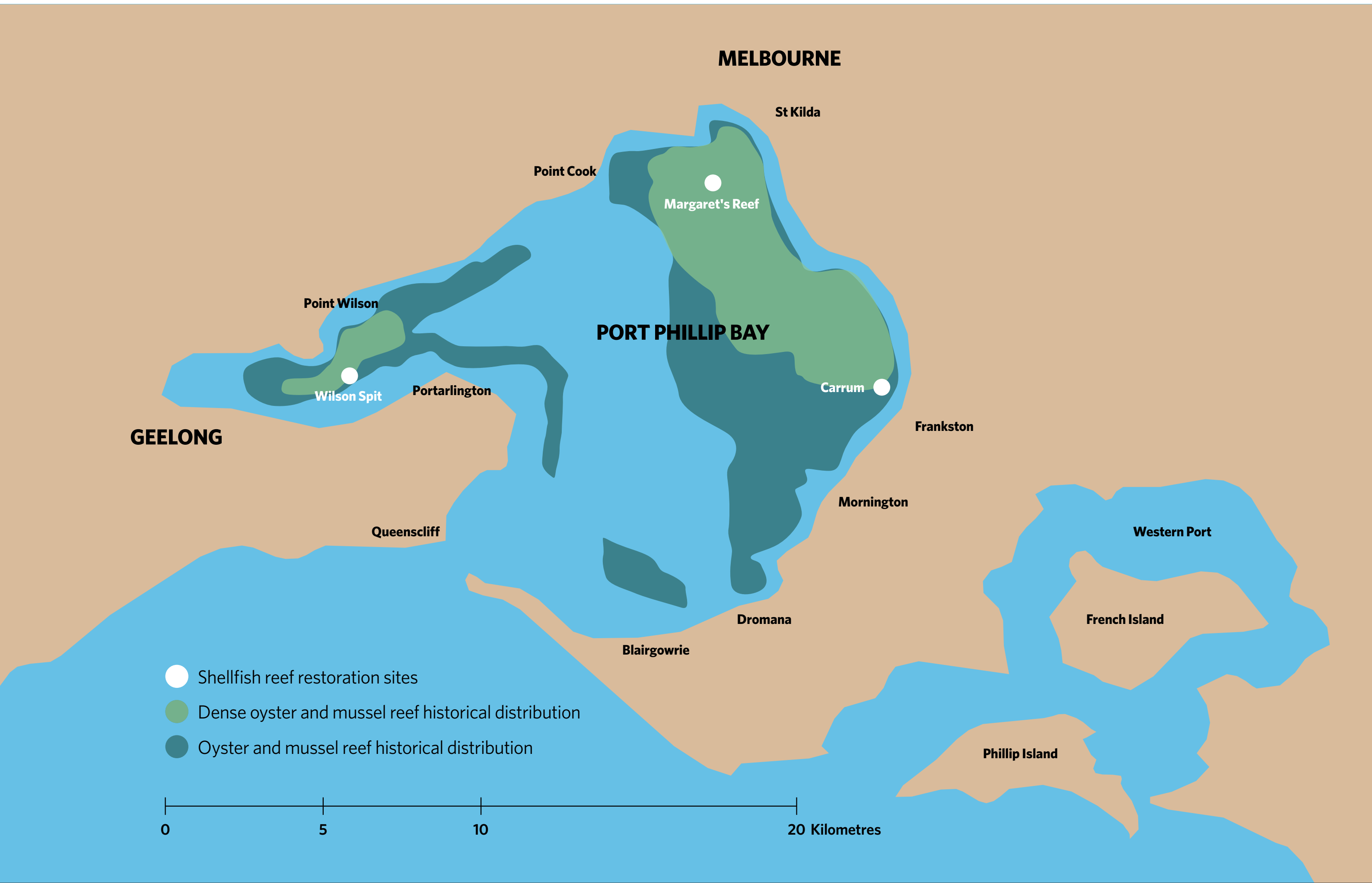

Figure 6.1: Map of Port Phillip Bay including historical shellfish reef distribution and restoration sites (adapted from Ford and Hamer 2016).

STAGE 1: PILOT PROJECT

Based on the results of the feasibility study, and once the necessary permits were secured and co-funding arranged with the foundation partners, a pilot project was instigated in collaboration with the University of Melbourne. This first stage was a small-scale trial at two locations in Port Phillip Bay, to assist in determining optimal restoration methods. The restoration techniques were essentially imported from the USA to test but tailored to local conditions.

The pilot, involving both oysters and mussels, resulted in a number of findings, including substantiating that elevating oysters off the seafloor with shells or limestone rubble improved survival and growth. The age of oysters deployed (i.e. spat-on-shell grown in the Victorian Shellfish Hatchery) influenced survival, but this differed between sites. Size and depth of the reef base was found to be an important factor to reduce edge effect, predation, sedimentation and movement from storms. The initial mussel reef trial did not use any substrate for elevation, rather deploying mussels at different densities, which resulted in generally limited survival.

SCALING UP

The lessons learnt from the pilot were then applied to Stage 2 – a medium scale, 2.5-hectare reef restoration project in Port Phillip Bay. As the size of the project increased, the project management tasks also amplified. These have included, for example: contractor procurement; sourcing reef base material (e.g. recycled shells, quarried limestone); drafting of contracts; redefining restoration targets, indicators and benchmarks; a monitoring and evaluation plan; and, securing additional permits.

Locating a suitable site for loading reef base materials onto the deployment vessels (e.g. barge or multipurpose vessel) is one task that proved to be difficult and should be considered early in the planning process to avoid it becoming a bottleneck. Another potential bottleneck is hatchery capacity. Port Phillip Bay has the advantage of a hatchery close to the restoration sites, whose personnel are experienced in growing oysters and mussels and continue to innovate to achieve results at the increased scale.

Stage 2 of the project involved two 'phases' and continued to test restoration approaches. While Phase 1 used limestone rubble for reef bases (~300 m^2 per patch reefs) seeded with spat-on-shell grown on longlines before deployment, Phase 2 tested different composites of limestone rubble and recycled shell for reef bases (300 to 400m^2 patch reefs), with spat-on-shell deployed direct from the hatchery (Figure 6.2). Overall, using a combination of limestone and recycled shell as the reef base and deploying oysters direct from the hatchery was found to be the most cost-effective approach, whilst continuing to achieve high survival (>70%) and growth of shellfish and biodiversity targets (The Nature Conservancy 2018). Planning is currently underway for Phase 3, a further 20-hectare plus scale-up of shellfish reef restoration in Port Phillip Bay.

BOX 6.1: COMMUNITY SUPPORT

Community support and involvement in the Port Phillip Bay project has been instrumental to the outcomes since inception. This support has been facilitated through establishing the 'Shuck Don't Chuck' shell recycling initiative and the 'Restore The Bay Network'. Both initiatives have created opportunities for business and community volunteers to be involved in the project in a practical and meaningful way.

With Shuck Don't Chuck, shells are recycled from hospitality venues and seafood wholesales to use in the shellfish reef restoration process (see Chapter 4). Similar to the restoration works, Shuck Don't Chuck was started as a pilot, then scaled up once all the necessary logistics were in place. This initiative has been embraced by the many partners now involved and been popular in media, helping to lift the profile of shellfish reef restoration in Australia.

The Restore The Bay Network is the volunteer arm to the project and provides community members (e.g. marine care, dive and recreational fishing groups), government, industry and corporate partners, with opportunities to contribute to restoration activities. These activities include, for example, OysterWatch (i.e. deploying and monitoring settlement plates – see Chapter 5), shell cleaning for the Victorian Shellfish Hatchery to produce cultched seed (see Chapter 5) and measuring individual shellfish (see Chapter 7). This network also provides an effective way to communicate about the project through information sessions and eNewsletters (see Chapter 9).

Figure 6.2: Shellfish reef construction at Margaret's Reef, Port Phillip Bay. Photo: Anita Nedosyko.

The results from the trials of different restoration techniques in Port Phillip Bay have subsequently informed the approach to the Windara Reef project in Gulf St Vincent, South Australia, which used the lessons learned to install the first project at a scale of 20 hectares (see Box 2.2). While the ecosystem service objectives (e.g. fish production) and restoration techniques were analogous between the Victorian and South Australian projects, important considerations for the funding and outcomes of the Windara Reef project were job creation and economic stimulus (Edwards *et al*. 2013).

Both are important considerations for larger projects, with the potential to access funding not traditionally associated with conservation. Information derived from the project included a cost benefit analysis of the restoration, a powerful justification for the funding of conservation at larger scales (Rogers *et al.* 2018).

More information on the Windara Reef and Port Phillip Bay projects is available at www.natureaustralia.org.au.

BACKGROUND

Chesapeake Bay, the largest estuary in the USA, is located near the Atlantic coast of Maryland and Virginia. The Chesapeake Bay's eastern oyster (*Crassostrea virginica*) population is estimated to be just one percent of historic levels (Newell 1988). Restoration has been developing in Chesapeake Bay for several decades, but in recent years two polices have been driving larger-scale, coordinated restoration: the 2009 Presidential Executive Order 13508, and the 2014 Chesapeake Bay Watershed Agreement signed by the governors of Chesapeake Bay watershed states and the US federal government. These call for restoring oysters in ten Chesapeake Bay tributaries by 2025.

These aspirational goals have raised the practical question of what constitutes 'restored', and/or, how much is enough? The implicit goal of oyster reef restoration at the tributary-level is to dramatically increase oyster populations and recover a substantial portion of the ecosystem functions once provided by these reefs within the tributary. To achieve restoration at this scale requires setting objectives against which to measure success.

KEY OBJECTIVES

A team of scientists and resource managers collaboratively developed both reef-level and tributary-level oyster restoration success metrics for the Chesapeake Bay. Commonly called 'Chesapeake Bay Oyster Metrics' (Oyster Metrics Working Group 2011), these were written specifically for the policy goal of restoring oyster populations in ten Chesapeake Bay tributaries.

The idea was to answer the questions, 'What constitutes a successfully restored oyster reef?', and 'How many successful reefs are needed to consider a tributary successfully restored?'.

At the reef scale, Chesapeake Bay Oyster Metrics defines a successfully restored reef as one that, six years post-restoration, meets the following criteria:

- oyster density: minimum threshold = 15 oysters per m^2; target = 50 oysters per m^2
- oyster biomass: minimum threshold = 15 grams dry weight per m^2; target = 50 grams dry weight per m^2
- multiple age classes: success = two or more
- shell budget: success = stable or increasing
- reef height and reef footprint: success = stable or increasing.

Once these criteria were established, reefs could be planned, built, and monitored relative to the criteria.

At the tributary scale, the Chesapeake Bay Oyster Metrics document recognises that not all of a tributary is suitable for reef construction, and that the entire tributary bottom was never historically covered in reefs. Tributary-level restoration was therefore defined as having >50% of the restorable bottom (present-day hard bottom) meeting the reef-level criteria. Additionally, the restored reefs should constitute at least 8% of the tributary's estimated historic reef area.

SCALING UP

Harris Creek was selected as the first of the ten tributaries for large-scale oyster restoration. Harris Creek is a 1,829-hectare oyster sanctuary (oyster non-harvest area) on Maryland's eastern shore of Chesapeake Bay. The Creek was historically known as a good oyster harvest area, but by the early 2000s was characterised by both limited oyster recruitment and reef structure. Partners from state and federal government and local NGOs collaboratively developed a restoration plan for the estuary (Maryland Oyster Inter-agency Working Group 2012). They initially compiled spatial information such as water quality data, sonar-derived benthic habitat characterisations, oyster population surveys, and bathymetric surveys to determine where on the river to construct oyster reefs. Areas with water quality suitable to sustain oyster populations, hard benthic habitat, in water depth 1.2 to 6 meters, and away from docks, navigational channels and aids to navigation were considered suitable for reef construction.

Two treatment types were planned (Figure 6.3):

- An assisted regeneration approach (see Chapter 5) using seed only, where spat-on-shell was planted directly onto the remnants of an existing shell reef (62 ha); and,
- A reconstruction approach (see Chapter 5) using substrate + seed, where a substrate base was constructed prior to planting with spat-on-shell (80 ha). This treatment was used where very little remnant reef remained. Substrate bases were constructed from stone or a mixture of conch, clam, and whelk shells.

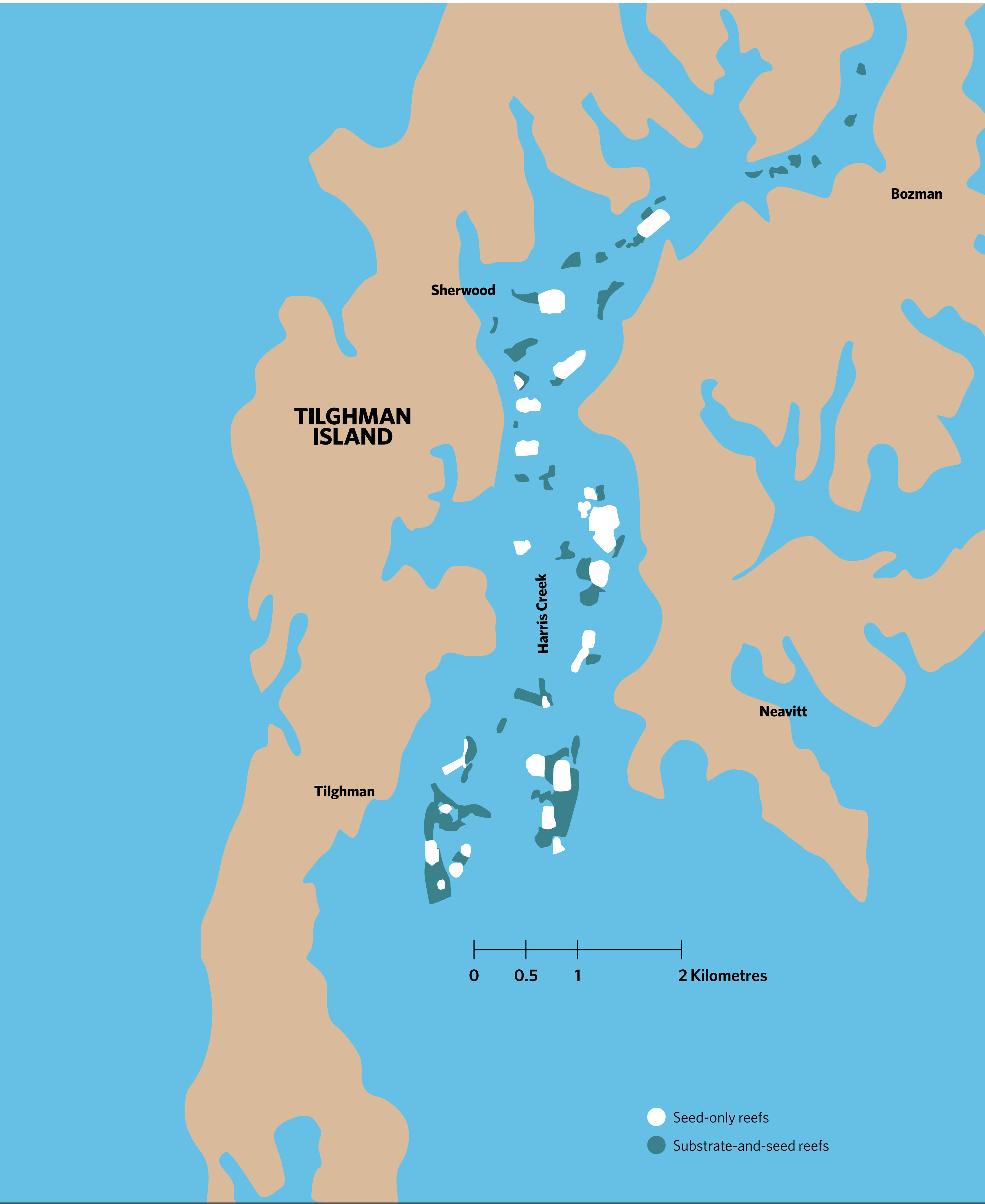

Figure 6.3: Map of Harris Creek indicating areas restored using substrate and those using spat-on-shell only.

Between 2011 and 2015, a network of reefs was constructed totalling 142 hectares. Primary funders were two U.S. government agencies (U.S. Army Corps of Engineers and the National Oceanic and Atmospheric Administration) and the state government of Maryland. Reefs were seeded primarily using spat-on-shell produced by the University of Maryland's Horn Point Oyster Hatchery. Seed was typically planted at a density of 12.5 million seed per hectare. The in-water reef construction cost was US$28.56 million, with over 200,000 m^3 of substrate added to create reefs between 0.15 m and 0.3 m high and seeded with >2 billion spat-on-shell.

For Harris Creek (and two nearby sites – the Tred Avon and Little Choptank estuaries) the proximity of the shell cleaning, hatchery and remote setting jetty developed to allow mechanised loading of spat-on-shell directly to a boat re-fitted for shell deployment, addressed several of the logistical considerations associated with operating at this scale.

RESULTS

By the end of the 2017 monitoring, 98% of Harris Creek reefs met the minimum 'threshold' success criteria for oyster biomass and density, and 75% met the higher 'target' criteria. The general methodology used in Harris Creek is now being used in the remaining nine tributaries slated for large-scale oyster restoration throughout Chesapeake Bay. Each reef was monitored three years post-restoration and will be monitored again six years post restoration. One surprising result was that reefs constructed using a stone-substrate base (Figure 6.4) averaged four times more oysters than reefs built using a shell-substrate base (NOAA 2018).

Modelling estimates that the restored reefs in Harris Creek can annually remove over 46,650 kg of nitrogen and 2,140 kg of phosphorous, an ecosystem service conservatively estimated at US$3 million annually (Kellogg *et al.* 2018). Additional modelling results predict that, relative to unrestored conditions, blue crab (*Callinectes sapidus*) harvest would increase by more than 150% when these reefs and other restored reefs in the nearby Tred Avon River and Little Choptank River mature; this harvest increase alone would contribute to an additional estimated dockside annual sales value of US$11 million yr^{-1} (Knoche *et al.* 2018). The same study (Knoche *et al*. 2018) predicts a total increase in regional economic impact for commercial fisheries of US$23 million yr^{-1} (direct + indirect + induced effects).

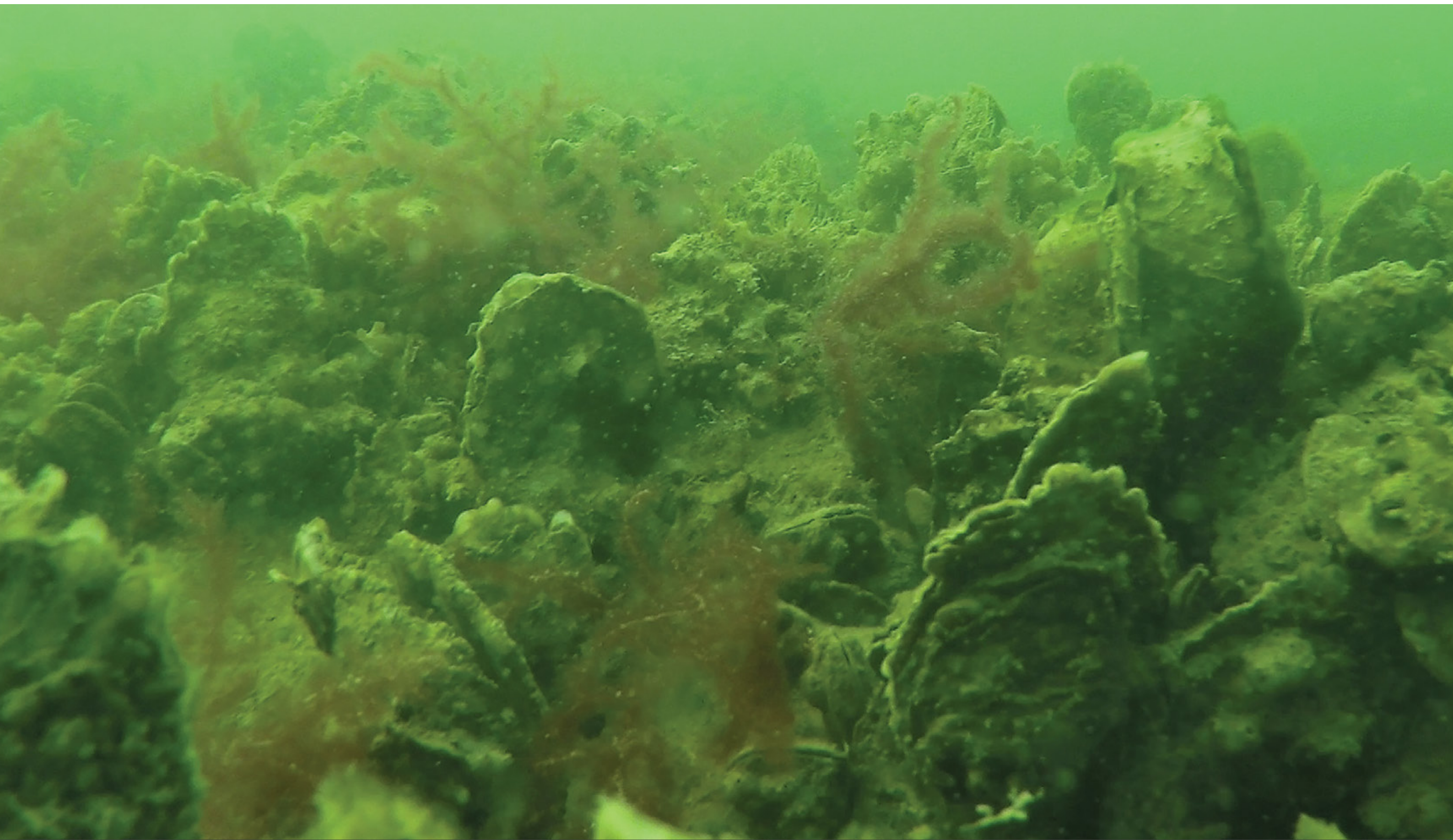

Figure 6.4: Restored *Crassostrea virginica* shellfish reef constructed with stone substrate in Harris Creek, MD, USA. Photo: NOAA Chesapeake Bay Office.

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CHAPTER 7
WHY MONITOR SHELLFISH REEFS?

Bryan M. DeAngelis and Laura Geselbracht

KEY POINTS

- **Restoration projects need to be monitored to evaluate outcomes at the project level, as well as monitored in a way that allows for comparison of results across projects.**
- **A set of minimum universal metrics and environmental variables have been created for oysters in the USA that are meant to be measured on every project, regardless of restoration objectives. These can serve as guides for other reef-forming shellfish reef restoration projects.**
- **Restoration goal-based monitoring, while more difficult to implement, can assess the delivery of one or more ecosystem-services provided by the restoration project, can inform monitoring for adaptive management, and inform other predictive ecosystem service models.**

INTRODUCTION

A primary motivation for restoration is to improve or enhance degraded habitat towards some reference condition, defined through a reference ecosystem or model (see Chapter 3). An assumption is that the restored ecosystem will return benefits to people and nature. Shellfish reef restoration is typically undertaken to accomplish one or more of several main objectives (described in Chapter 2; Coen *et al*. 2007; Grabowski and Peterson 2007; and others). To know if the restoration projects are achieving their intended outcomes, projects need to be monitored to evaluate outcomes at the project level, as well as monitored in a way that allows for comparison of results across projects (Figure 7.1).

Comparison across projects is important to assess programmatic and/or landscape level outcomes and to determine the variability of restoration impacts across multiple restoration sites. Too often, restored reefs have not been monitored to an extent that allows for comparison (Kennedy *et al*. 2011; La Peyre *et al.* 2014). When restoration practitioners implement systematic pre- and post-restoration monitoring, project outcomes can be evaluated against expectations and project objectives. Importantly, project outcomes can be evaluated across multiple locations, enabling improvements to restoration methods and addressing research questions that apply across broader spatial scales.

Recently, The National Academies of Sciences, Engineering and Medicine (2017) provided guidance and identified the best approaches for monitoring and evaluating restoration activities in the Gulf of Mexico, including the eastern oyster (*Crassostrea virginica)*. While the ecosystems reviewed in that report are Gulf of Mexico-focused, the overall guidance on monitoring approaches is highly applicable to shellfish reef restoration world-wide. Furthermore, Baggett *et al*. (2014, 2015) published a review and practitioner's handbooks (expanding on previous efforts) on oyster restoration monitoring, including specific recommendations for the eastern oyster and Olympia oyster (*Ostrea lurida*). The fundamental concepts of monitoring shellfish reef restoration are summarised from these two primary publications, and are critical for practitioners to be aware of.

Figure 7.1: Monitoring of Palmetto Plantation shellfish reef restoration site in South Carolina, USA. Photo: Joy Brown.

RESTORATION OBJECTIVES AND PERFORMANCE METRICS

A critical, but surprisingly often over-looked step of any restoration project is first identifying clear objectives of the restoration project. Clear objectives should be determined before any active restoration happens. As described in Chapter 3, clearly defining the restoration objectives provides several benefits to the restoration project and guides the monitoring of the project. Firstly, it forces project managers to sharpen their thinking about what the active restoration is seeking to accomplish, and the desired state of the restored ecosystem. Second, it helps decide on the most effective indicators, or metrics, to monitor the restoration activities, often called performance criteria, derived from reference ecosystems or models. Understanding the metrics and performance criteria provides direction for the appropriate type of monitoring. Lastly, clear restoration objectives allow for a measure of restoration success, as well as informs how to adaptively manage restoration to improve outcomes.

THREE TYPES OF MONITORING

As described above, monitoring is conducted to achieve multiple purposes. The type of monitoring performed should inform one or more of the following monitoring types. The first type of monitoring is **implementation monitoring**. Implementation monitoring assesses whether the management actions for restoration were implemented as designed and planned. Implementation monitoring is a straightforward assessment of whether the restoration that was designed and planned was carried-out and accomplished. The second type of monitoring is **performance monitoring**. Performance monitoring is used to determine whether the restoration activities are having the desired habitat response, such as a change in overall shellfish recruitment, biomass, or another population-level parameter towards the trajectory of the reference ecosystem or model.

Palmetto Plantation Annual Monitoring. Photo: The Nature Conservancy.

There may also be ecosystem level responses intended by a project such as localised changes in fish biomass or water quality. Performance monitoring requires development of clearly articulated objectives and identification of informative indicators as outlined in Chapter 3. Lastly, **monitoring for adaptive management** is meant to inform restoration management and improve the design of future restoration efforts. Systematic monitoring using standardised 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.

MINIMUM UNIVERSAL METRICS FOR ALL SHELLFISH REEF RESTORATION PROJECTS

Regardless of the restoration objectives, every project should sample the same set of minimum **universal metrics** to assess the basic performance of the restoration project. While no universal metrics exist that cover all reef-forming shellfish species, Baggett *et al.* (2014, 2015) published minimum universal metrics for eastern and Olympia oysters, which can serve as a guide for other reef-forming shellfish species (see Table 7.1). Sampling of such universal metrics allows for the basic performance of each reef to be assessed through time, while also allowing for comparisons with other projects. Sampling of universal environmental variables (water temperature, salinity and dissolved oxygen, tidal emersion) also provides valuable information that can aid in the interpretation of data collected during reef monitoring activities (Baggett *et al.* 2014, 2015; Walles *et al.* 2016).

To ensure a systematic approach to monitoring of the universal metrics, shellfish reef restoration practitioners should incorporate similar methods for assessing impact, sampling methods, sampling frequency and sampling duration (as described in Baggett *et al.* 2014, 2015; Table 7.1).

RESTORATION GOAL-BASED METRICS

As described earlier, shellfish reef restoration projects are implemented with the intent of delivering specific benefits for nature (e.g., increased biodiversity, habitat enhancement for fish and crabs, or removal of excess nitrogen) and/or for people (e.g., enhanced fishing opportunities). The restoration project can assess the delivery of these benefits by developing one or more goal-based metrics to monitor (see examples in Baggett *et al*. 2014, 2015 and The National Academies of Sciences, Engineering and Medicine 2017). Monitoring for goal-based metrics is typically more complicated and requires additional capacity and expertise to ensure that useful, scientifically rigorous information is gathered that enables evaluation of these services being delivered by the project, as well as improvements to design and implementation of future restoration projects. Following restoration activities, the expected benefits may take a very long time to develop (decades in some instances) and depend on environmental drivers operating at scales well beyond the project boundaries and duration. Support for long-term monitoring can be difficult to secure given the priorities and budget constraints of funders and restoration programs. It may be unrealistic to expect every project to monitor an extensive number of performance metrics that require extensive field ecology experience and expertise, or performance metrics that are likely to require several years to show observable results. However, in some cases, particularly when the restoration response cannot be predicted ahead of time, restoration goal-based monitoring can inform monitoring for adaptive management. If the practitioner identifies a structured adaptive management process (e.g. a predictive ecosystem service model, management decision or restoration question) by which to incorporate their monitoring data into, that restoration project can substantially contribute to improving the effectiveness of restoration, by helping reduce uncertainties and enhance ongoing or future restoration decision making.

CITIZEN SCIENCE

Well-managed citizen science programs can alleviate some of the financial and staffing burdens of monitoring and can provide valuable public engagement. When citizen scientists have been trained and involved in conducting monitoring using the minimum universal metrics outlined in Baggett *et al.* 2014, 2015 (such as measuring reef dimensions and height, number and size of shellfish, and enumerating live versus dead shellfish) citizen scientists help with elucidating performance of projects (Figure 7.2). They can also serve as effective project ambassadors in their communities and help to build support for restoration projects (DeAngelis *et al.* 2018). Several examples of citizen science programs exist in the USA (for example, see the Charlotte Harbor National Estuary Program's Volunteer Oyster Habitat Monitoring Manual for additional information: http://www.chnep.org/publications).

Figure 7.2: Citizen scientists assisting in measuring shellfish at Warmies Boat Ramp, Port Phillip Bay, Australia. Photo: The Nature Conservancy.

Table 7.1: Universal metrics for measuring restoration of shellfish reefs (adapted from Baggett *et al.* 2014, 2015). The specific target or performance criteria should be developed from the reference ecosystem or model. dGPS = differential Global Positioning System

METRIC	METHODS	UNITS	FREQUENCY	PERFORMANCE CRITERIA
Reef areal dimension				
Project footprint	Measure maximal aerial extent of reef using dGPS, surveyor's measuring wheel or transect tape, or aerial imagery; subtidal, use sonar or SCUBA.	m^2	Preconstruction, within 3 months postconstruction, minimum 1-2 years postconstruction; preferably 4-6 years. After events that could alter reef area.	None
Reef area	Measure area of each patch reef using dGPS, surveyor's measuring wheel or transect tape, or aerial imagery; subtidal, use sonar or depth finder with ground truthing. Sum all patches to get total reef area.	m^2	Preconstruction, within 3 months postconstruction, minimum 1-2 years postconstruction; preferably 4-6 years. After events that could alter reef area.	None
Reef height	Measure using graduated rod and transit, or survey equipment; subtidal, use sonar or depth finder.	m	Preconstruction, within 3 months postconstruction, minimum 1-2 years postconstruction; preferably 4-6 years. After events that could alter reef area.	Positive or neutral change
Oyster density	Utlise quadrats. Collect substrate to depth necessary to obtain all live oysters within quadrat, and enumerate live oysters, including recruits. If project involved the use of see oysters, enumerate all seed oysters present in quadrat.	individuals/ m^2	Immediately after deployment if using seed oysters. Otherwise, annually at the end of oyster growing season (will vary by region), 1-2 years at minimum; preferably 4-6 years.	Based on short- and long-term goals developed using available regional and project-type data, as well as current and/ or historical local/ regional densities.
Size-frequency distribution	Measure shell height of at least 50 live oysters per oyster density sample.	mm (size), number or % per bin (size dist.)	Annually at the end of oyster growing season (will vary by region) in conjunction with oyster density sampling, at a minimum.	None

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CHAPTER 8
SHELLFISH REEF RESTORATION: BEYOND OYSTER REEFS

Andrew Jeffs and Philine zu Ermgassen

KEY POINTS

- **Restoration of mussels and other reef building shellfish species offer similar benefits to those of oyster reef restoration.**
- **Juvenile and adult mussels are more mobile than oysters, which often alters the manner in which restoration is best undertaken.**
- **Juvenile mussels may have different habitat requirements from the adults, and needs to be considered in mussel reef restoration efforts.**
- **Monitoring should be long term in order to account for interannual variability in recruitment and survival.**

INTRODUCTION

Much of the shellfish reef restoration activity to date has been focussed on oysters. However, 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, but they often differ from oysters with regards to their life history (Figure 8.1), especially in terms of varying habitat requirements throughout their development. Consequently, these habitat-building shellfish species often require different approaches to those used for oysters to achieve successful restoration.

Restored mussel reef, East of Waheke Island, New Zealand. Photo: Shaun Lee.

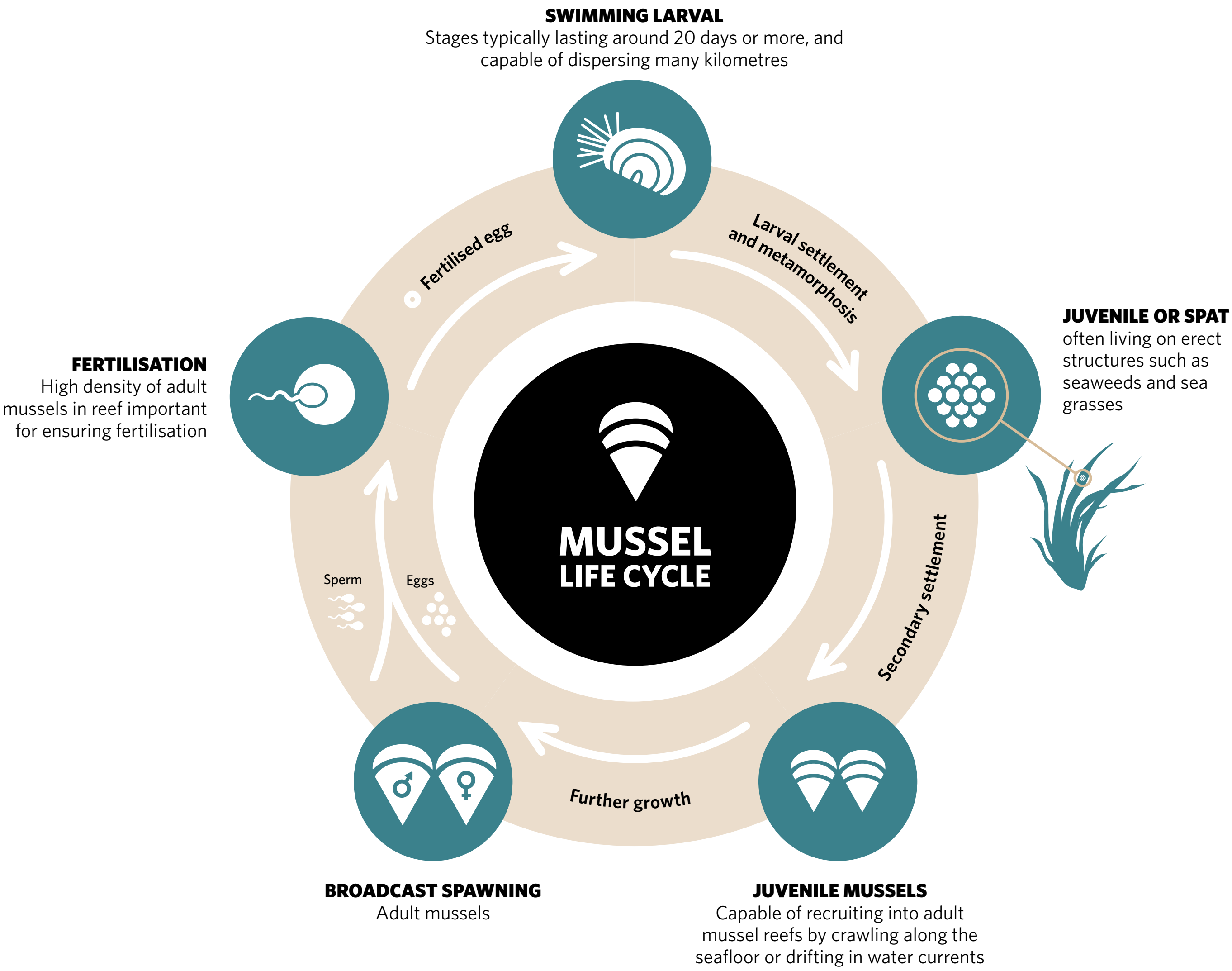


Figure 8.1: Mussel life cycle

Like oysters, many populations of these shellfish have been greatly diminished, most often as a result of a combination of over-harvesting and various types of environmental degradation including pollution, sedimentation, destructive fishing practices (such as seafloor dredging), and the loss of natural larval settlement habitats.

Therefore, the potential for the successful restoration of populations of these shellfish species often relies primarily on identifying and managing the threats and environmental degradation that limit the establishment or recovery of shellfish reefs.

IDENTIFYING AND MANAGING THREATS

As with oyster reef restoration, it follows then that the initial critical step for restoring mussel reefs is to identify the cause of decline. The subsequent removal or reduction of the threat(s) will allow for successful restoration to proceed; and, on occasion, this will be sufficient in itself for successfully restoring mussel reefs. In the case of intertidal reefs of blue mussels (*Mytilus edulis*) in the Dutch Wadden Sea, numerous active restoration projects involving the placement of seed or adult mussels without firstly dealing with the threats to the mussels, had limited and often low success (de Paoli *et al*. 2015).

In contrast, the identification and subsequent protection of cockle beds from harvesting, restored an important settlement and nursery habitat for juvenile mussels which ultimately resulted in the large-scale, and far less costly, recovery of mussel reefs (Dankers *et al.* 2001).

ASSEMBLING APPROPRIATE KNOWLEDGE

Where removing the threat is insufficient by itself to stimulate ecosystem recovery, other interventions may be necessary. Mussels, like oysters, may become substrate or recruitment limited following population-level declines and require addition of settlement habitat, or enhancement of spawning stock, or both.

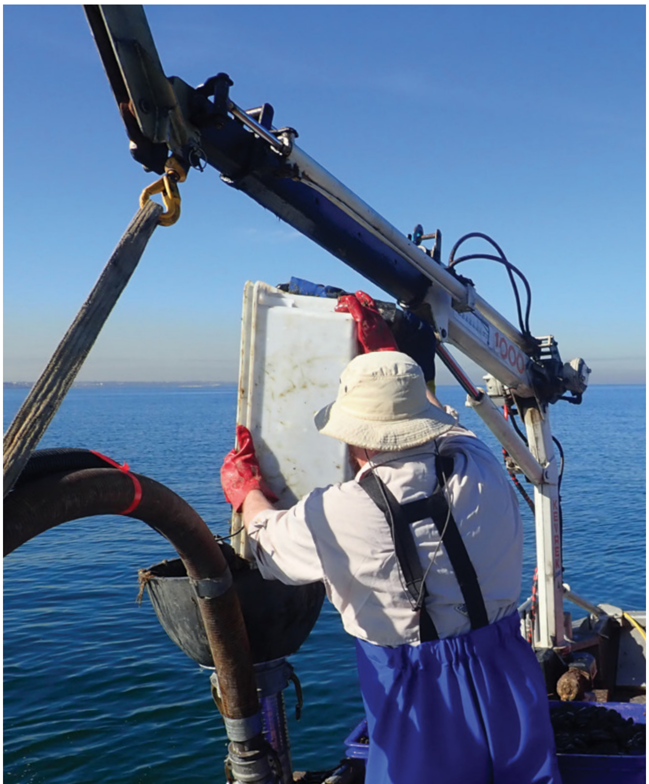
However, relative to oysters, there are some key knowledge gaps surrounding the re-establishment of mussel reefs in the wild.

- Knowledge of the lifecycle can be particularly important for developing effective mussel restoration measures because many mussel species have larval settlement and juvenile phases with different habitat requirements to the adult phase (Figure 8.1). 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 whilst they become established. 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.
- Knowledge of critical habitats for supporting the completion of the lifecycle is also often important to successful restoration of mussel reefs. For example, the loss of settlement and nursery habitats may be a common cause for the decline or disappearance of mussel reefs due to the lack of a ready supply of recruits. In such situations, successful mussel reef restoration may rely on the rehabilitation of the mussel settlement and nursery habitat, such as beds of seaweeds and seagrasses, which are also frequently impacted by human activities in coastal waters.
- Knowledge of the spatial arrangement of critical habitats and the corresponding movement abilities of various stages of the lifecycle of mussels are also important in achieving successful restoration of mussel reef habitat. While determining the suitability of settlement substrates is a vital prerequisite for establishing ongoing recruitment into a restored mussel reef, the location of the settlement substrate relative to the adults is critical to ensure the juveniles are able to migrate and recruit into the adult mussel reef. The juveniles of many mussel species are highly mobile, capable of migrating from their initial larval settlement site by crawling across the seafloor or by passive drifting in water currents over longer distances. In this regard, restoration in locations of historical mussel reefs are likely to be more successful as these spatial prerequisites to allow migration of juveniles from larval settlement sites into adult populations are most likely to be already in place.

TECHNIQUES

Once causal factors have been addressed, a range of treatment options can be applied, selected to suit the level of degradation at the site. Where enhancing larval settlement through the addition of substrate is insufficient to stimulate the recovery of mussel reefs, the addition of adult or post-settlement individuals for expanding adult reefs may be appropriate to increase the size of broodstock populations. Compared with the sedentary nature of oysters, mussels are highly mobile, which results in key differences in terms of approaches to restoration. For example, the deployment of juvenile mussels to restoration sites may require the use of biodegradable socking or netting to prevent them from moving whilst they become established.

Likewise, loads of live adult mussels can be dropped overboard from a vessel in a suitable location and once they settle onto the seafloor they will move around, orientate themselves so they can feed, and then attach to one another using byssus threads to form the basis of a fully functioning mussel reef (Figure 8.2). This also means that, unlike oysters, mussel restoration can take place in the absence of hard structures, such as oyster cultch, as the adult mussels can develop a stable carpet-like reef structure on top of the seafloor sediment by anchoring to one another. The ability of contiguous mussel reefs to stabilise soft sediments and generate complex structure on the surface of sediments, are major reasons for their ecological importance in providing habitat for other species.



Deploying mussels, Port Phillip Bay, Australia.
Photo: Johno Rudge.

Figure 8.2: Revive Our Gulf volunteers in New Zealand shoveling mussels onto restoration site. Photo: Shaun Lee.

LEARNING FROM RESTOCKING AND STOCK ENHANCEMENT

Many mussel species are fished because they are recognised as an excellent food source and they usually occur in concentrations (mussel reefs) in shallow coastal waters. This can make them vulnerable to overharvesting. While this can be problematic in some restoration scenarios, it can also provide the impetus for communities to restore mussel reefs. Restoration of shellfish populations, including mussels, for the purpose of restoring or improving their harvesting has been common practice among coastal populations for centuries and in more recent times generally takes two forms, which are commonly referred to as restocking and stock enhancement.

Restocking normally involves the release of cultured juveniles into the wild in an attempt to restore the spawning biomass of a depleted fishery so that ultimately the increased recruitment will restore harvests. In contrast, stock enhancement is specifically aimed at increasing the harvest from an existing fishery by a range of possible direct interventions, such as artificially enhancing settlement or recruitment (Bell *et al.* 2005).

Although the ultimate aim of restocking and stock enhancement of shellfish populations is different to restoration of shellfish reefs (i.e. increasing harvests versus conservation) the approaches used are often similar. As such, there is substantial knowledge that can be transferred to mussel reef restoration from past commercial restocking and stock enhancement efforts with a variety of shellfish species, including mussels. A number of useful reviews are available that are worthwhile examining more closely for this purpose (see Bell *et al.* 2005).

Some key lessons that can be transferred include the importance of establishing a large enough local population of broodstock to provide a sufficiently large spawning biomass capable of producing adequate self-recruitment to maintain a sustainable or expanding population (Bell *et al.* 2005). Building a sufficiently large broodstock population to meet this requirement may take some considerable effort or an accumulation of mussels from multiple deployments over a number of years. However, defining what constitutes a sufficiently large broodstock is difficult because it will vary with mussel species and for the local context.

MONITORING

Monitoring settlement and recruitment is a particularly important tool for determining changes in the supply of juveniles into restored populations of mussels (see Chapter 7).

Such monitoring needs to be undertaken in a consistent manner over a long term, because most mussels are highly variable in their reproductive output and larval settlement, and consequently this background variability may mask the true impact of restoration efforts in the short term.

Monitoring of established mussel reefs is also a long term endeavour, as mussel reefs appear to frequently undergo quite large natural fluctuations in their extent due to variation in predator numbers and natural events, such as severe storms. The persistence and recovery of mussel reefs after such occurrences are strong indicators of successful mussel reef restoration.

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Deploying settlement plates, Yueng Shui O, Hong Kong. Photo: Lori Cheung.

CHAPTER 9
SUCCESSFUL COMMUNICATION FOR SHELLFISH REEF RESTORATION PROJECTS

Ian McLeod

WHY COMMUNICATE?

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. Effective communication needs to be budgeted for and incorporated directly into the project planning. This section of the report describes the key elements of an effective communication strategy for a shellfish reef restoration project.

COMMUNICATION PLANNING

Planning for successful communication can seem daunting, but a good strategy 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. Often these elements are not clearly defined until a group is faced with building a website or preparing a supporting document for the project. So where do we start?

Build the team – identify the people involved in your project who can assist with communication activities. This could include communication professionals from associated permitting or research institutes. Consider appointing a communications manager to oversee this aspect of the project, and recruiting paid professionals if the budget allows.

Define the audience – write down the most important people for the success of the project in order of importance and make sure these people are prioritised in your communication strategy. Make sure this includes funders, the team, project champions, local stakeholders and potential beneficiaries. Further guidance about how to define the project's audience can be found on the Reef Resilience Network website (http://reefresilience.org/communication).

Work out the key messages – start with the vision for the project. What problems is the project trying to overcome, and what benefits are envisaged? Keep it positive, non-political and based on evidence. Do not forget to mention partners and funders, and do not overstate what can be achieved through the project. Discuss benefits to local people and the economy rather than just ecological benefits as many people care more about the former.

Work out 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 – write down objectives and track the project's success. Objectives should be S.M.A.R.T. (Specific, Measurable, Attainable, Realistic, and Time-bound).

Review the strategy – projects change so make the time to review the strategy and reflect on what has and has not worked well. Make a calendar entry to ensure the strategy is reviewed and renewed at least once per year. Tools such as Google Analytics can be useful to determine what has been the most effective, for example by allowing tracking of posts that lead to visits to the project's website. Also ask the audience directly what they find the most effective. Cull communication methods that are not helping reach the goals and objectives, or be prepared to modify the content being provided to the audiences to increase communication effectiveness.

✔ **PRO-TIP:** Make the effort to engage with potential opponents and be willing to make some modifications to get them on board. One of the most exciting things about shellfish reef restoration projects is that they bring together a diverse group of stakeholders, who may be adversarial in other situations.

Figure 9.1: A shellfish restoration information tent at a harbour regatta day in New Zealand, with a yacht skipper coming by to talk over shellfish reef restoration activities in the nearby harbour. Photo: Andrew Jeffs.

DO THE BASICS

It is tempting to focus on social media or news stories but as most projects rely on the buy-in of just a few people, face to face meetings, phone calls, public forums and visiting local stakeholders, these will often be more useful than thousands of followers on Twitter (Figure 9.1).

Ensure traditional owners and local industry are included early in communication planning as they are key partners and audiences for most projects (McLeod *et al*. 2018). Building websites is no longer a daunting process with many companies offering easy to use templates that can provide a home for the project where anyone can find out the basic details.

Keeping websites up to date, however, can stop being fun after a burst of initial enthusiasm, so consider linking social media accounts to the project's website to keep some new content popping up.

Email and eNewsletters are still a powerful way to communicate with an audience and effort put into building comprehensive distribution lists will be well worth it.

Consider partnering with a research institution and include scientific publications in the project's communication strategy so that lessons learned through the project can be recorded and shared with the scientific community.

Spend some time to generate frequently asked questions and answers about the project. These will provide a great resource for future media coverage and spending time generating these will help the project team get on the front foot with risks and objections. This is an opportunity to address perceived project risks and reduce concerns by providing context and evidence.

TRADITIONAL NEWS AND MEDIA

Local newspapers and similar media can be really important for the project and local journalists can be key project champions, especially if the project includes a lot of local people and offers solutions to local problems. Journalists are generally really busy and often do not know a lot about the context of the project. Providing key messages, photos and video will increase the chance that they will tell your story without misconstruing it. Be cautious about overstating project objectives and expected outcomes. It is tempting to get enthusiastic when speaking with media and overblow the potential outcomes of a project (for example 'this project will clean up the bay'). Better to keep these realistic, but with a positive spin. When speaking with media, think about the key message before the interview, do not get political or off track, and avoid adding too much technical detail.

VISUAL COMMUNICATION

Good visuals are extremely important for getting key messages across to your audience.

Photos and video

Great photos and short videos are powerful ways to share news of the project. Budget for professional photography if possible. However, not every photo needs to be *National Geographic* standard, 'bad' photos are still useful, so take a lot of photos to show the project's progress and the people involved.

Make sure people look (and are) safe and professional in photos and consider using release forms (or use a phone App to record informed consent). Take photos from the same place over time as time-series photographs are a great way to show project progress. Develop an 'electronic media pack' – a folder stored online with photos and video for media and including information about appropriate use and credit.

✔ **PRO-TIP:** Use a phone to shoot, edit and share videos. These are always handy and most phones are capable of capturing high quality videos and photos.

✔ **PRO-TIP:** Action cameras such as GoPro cameras are ideal for shooting underwater visuals for shellfish restoration projects because they can shoot at a wide angle and therefore can be placed closer to the subject. This is especially useful in low underwater visibility conditions.

Infographics and other visualisations

Non-scientists rarely understand traditional graphs and charts so if these are used, make sure they are simple and clear. A better solution is to use infographics that display the main points in a visual and entertaining way. See Figure 9.2 for an example of an effective infographic.

It is relatively easy to make free online infographics using the free online software such as Easelly (https://www.easel.ly/).

GETTING SOCIAL – HOW TO USE SOCIAL MEDIA

The advantages of social media include that it is an interactive process rather than one-way communication through traditional media. This also allows more control of messages because they are not being interpreted and modified by a journalist. Social media is usually free to use and relatively easy to run. Social and traditional media are converging, and journalists will often trawl through social media to get stories. There is a wide-range of platforms (Box 9.1) and you will not have time to use them all, so choose one or two that you and your audience are comfortable with.

In general, keep it short, make it visual, do not get political, check the spelling, and give all posts a final read over before they go live. Spend time to understand how each platform works. Be nice to others, and take a balanced and reasonable approach when dealing with others' points of view.

Choosing the right social media platform will depend on the needs of the project's audiences, and the capacity, comfort level and time commitment of those managing the project. Do not try to do everything, choose what works for the team and commit to achievable goals (like one post a week) rather than building up an audience and then running out of steam. Consider developing a one-page social media plan for the project, defining platforms, and who is responsible for posting.

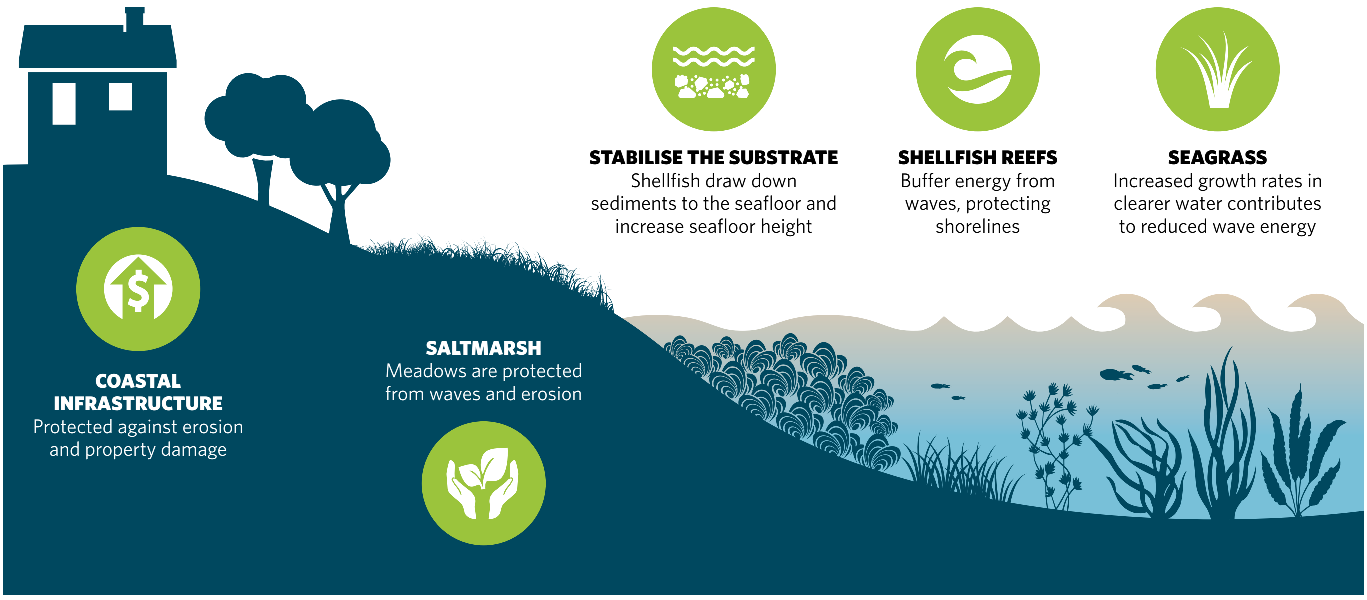

Figure 9.2: Infographic of the coastal protection, water quality and other habitat benefits of shellfish reef restoration.

BOX 9.1: SOCIAL MEDIA PLATFORMS

Below are some of the more commonly used platforms for shellfish reef restoration projects. These platforms are likely to change, come into or go out of fashion and may not even exist in the future, but represent our best advice in 2019.

Facebook – this is still the most used social media platform with 2.5 billion active users in 2018. Facebook groups can be a good way to keep in touch with project participants and these can be 'closed' so only people specifically added can see the content. Facebook has powerful video and photo compression so your project's audience uses the minimum amount of data. The downsides of Facebook include that a post will generally only be shown to a small proportion of a potential audience unless you pay the Facebook company.

WeChat and **Weibo –** both are the most dominant social media platforms used in China, with 1 billion active users on WeChat and 300 million users on Weibo. Both platforms allow convenient posting and sharing of images, videos, short messages or blog-type of articles. Posts and articles can be in foreign languages such as English, depending on the targeted audience. In WeChat, an official account needs to be created, and only people with subscription to that account gets automatic notification for new posts; whereas on Weibo posts can be promoted by using #tags.

YouTube – often forgotten as a platform, but very powerful and a great way to house and share videos. When media agencies create videos about the project, ask for a copy and permission to upload these to the project's YouTube channel. YouTube detects the bandwidth of a device and chooses an appropriate playback quality and provides the easiest way to embed the videos on websites.

Instagram – focussed on images and can be good for reaching a younger audience. One challenge with shellfish reef restoration is that people often do not have a picture of them in their mind, so providing compelling imagery through Instagram can help people care.

Twitter – tends to be more important for researchers, journalists and politicians. Journalists love Twitter and get many of their stories from it.

LinkedIn – could be suitable for some projects, as it is often used by consultants, engineers, and government workers.

ResearchGate – is a social networking site for scientists and researchers to share papers, ask and answer questions, and find collaborators. The questions and answers section can often generate specific answers to detailed questions. Great for sharing scientific outputs and project descriptions.

LEARN MORE

Check out the communication content in the Reef Resilience Network toolkit - there is a communication planning section that is for marine resource managers and conservation practitioners with little to no communications training (see http://reefresilience.org/communication).

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Margaret's Rock, Port Phillip Bay, Australia. Photo: Paul Hamer.

SER SOCIETY FOR ECOLOGICAL RESTORATION

The Nature Conservancy