ADAPTA BLUES

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C3.2. Report on review of experiences of oyster restoration in the US and Australia Method; and how to capitalize application potential in Europe including market-based approaches

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1 INTRODUCTION

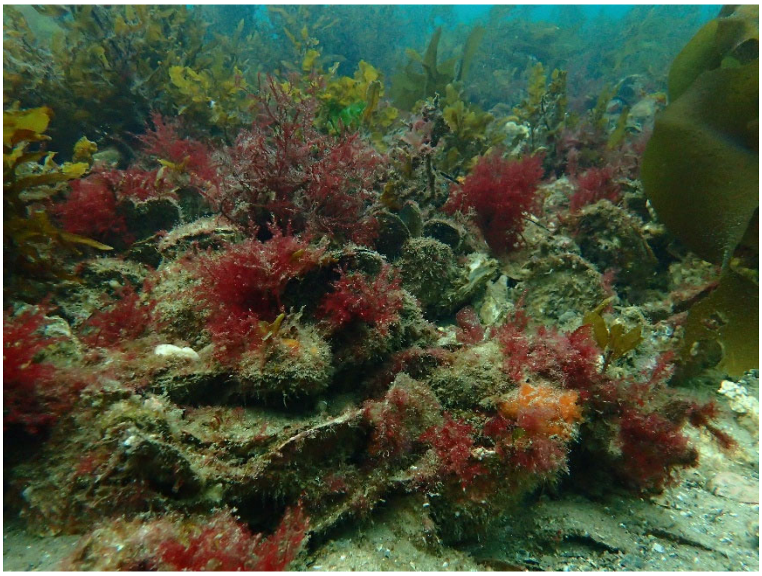
1.1 The wealth of oysters

Oyster habitats are hot spots of biodiversity and productivity which makes them vital to the health of the surrounding ecosystem. As an ecological keystone-species they offer reef substrate, spawning grounds, food, and shelter for many species and enhance processes such as nutrient mitigation. Their ecological role can be compared to the function of coral reefs in tropical regions and their benefits to society are numerous. They help stabilise shorelines, improve water quality through filtration and nutrient mitigation, support coastal economies and fisheries, and sustain generations-old cultural practices (zu Ermgassen et al. 2016).

These ecosystem services arise from both the physical properties of the reef structures which oysters build and the biological processes supported by the oysters themselves. Biologically, oysters provide the service of improving water quality through filtration, denitrification and carbon capture. Through filter feeding, oysters draw suspended sediment and particles out of the water column and deposit them on the seabed. This deposited organic matter over time captures carbon on the seabed and also stimulates bacteria in the sediments of the seabed, many of which remove available nitrogen compounds from the surrounding waters (Kellogg et al. 2014, Fitzsimons et al. 2019). The organic matter deposited into the reef structure also fuels biodiversity and biomass that oyster reefs are known for. The complex, three-dimensional structures which oysters build over time provide shelter and nursery habitat for many other species, increasing the biodiversity and biomass in coastal zones where there are healthy oyster reefs (Fitzsimons et al. 2019). Furthermore, it is shown that oyster beds and oyster reefs reduce wave energy in shallow coastal and intertidal zones, which allows sediments to settle and accumulate inshore of the reef, thereby stabilizing the shoreline (Baggett et al. 2014).

The collective ecosystem services of oyster reefs benefit not only the larger coastal ecological landscape but also coastal socio-economic systems. There is increasing recognition of the critical role oyster reefs play in benefiting coastal communities. Oyster reefs play a key cultural role in many coastal communities by supporting generations-old traditions of oyster fishing and gastronomy. Furthermore, the ecosystem service benefits of increased biodiversity and biomass translates directly to increased fish stock and fish landings for the local fisheries and gastronomy economies. The water filtration provided by oyster reefs, in turn, creates much clearer and cleaner water in the coastal zone, which provides opportunities for a host of recreational and tourism activities. Grabowski et al. (2012) values these collective benefits to people (in tonnes of additional fish landed, increased tourism spending, value of homes & infrastructure, and amenity value) between $55,000 and $99,000 per hectare per year. The role of oyster reefs in shoreline stabilization is valued in terms of avoided losses to infrastructure and property at between $278,000 to $2.3 million per mile of reef (zu Ermgassen et al. 2016).

The benefits of oyster reefs are numerous and substantial, both in ecological and socio-economic contexts. However, it is important to note that the benefits of oyster reefs increase proportionally to the area of oyster reef. Ecosystem services such as improved water quality, increased biomass and biodiversity, and denitrification, are not seen at a noticeable scale if oysters only exist in sparse and dispersed patches or clusters of individuals (Fitzsimons et al. 2019). Rather, as we see in the quantification of economic benefits through fish catch and shoreline protection, ecosystem services are more apparent and easier to measure on the landscape scale when oyster reefs are functional on a scale of hectares and kilometers. Unfortunately, in most parts of the world there is insufficient oyster habitat left to deliver these services at the scale necessary to benefit the socio-ecological systems tied to these reefs (Fitzsimons et al. 2019).



Last remaining natural oyster reef (*Ostrea angasi*) in southern Australia. *O. angasi* is a close relative of the European native oyster *O. edulis*. C Gillies.

1.2 Decline to near-extinction

Despite the growing recognition of their numerous benefits oyster reefs are the world's most threatened marine habitat, with over 85% loss globally (Beck et al. 2011, Fitzsimons et al. 2019). In Europe, the loss of wild native oysters (*Ostrea edulis*) is even more pronounced due to destructive trawl fishing practices and historical mining of reef foundations to supply lime kilns for lime production. In many parts of Europe, native oyster reefs have even been declared functionally extinct, with over 99% loss of their former distribution (Gamble et al. 2020). Oyster reefs used to be an important structural and ecological component of Europe's marine environment, spanning vast stretches of the North Sea. Shell piles show historical harvests in France containing more than 1 trillion shells, while further north, records show nearly 120,000 workers employed as oyster dredgers in Britain in the 1860s (Gamble et al. 2020). In Europe today native oyster populations are highly fragmented and sparsely distributed throughout the North Sea, Atlantic Coast, Mediterranean, Adriatic and Black Seas.

1.3 Growing momentum for restoration

Against this dire backdrop, there are positive trends of recovery for native oysters. Restoration is increasingly being seen as a necessary management intervention in order to sustain or recover the critical ecosystems oysters provide. Over the past two decades, substantial headway has been made in progressing restoration of oyster habitats (Fitzsimons 2019). Much of this work has been in the US and Australia, but across Europe, native oyster restoration is also starting to gain momentum (Preston et al. 2020).

From a policy standpoint, shellfish reefs have been recognized globally as threatened and in need of protection. Shellfish reefs were added to the list of wetland types eligible for designation for protection under the Ramsar Convention on Wetlands in 2012 (Kasoar et al 2015). Several legal frameworks in the EU are focused on the protection and restoration of habitats and the biodiversity they support. The initial Birds Directive of 1979 was expanded to become the Habitats Directive of 1992 encompassing the Natura 2000 network of protected areas. This network encompasses numerous marine habitats of focus, including reefs, with oyster reefs currently being nominated for inclusion. The current expansion to the Biodiversity Strategy for 2030 continues this intention and has promoted discussion of restoration targets through the Restoration Strategy (European Union 2020). Many of the targets included in these EU instruments are relatively well defined for the terrestrial environment. In the marine environment the pathway to achieving the protection and restoration targets are less well defined. Oyster reefs represent a historically large area of highly diverse and productive marine habitat. The restoration community also have a long record of demonstrating success with oyster habitat restoration and scaling the restoration to ecologically significant scales. With the examples of large-scale oyster reef restoration described herein and the incentives and mechanisms for expanding the work described, oyster reef restoration presents one of the most tangible and achievable mechanisms for meeting the EU biodiversity and restoration targets and comes with well documented benefits that create an attractive business case from the perspective of return on investment.

With policy support in place, restoration action is starting to follow. Restoration to the historical extent is likely not possible, as too much has been lost and the biological and physical conditions of Europe's waters have changed. However, the aim of restoration is instead shifting to focus on restoring ecosystem services rather than restoring to a historical baseline (zu Ermgassen 2016). With the multitude of motivations which drive restoration of oyster reefs, there is a recognized need to better define and quantify objectives for restoration at an estuary or system-wide level in order to ensure optimized restoration planning and maximized ecosystem service benefits (zu Ermgassen 2016). The Native Oyster Restoration Alliance (NORA) Network emerged in 2017 with the express purpose of addressing this need and better coordinating and marshalling European expertise and resources on native oyster restoration. The NORA network has grown since 2017 to become the primary platform in Europe for stakeholders to connect to develop native oyster restoration. The network hosts a diversity of stakeholders ranging from aquaculturists to conservationists to research institutions, spanning from Scandinavia to the UK to the south of Spain to Croatia. The network actively promotes coordinated restoration efforts in Europe through working groups which allow stakeholders to build and share expertise to develop standardized protocols and guidelines for restoration.

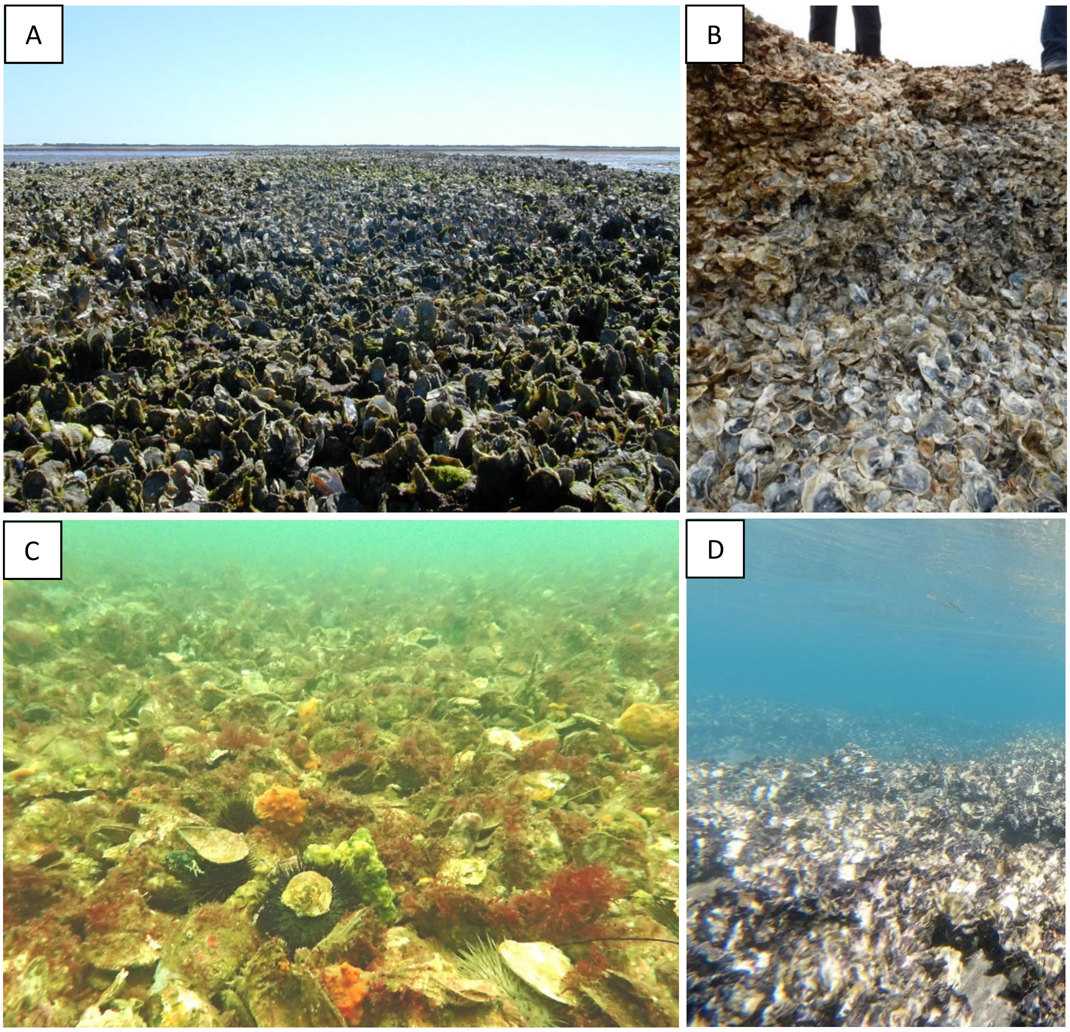
While the momentum for restoration is gaining in Europe, there are still many knowledge gaps to be addressed and much greater resources needed to return this critical species from the brink of extinction.

2 CONTEXT

This report aims to synthesize and review global oyster restoration experience, particularly that of the US and Australia, to capitalize on lessons learned for application in the European context. The report will highlight strengths and weaknesses of past restoration cases to draw up lessons for success in translating science into restoration at scale. Through convening with lead oyster restoration experts at The Nature Conservancy, representative best practice examples have been selected from Australia and the US to showcase key global restoration learnings for how restoration can be achieved at scale. The lessons learned from these cases will be supplemented by general insights from The Nature Conservancy's global experience on additional aspects of restoration which are relevant to Europe. Specifically, this report will address financing strategies to fund oyster restoration work and the possibility to pursue oyster restoration from the perspective of coastal protection.

It is important to note that biological differences between oyster species must be accounted for when extrapolating from global experience to a European context. Species in the *Ostrea* genus brood their larvae for part of their development period and tend to favour full salinity oceanic environments and hence historically occurred in deeper water and more oceanic environments while the *Crassostrea* are broadcast spawners and occur in more estuarine environments, typically shallow subtidal and intertidal areas with variable salinity. In the case of the Australian experience this is less relevant, as the native Australian species of *Ostrea angasi* is closely related and has many similarities to the European native *Ostrea edulis* in terms of physiology and life history, reef structure, susceptibility to pests, and habitat range. However, in the case of US experience, there are more significant differences between the US *Crassostrea virginica* and the European *Ostrea edulis*. These differences affect recommendations and learnings for oyster management and restoration not only from the biological perspective of disease management (Bonamia), but also from the perspective of restoration siting and ecosystem service provision as these species build different reef structures and inhabit different coastal zones. Despite these differences, the examples presented in this report are still highly relevant to Europe, as the report focuses on general lessons for governance and planning, rather than providing detailed restoration guidelines.

This report is embedded within the ongoing efforts to further oyster reef restoration in Europe. In Europe, oyster-related restoration efforts, knowledge, and stakeholders are largely coordinated through the NORA network. This report is therefore closely aligned with the objectives and work of the NORA network, in order to ensure relevance to the European audience. The report is launched as an accompanying report to the network's recent European native oyster restoration biosecurity guidelines (zu Ermgassen et al. 2021, for release in Nov. 2021), restoration handbook (Preston et al. 2020) and monitoring guidelines (zu Ermgassen et al. 2020), also co-authored under the LIFE Adapta Blues project by this report's authorship. These publications present detailed technical guidelines for how to ensure safe and successful restoration practice. This report, in turn, provides the accompanying background information on types of policy levers, restoration planning approaches and funding strategies which can be used to achieve restoration at the scale needed in Europe. This can help restoration practitioners in framing their objectives and scope of restoration before turning to the technical guidelines.



Examples of remaining oyster reefs from around the world. A, *Crassostrea viginica* from the east coast of the USA (B. Hancock), B, cross section through a reef of mixed *Crassostrea sp.* From the East China Sea (B. Hancock), C, *O. angasi* from Tasmania, Australia (C. Gillies) and D, *Saccostrea glomerata* from NSW Australia (F. Martinez Baena).

3 THE CHESAPEAKE BAY, USA: LEVERAGING POLICY AND SETTING SCIENCE-BASED GOALS TO ACHIEVE RESTORATION AT SCALE IN THE CHESAPEAKE BAY, USA

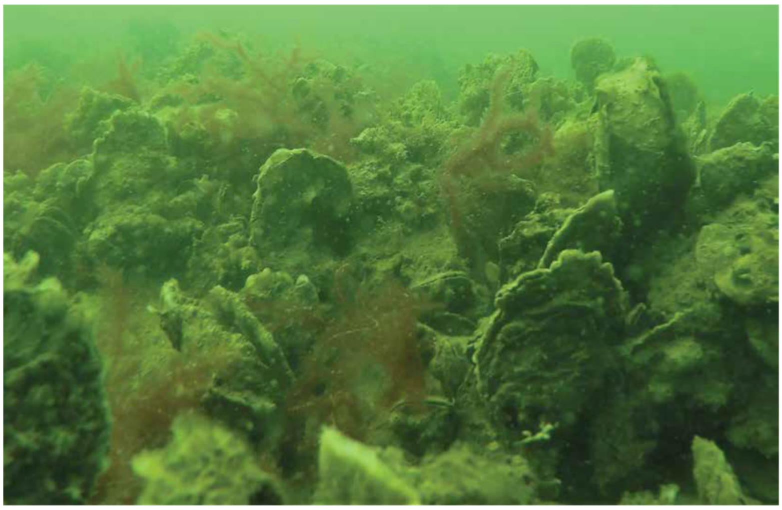
3.1 Overview:

The Chesapeake Bay is the largest estuary in the USA and was once home to a thriving abundance of eastern oyster (*C. virginica*). However, due to overharvesting, sedimentation, and disease, currently less than 1% of the historic oyster population remains (Knoche et al. 2020). Accordingly, restoration efforts have been on-going over the past several decades to reverse this trend. More recently, partners from NGOs, state and federal government agencies have collectively enacted key policy measures to push for ambitious restoration at scale. With the signing of the 2009 Presidential Executive Order 13508, and the 2014 Chesapeake Bay Watershed Agreement, legislative pressure was leveraged and funding was released to commit the Chesapeake Bay states to restore ten Chesapeake Bay tributaries by 2025 and ensure their protection (Knoche et al. 2020).

As the first large scale restoration of its kind, the ten tributaries partnership grappled with the question of what constitutes 'restored' and how much restoration is sufficient to recover the ecosystem functions and services of oyster reefs within the estuary when planning the effort. The approach employed in the Chesapeake Bay therefore represents an iterative learning process of first piloting large-scale restoration in three of the bay's historically oyster-rich tributaries and then scaling this methodology to the remaining tributaries (Fitzsimmons et al. 2019). To guide this process, the restoration partnership had to draw upon existing science to set clear objectives against which to measure success and to identify restoration methodologies which would likely work at scale.

A collective of state, federal and NGO partners joined to drive the scientific foundations behind this effort through the Maryland Oyster Inter-Agency Working Group. The group was responsible for developing definitions of what constituted 'restored' at both the reef and estuary level, then developing a restoration plan and compiling spatial data to select the areas for the restoration reefs that would make up a fully restored tributary for the five Maryland tributaries to be restored. The first three tributaries restored were Harris Creek, Little Choptank River and Tred Avon River (collectively the Little Choptank complex) with Harris Ck being the first completed (Knoche et al. 2020; Fitzsimmons et al. 2019). To set the targets and guide success, the team drew on best available science to develop a set of reef-level and tributary-level oyster restoration success metrics. To allow for an iterative process, the team plans to monitor the program at three and six years after implementation in order to best incorporate learning and guide the subsequent restoration efforts in the remaining tributaries. For the reef-level metrics, the partnership set oyster density targets of at least 50 per m^2 of reef (minimum 15 oysters m^{-2}), oyster an oyster biomass of 50g dry weight per m^2 of reef (minimum 15g dry weight per m^2), presence of multiple age classes in a reef (≥2), a stable or increasing shell budget, and a stable or increasing reef height or footprint. For the tributary-level metrics, the partnership set the target of at least 50% of the restorable bottom and at least 8% of the historic reef area having reefs which meet the reef-level criteria (Fitzsimmons et al. 2019).

Following this methodology and set of targets, a network of reefs covering 142 hectares was constructed in Harris Creek between 2011 and 2015. To meet diverse biophysical contexts within the tributary, two restoration approaches were trialed: ‘assisted regeneration’ of spat-on-shell planted directly on existing shell reef and ‘reconstruction’ of a paired substrate base construction with spat-on-shell planting on top of that base in areas where no pre-existing reef remained (Fitzsimmons et al. 2019). Funding was provided through both US government agencies, the state government of Maryland and NGO’s, and logistical and technical support was provided by the University of Maryland’s Horn Point Oyster Hatchery. By the end of the first round of monitoring in 2017, the restoration efforts were shown to be largely successful with 98% of the reefs meeting the biomass and density targets (Fitzsimmons et al 2019). Following this success, the methodology is currently being replicated in the remaining estuaries.



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

3.2 Key Learnings for success:

Several factors contributed to the success of this restoration effort. The two key levers driving success are the basis of a strong policy framework and the approach of setting ambitious and measurable science-based goals. The overall project is supported by the enabling factors of dedicated funding, inclusion of a broad stakeholder base, effective coordination platforms and effective communication of benefits.

Strong policy framework. The ten tributaries by 2025 project benefits immensely from strong policy support. President Obama’s Presidential Executive Order 13508 mandated renewed protection and restoration efforts in the Chesapeake Bay to meet the requirements of the Clean Water Act. Building from this executive order, the Chesapeake Bay Watershed

Agreement was signed in 2014 with concrete goals to protect, restore, and enhance a network of land and water habitats and species to support a healthy ecological balance, biodiversity, and ecosystem services. The agreement delegates the EPA to steer these efforts and coordinate the core partners behind the agreement to engage stakeholders from academia, NGOs, and industry to collectively implement the actions necessary to meet the goals (Chesapeake Bay Program 2014).

Strong science-based goal setting. With the foundation of a strong policy framework, the second key factor driving the successful implementation of restoration at a scale sufficient to restore ecosystems services was the setting of ambitious science-based goals. Amongst the core partnership, the "Chesapeake Bay Program partnership" drew on collective global knowledge and best practice to set forth a set of clear tributary-level and reef-level goals for the restoration of shellfish (Chesapeake Bay Program 2014).

Dedicated funding. The long-term timeframe of the project and the large scale of action was made possible through a dedicated stream of funding. Under the policy mandate for action in the Chesapeake Bay and thanks to the engagement of multiple national government agencies, stable funding for the work was secured from the National Oceanic and Atmospheric Administration (NOAA), the US Army Corps of Engineers, and the state governments of the Chesapeake Bay states (Fitzsimmons et al. 2019). With this primary funding secured to guarantee the project, key NGOs involved in the partnership were also able to bring in private funds to further support implementation.

Effective coordination across a broad stakeholder base. The project benefited from thorough planning and design thanks to the inclusion of a broad base of stakeholders. The core Chesapeake Bay Program partnership enlisted the engagement of a wide range of stakeholders in the planning process, including actors from academia, NGOs, industry, state and federal government. The vertical integration from community-level groups to national government agencies ensured that action was both publicly supported and supplied with sufficient resources. The broad range of stakeholders involved in the partnership also benefited the project from the logistical side as it granted the partnership access to a well-located shell cleaning facility, hatchery and remote setting jetty to access the dispersed reef sites (Fitzsimmons et al. 2019).

Effective communication of benefits. Describing the intended outcomes of the project in terms of the ecosystem service benefits to the community was important to separate the concepts of restoring oysters to revive an oyster fishery from restoring the habitat and the benefits the oyster reefs provide. Benefits such as reviving the crab and finfish fisheries based on the extra fish created by the reefs and restoring the ecological function of the tributary for the many recreational and commercial uses a functioning estuary supports. Following completion of the Harris Ck. Work and the year-3 monitoring results, a cost-benefit analysis was conducted to highlight some of the key benefits of the restoration projects. The clear detailing of these benefits in terms which matter to local communities is a key enabling factor in securing longer-term support from the community and industry stakeholders. Providing numbers on the annual predicted increase in finfish, shellfish and blue crab biomass and what this amounts to in dockside sales for commercial harvests, job creation, and denitrification services to the Bay helps to garner further stakeholder buy-in and provide useful ecological and socioeconomic metrics to support long-term decision-making for the oyster fishery (Knoche et al. 2020). For Example, the completed restoration of Harris Ck. Cost $52 million USD to deploy 200,000m^3 of substrate, seeded with >2 billion spat-on-shell. Economic modelling estimates that the restored reefs in Harris Creek 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). Relative to unrestored conditions, blue crab (Callinectes sapidus) harvest would increase by more than 150% when these reefs 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), making the cost of the restoration a highly attractive investment.

4 THE AUSTRALIAN EXPERIENCE: LEVERAGING THE ECONOMIC BENEFITS OF OYSTER REEFS TO CAPITALIZE STIMULUS FUNDING FOR NATION-WIDE RESTORATION

4.1 Overview:

Australia's oyster reef ecosystems, much like those of the United States and Europe, were once vast but now count among the nation's most endangered ecosystems. Australian flat oysters and Sydney rock oysters have experienced 99% and 94% habitat loss respectively and are classified as Critically Endangered by the IUCN Red List of Ecosystems (Gillies et al. 2020). The decline in oyster reef ecosystem extent and condition has contributed to the loss of biodiversity, fisheries and water quality and has enabled directing national attention toward oyster habitat as a restoration focus.

The Nature Conservancy (TNC) has championed the restoration of oyster reefs in Australia. TNC launched its first shellfish restoration project in Australia in 2015, near Melbourne. Since then, it has established seven other projects across four states and developed a community of restoration practitioners and partners. Throughout this process, the restoration community has conducted enabling science to determine the extent of ecosystem loss, identify opportunities for recovery, and develop methodologies and policy for restoration and protection. In 2018, TNC nominated the ecosystem for the national protection under federal environmental legislation. While TNC has played a driving and coordinating role, this work was largely made possible through the over 150 partnerships TNC has established with community groups, traditional owners of the land, and key coastal stakeholders such as recreational and commercial fishers.

The cornerstone of shellfish restoration work in Australia is TNC's latest shellfish recovery plan: Reef Builder (see https://www.natureaustralia.org.au/search/?q=reef%20builder). Building on the restoration work in the US, TNC has piloted projects to demonstrate proof of concept, engaged stakeholders from community groups to key decision-makers, conducted enabling science, and promoted supportive policy development. This background was used to tap into a recent policy initiative and develop a national proposal for restoration at a meaningful scale to return biodiversity and ecosystem services associated with oyster reefs in Australia. Reef Builder aims to restore reefs at 60 sites across Australia, amounting to recovery of the ecosystem in roughly 30% of its historic locations. TNC estimates that the total program will cost AU $100 million, create over 800 full time jobs, greatly improve marine biodiversity, support the commercial and recreational fishing industries, and could provide financial returns in the range of 2x to 4x return on investment (Rogers et al. 2018). The total benefits of the program will vary depending on a number of factors, including; which final sites are chosen for restoration, the scale of restoration, community engagement, and marketing for tourism, etc. (Rogers et al. 2018). Reef Builder expands on TNC's current wealth of experience in oyster reef restoration and incorporates the learnings of the largest oyster reef restoration project in Australia, the Windara Reef. Through these learnings, and a solid foundation of enabling science, TNC developed a series of investment options for the national and state governments to invest in oyster reef restoration as an economic recovery plan to combat the economic downturn from Australia's recent severe bushfire seasons and the COVID-19 pandemic. With the aid of an extensive network of partnerships, a credible track record and persistence, TNC secured an AU$20 million Federal Government investment as part of the national government's COVID-19 Relief and Recovery fund. This funding will kick-start TNC's Reef Builder program and will seek to generate further supporting evidence of the economic, environmental and social case for large-scale shellfish reef restoration in Australia. This funding alone will contribute to restoration of shellfish reefs across 13 sites in Australia.

Deployment of rock substrate during construction of the 20 hectare Windara reef construction in South Australia (A Bolton).

4.2 Key learnings for success:

Several factors contributed to the success in the first phase of TNC's Reef Builder program. The primary driver of success here was the presence of a strong champion to lead action and connect disparate or even opposing stakeholders for shellfish restoration in the absence of government leadership and the creativity and flexibility of this champion in finding policy levers to capitalize on to support the work. Additionally, the project benefited strongly from following the learnings of the large-scale shellfish restoration experience in the US, including Chesapeake Bay.

Strong champion to lead action. In most geographies the restoration of marine habitats is relatively new and not yet a public priority with a planned trajectory. In the absence of leadership on shellfish restoration from government, as was the case for the Chesapeake Bay work, having a strong champion is key to take the lead in pushing for restoration support. TNC took on this role in Australia and maintained a persistent logic across all negotiations with state and national government agencies and continually tried to find points of agreement between the federal and various state government agencies. Once the first state government indicated their official support for the proposed restoration measure, it became easier to influence the other state governments. The support indicated by state governments and TNC's private investment was critical in demonstrating to the national government that the project was low risk and offered value for money. TNC made a strong champion for this work since they already had high credibility with national and state government partners through prior collaborations. The support of recreational and commercial fishers and other environmental groups was also highly regarded.

Flexibility in following policy opportunities. In the absence of policy opportunities which explicitly focused on supporting shellfish restoration, a strong business case was needed to allow the government to invest in shellfish restoration as a means for economic development. The government appetite for economic recovery and stimulus opportunities proved to be the perfect entry point for shellfish restoration. Fitting the dimensions of the restoration project to the government interests, while still maintaining an ecosystem service and biodiversity focus, required flexibility and responsiveness in the framing and design of the work. The restoration plan changed several times during the development of the federal proposal in order to meet the changing focus of the Government. In the end a series of maps were created to identify COVID-19 related unemployment and bushfire affected areas. Through these maps it was possible to show where reef builder could make the biggest impact on areas that the government was prioritizing. The overarching strategy included reef restoration at 60 sites. All 60 sites had been previously assessed as environmentally suitable for restoration, which allowed the Federal Government flexibility when considering a range of investment options and locations. This was a key advantage over other place-based investments and allowed the Government to focus on optimizing social and economic outcomes. Ultimately, flexibility and a strategic project design allowed demonstration of Reef Builder as both a collective benefit for conservation, community and economy – but also as something which the Australian representatives could announce on behalf of the Australian action for sustainable oceans.

Strong foundation of science. TNC Australia followed the example of the Chesapeake Bay work and began their work with a strong emphasis on preparation and building the science foundation for restoration. Since 2014, the restoration community in Australia had built up a wealth of enabling science to support oyster reef restoration, both in Australia and globally. This preparation and familiarity with the subject allowed staff to quickly harvest information and case studies from a range of similar local and global projects. Without this resource base, it would have been difficult to respond to the multiple requests from different groups for evidence/data regarding the benefits of the project. Even in the absence of local evidence, general global learnings can be useful (e.g., information on jobs, fishery benefits). Knowledge sharing and existing capacity within the organization also played a large role, as TNC global staff were able to help the Australian team identify key science to be conducted and to design a ready-for-implementation Roadmap.

Broad stakeholder base. TNC's supporters and Trustees played an important role in helping to advocate for the project. This gave the Ministry of Environment and Ministry of Agriculture confidence that the project would be well supported by communities and result in minimal conflict. A number of ministries and ministerial advisors needed the confidence that the project would be well supported by local communities and result in minimal conflict before they were able to champion the project. The commercial fisheries sector also supported the project, accounting for a group that is often not considered in Government partnerships for conservation.

5 FINANCING

Two successful means of financing large-scale restoration through public funding have been showcased in the above cases: 1) capitalizing on the business case of oysters to take advantage of public investment opportunities such as stimulus funding and 2) leveraging strong science and environmental regulations to unlock government funding. However, these funding pathways are contingent on the contexts of each case and rely on government buy-in to restoration. Like the US, Europe has a strong set of policy frameworks which support shellfish Restoration. It is also, similar to the Australian case, currently investing in stimulus spending. While both of these pathways are relevant to unlocking public funding for restoration in Europe, further exploration of financing strategies can support restoration actors in Europe to approach large-scale restoration from a broader portfolio of strategies – thereby improving chances for success.

The cost for restoration is typically substantial. For example, the Harris Creek restoration cost approximately \$200,000 USD ha^{-1} to deploy substrate at ~0.3m depth and seed with ~12.5 million spat-on-shell ha^{-1}. There are also substantial up-front costs to finance the restoration planning, establishing governance schemes for management, and monitoring the restoration. Restoration has traditionally been financed through public grants or philanthropy, but public budgets are often stretched too thin and biodiversity objectives often too low on the public agenda for restoration to successfully be rolled out at scale through public funding alone. Given the demand for larger scale and more rapid action in Europe, new financing mechanisms to explore private funding or blended public-private funding sources are becoming increasingly important (Fitzsimons 2019).

While there is some interest in exploring the potential of the investment market to leverage funding for oyster habitat restoration, this approach has not yet proven effective. The issuance of bonds by the government could theoretically fund restoration work, but in practice this model is unlikely to be viable due to the high upfront costs of restoration and the delayed generation of gains (payout on ecosystem services, DePiper et al. 2017). In an effort to garner a greater buy-in of stakeholders across both public and private sectors, much work is being done to value the benefits of oyster reefs in economic terms and to develop business cases and financing models to incentivize investment in restoration. Economic estimates of the value of ecosystem services depends largely on whether or not there is local demand for this service. In general, where there is a demand for a particular service and communities would need to invest in alternative measures in the absence of oyster reefs, a business case can be made for investing in conservation or restoration. The following subsections explore ways in which demand for specific ecosystem services of oysters are being used to create a private or blended finance business case for conservation and restoration.

5.1 Private Funding: Nutrient Trading Schemes

Throughout the world coastal bays and estuaries are being confronted with eutrophication, hypoxic conditions and fish kills from anoxic events driven by increased nutrient loads, particularly nitrogen (in the marine environment). Oysters have been shown to be important for nutrient mitigation in these situations in two important ways. Firstly, as oysters grow, they convert the nitrogen from the phytoplankton they eat into their own body tissues. This is extracted at harvest, with a simple conversion required to calculate the total N extracted. A second, and more powerful pathway for nutrient mitigation is via enhanced denitrification. Denitrification (DNF) is a bacterial process where organically available nitrogen compounds are reduced to N2 gas, which is inert and leaves the marine system. This tends to be highest on restored reefs where the oysters are filtering the nitrogen containing material from the water and depositing it on the reef as biodeposits. This makes the compounds available to the bacterial community and can substantially increase rates of denitrification. (Kellogg et al. 2014, Humphries et al. 2016). While the rates of N removal for DNF tend to be higher than for harvest of assimilated N the pathways are more complicated and quantifying the rates of N removal more difficult Ray and Fullweiler 2020). This introduces the emerging mechanism of leveraging private funding for oyster restoration by capitalizing on the oyster’s nutrient capture through a nutrient trading market (Kellogg et al. 2018, Rose et al 2021).

The development of a nutrient trading market to support oyster restoration has been investigated in the US for nearly 15 years. There was initially a focus on developing the science to support the concept and subsequently a focus on developing the markets. In the Chesapeake Bay, Cape Cod Massachusetts, and parts of Florida, management authorities are pursuing the possibility of supplementing and ultimately transitioning the current public funding approach to restoration towards a self-sustaining private funding stream. This work capitalizes on oysters’ nutrient mitigation as a cost-effective means to reduce nutrient pollution loads in order to meet legal environmental health requirements. Like many nearshore areas, Chesapeake Bay suffers from heavy nutrient pollution (Nitrogen and Phosphorous) which is impacting the region’s fisheries sector and overall environmental health (U.S. EPA, 2010). Not only is this heavy nutrient pollution harming the environmental health and fisheries economy, it is often also impeding the Chesapeake Bay states from meeting the legal water quality standards (Total Maximum Daily Load) set by the EPA. The Chesapeake state governments therefore began exploring the possibility of using commercial oyster production to manage and mitigate the nutrient load of bay (Cornwell et al. 2016; U.S. EPA, 2010).

With a growing body of scientific research demonstrating that oysters can contribute to the reduction of nutrients from the water column the management authorities of the Chesapeake Bay developed a market-based mechanism to promote and leverage funding for oyster aquaculture in the bay. A nutrient trading market was established where oyster cultivation can be funded through the purchasing of nutrient load reduction credits as a means to offset nutrient discharges from districts into the bay. Regulations for growers to be paid took a long time to be implemented (Parker & Bricker 2020). Nevertheless, the nutrient trading market is now up and running, with a standardized protocol for assessing and valuing the nutrient capture of different types of oyster cultivation practices (Cornwell et al. 2016; Parker & Bricker 2020). With private oyster cultivators (e.g., aquaculture) now able to become accredited for selling nutrient load reduction credits, there is a strong business case for further private oyster cultivation in the bay. The same business case and trading mechanism is now being applied to oyster restoration.

Parker & Bricker (2020) suggest that despite being in early stages of implementation, the nutrient trading program of the Chesapeake Bay is transferable to other waterbodies that have nutrient-related degradation. In Europe, oyster restoration siting and planning should first and foremost follow the NORA network publications “European Native Oyster Habitat Restoration Handbook” and “European Guidelines on Biosecurity in Native Oyster Restoration” to ensure restoration is appropriate and safe. In cases where restoration is suitable, there are some key factors which should be considered when considering the development of a nutrient credit trading scheme:

Conducive Policy Environment. The nutrient credit trading scheme in the Chesapeake was largely enabled by the policy framework which requires waters to be kept at a specified ecological health status. The Clean Water Act in the US sets a national environmental regulation that all waters of the US must be “fishable” and “swimmable”. Under this Act, States and Districts are required to establish appropriate uses for their waters and adopt water quality standards which maintain and protect those uses and adhere to the national regulations. States and Districts must also report every two years which waterways do not meet water quality standards. Where standards are not met, a “Total Maximum Daily Load” (TMDL) for pollutants must be developed (U.S. EPA, 2010). The Chesapeake Bay does not meet the Clean Water Act’s standards and therefore was required to develop a TMDL to restore clean water in the Bay and the region’s waterways. As part of this process, Watershed

Implementation Plans were developed which detail limits on pollution and how and when the six states and the District of Columbia that make up the Chesapeake Bay watershed will meet their pollution reduction targets (U.S. EPA, 2010). The Chesapeake Bay TMDL is particularly conducive to fostering large-scale action, as it involves collaboration across several state governments and set strict accountability measures and deadlines for progress (U.S. EPA, 2010). For replication in other bodies of water, a similar policy framework in place regarding nutrient pollution and water quality is critical for setting the underlying need for action and the baseline from which to base nutrient pricing.

Strong leadership and governance arrangements. In addition to the conducive national policy environment in the framework of the Clean Water Act and the requirement for polluting districts to set TMDLs, the Chesapeake Bay nutrient trading market benefits from a local governance structure which supports both aquaculture and ecological restoration. The management body responsible for maintaining the Chesapeake Bay's health, the Chesapeake Bay Program, was open to exploring ecological means to manage the bay's health and meet multiple other objectives for communities of the bay. Without awareness of the nutrient filtration potential of oysters and willingness to consider them as a means of maintaining environmental health, an initiative to establish a nutrient credit trading scheme is unlikely to succeed. In the case of the Chesapeake, awareness and support for this concept was built through working with key stakeholders. The National Oceanic and Atmospheric Administration (NOAA) hosted a workshop with 30 scientists, policymakers, and restoration practitioners to explore the feasibility of using oysters to remove nutrients from the bay. In this workshop the Chesapeake Bay Program's Water Quality Goal Implementation Team (set up under the TMDL process) created an oyster best management practice expert working group to further explore feasibility and implementation options (Cornwell et al. 2016, Kellogg et al. 2014). Local NGOs were also active in this process and supported the formal governance structures to explore the capacity of oyster grow operations in reducing nutrient loads (DePiper et al. 2017). Following recommendations and outputs of this workshop and technical working group, the Chesapeake Bay Program adopted a standardized framework to assess and issue credits for oyster cultivation projects (Cornwell et al. 2016). The diversity of stakeholders engaged in process supported a science-based, needs-based and policy-supported approach to developing the nutrient trading market which had support from both oyster producers and polluters. Active leadership to promote oysters as a viable means for nutrient pollution control as well as inclusive governance structures are key to building a functional and stakeholder-supported nutrient trading scheme.

A strong business case. Finally, to secure buy-in of the necessary trading stakeholders in a nutrient trading market, there needs to be a strong business case for the crediting, purchasing and trading of nutrient credits to offset pollution. In the case of the Chesapeake Bay, the rigorous scientific research on oysters in the bay and the science-based approach to exploring the potential for a nutrient trading market led to the standardization of assessing nutrient reduction and accordingly pricing credits for growers. The cap on total pollution allowed in the system is set by the national policy framework of the Clean Water Act and the TMDL for the bay, thereby securing buy-in from polluters who must reduce their nutrient pollution. However, to support oyster production to a scale which can meet the reduction needs, there needs to also be incentives and support for oyster growers and subsequently restoration. Parker & Bricker (2020) show that oyster farms could expect to receive between $7 to $1,034 per Kg of Nitrogen removed if they are integrated into a fully functioning nutrient credit trading program. The current price for growers engaged in the Virginia Nutrient Credit Exchange is $8.33 per Kg of N removed, but this can increase as the market expands and oysters are proven to be an effective means of reducing nutrient pollution levels in the bay (Parker & Bricker 2020). With increasing empirical evidence and a price for Kg of nutrient removed, oyster producers can receive reliable financial support to start, expand and maintain grow operations in the bay. Work to support nutrient removal efficiencies in native European oysters will also be needed to develop a similar market in Europe.

5.2 Public-private: (windfarms)

When considering large-scale restoration, a blended finance approach may be effective. Public funding can be used to kick-start a funding mechanism which ultimately will become self-sustaining through private sector investment. We see this approach being investigated in the cutting-edge oyster restoration work on wind farms in the North Sea.

The pairing of oyster restoration with offshore windfarm development emerges out of both a political prioritization of biodiversity conservation and a business opportunity in the growing renewable energy market. Here several factors converge to create a compelling opportunity. Oyster restoration is a high priority action for marine biodiversity conservation in the North Sea and has both national and European level support. Historically around 20% of the North Sea was oyster reef, nearly all of which has been fished to extinction. This provides a vast opportunity for restoration. Oyster reefs are areas of particularly high biodiversity, biomass and have been shown to produce large tonnages of additional commercially important fish species compared to the bare sediment that the extinct reefs have been converted to (zu Ermgassen et al. 2016). In parallel, there is growing interest and investment in developing offshore wind energy infrastructure to meet renewable energy mandates. The UK aims to have over a third of British electricity produced by offshore wind by 2030 and the Netherlands is also heavily investing in growing the sector (Robertson et al. 2021). This development offers opportunities for fisheries and conservation management as marine renewable energy installations can boost biodiversity and fisheries if appropriately designed and managed. The hard base structures, or scour fields, of offshore wind turbines can be modified to serve as artificial reefs and provide areas for fish habitat. These structures also prevent bottom trawling, thereby supporting natural growth of oyster reefs (Robertson et al. 2021). The opportunity on the wind farm developers' side is the chance to save costs on the decommissioning of wind parks at the end of their lifespan. Decommissioning costs are typically high for wind parks, driven in large part by the cost of removing the scour field infrastructure on the seabed surrounding the monopiles. Where this stabilization infrastructure – typically rock substrate – is successfully repurposed to become an oyster reef, wind farms will be able to leave this substrate behind after they decommission wind turbines, thereby contributing to biodiversity targets while saving considerable costs.

Currently public funding is being used to fund a large part of the exploratory work in this concept with several private-public partnerships. Through collaboration between NGOs and private sector actors such as marine engineering and infrastructure firms and wind farms, pilot projects have been conducted in the Netherlands and UK to explore the feasibility of developing healthy and functional oyster reefs on wind farm infrastructure. WWF and ARK Nature Development worked with Gemini wind farm in the Netherlands to deploy oysters and get some initial measures of suitability for oysters at a wind farm site. While the pilot was ultimately discontinued, it did show that oysters can grow and reproduce at wind farm sites (Gemini Wind Park NL 2021). The promising results then encouraged the involvement of the 'Rich North Sea' initiative. The 'Rich North Sea' initiative was launched by €8.5m in funding from the Dutch National Postcode Lottery and seeks to foster a healthy North Sea which is both a source of sustainable energy and rich in nature. The initiative launched a pilot artificial reef in 2018 at the Luchterduinen offshore wind farm in the Netherlands, which aims to provide a blueprint for underwater nature restoration at all offshore wind farms (Robertson et al. 2021; Van Oord 2021).

Ultimately the 'Rich North Sea' initiative seeks to develop a standard for this practice so that new wind farms can follow this procedure and both boost biodiversity and provide cost-saving incentives for further development of offshore renewable energy production. Once the proof of concept becomes clear and is effectively implemented at demonstration sites, private sector actors engaging in this innovative approach are more likely to start investing their own capital into reef restoration and seeding of turbine stabilization infrastructure. The blended finance approach involves public funding first supporting the development of a proof of concept to give private sector investors security in the knowledge that their investment will work and will lead to cost savings in avoiding decommissioning costs. In this case, there also needs to be government interest in, and commitment to, preserving the artificial reefs at the base of monopiles to assure investors that they will not be required to remove the stabilization infrastructure when decommissioning wind turbines if there is a healthy reef present. With the widespread historical presence of native oyster reefs across Europe and the growing demand for offshore wind energy production, there is high potential for this approach to be replicated further in Europe, once proven effective.

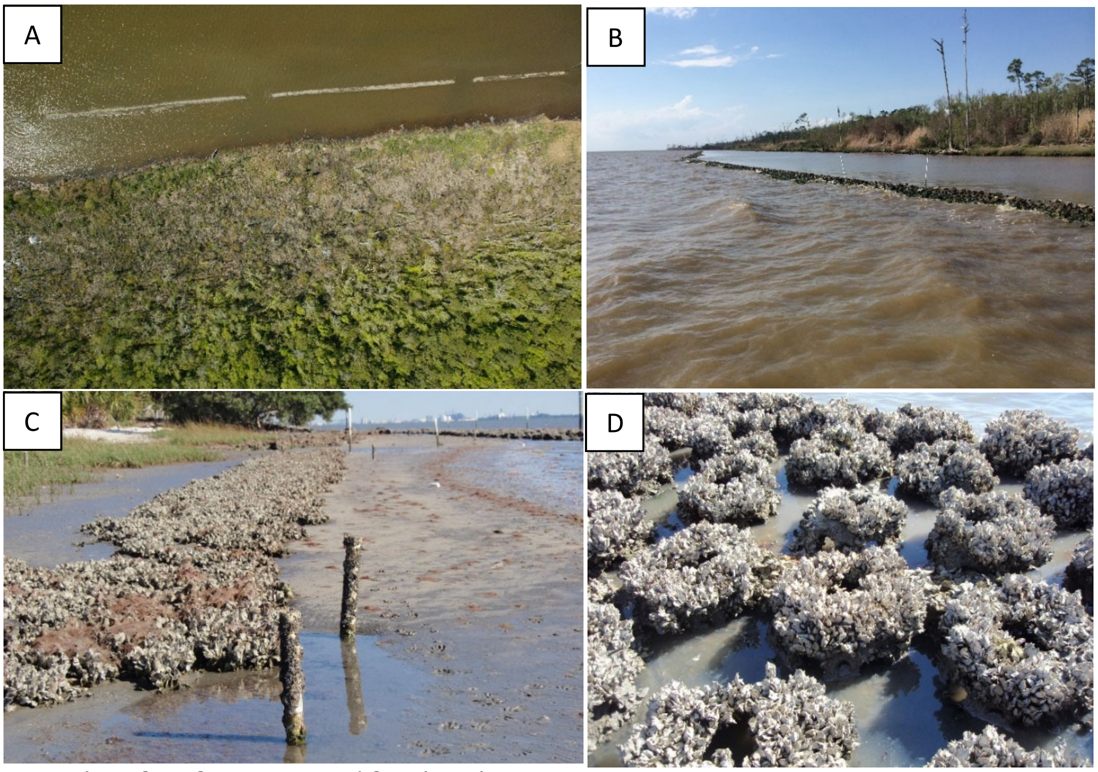
6 ON THE HORIZON OF OYSTER RESTORATION: SHORELINE PROTECTION

The above examples and strategies for motivating and funding oyster restoration represent established and piloted approaches to scalable oyster restoration. However, there is a further emerging strategy for motivating and funding oyster restoration which potentially has far-reaching implications for catalysing this work. The implementation of native oyster restoration projects for shoreline protection has not yet been developed in Europe, but there is a growing body of research which suggests a strong case for doing so.

Grabowski et al.'s (2012) seminal work on valuing the ecosystem services of oyster reefs emphasized the shoreline protection values as being the greatest of all the ecosystem services provided, ranging from an estimated $860 to $85,998 per hectare per year. As with the valuation of other ecosystem services, the monetary value attributed to this function of oyster reefs depends on whether there is local demand for shoreline protection and whether communities would have to invest in other measures or incur other costs in the absence of oyster reefs.

Coastal erosion is an increasing problem worldwide due to human intervention, coastal development, sea-level rise and more intense storms. With a growing awareness of the shortcomings of grey infrastructure in addressing these challenges and the role green infrastructure can play, shellfish reef restoration is increasingly being considered as a means to protect coasts through a living shorelines approach. Coastal engineers have begun to characterize reef systems as low-crested or submerged breakwaters which can complement traditional grey-infrastructure solutions for coastal protection. Increasingly, coastal engineers are modelling these systems and confirming the protection benefit of reef structures on reducing wave energy. However, this literature and body of work has predominantly focused on oyster reefs in the US. The literature is much less developed for reefs of other species or in other areas and empirical evidence is limited. Nevertheless, this body of work is growing, with 30% of oyster reef restoration in the US involving aspects of coastal protection as one of the supporting motivations for restoration (Grabowski et al. 2012).

The theory behind oyster reefs providing shoreline protection is that three-dimensional reef structures in shallow coastal areas can provide coastal protection benefits by attenuating wave energy and thereby reducing coastal erosion and encouraging shoreline stabilization through accretion of sediments on the protected, 'leeward' side of reefs (Ysebaert et al. 2018). Oyster reefs can form similar structures to traditional coastal grey infrastructure and can therefore act as natural, living and evolving breakwaters, bulkheads, or jetties, as they interact with wave and tidal energy in the same way (Morris et al. 2019). Oyster reef restoration is thought to be not only more cost-effective than traditional grey infrastructure, but also can provide greater long-term shoreline protection. The dampening of wave energy in combination with the localized improvements in water quality, capturing of suspended sediments, and increases in biodiversity provided by oyster reefs creates enabling conditions which support the growth of healthy adjacent coastal ecosystems such as sea grass beds and saltmarshes (Ysebaert et al. 2018). These ecosystems collectively create a living shoreline, which can keep a coastal area healthy and safe for longer and with lower costs than traditional grey infrastructure, or can be combined with grey infrastructure. Furthermore, oyster reefs, unlike traditional grey infrastructure which needs to be maintained and updated, can grow vertically faster than or at pace with sea level rise and localized subsidence (Morris et al. 2019). In cases where reefs die off, of course vertical growth to keep pace with sea-level rise is no longer possible. However, even in these cases dead reefs are long-lasting and stable and can provide long-lasting protection benefits, as they are constituted of calcified connections between shells and substrate (Ysebaert et al. 2018).

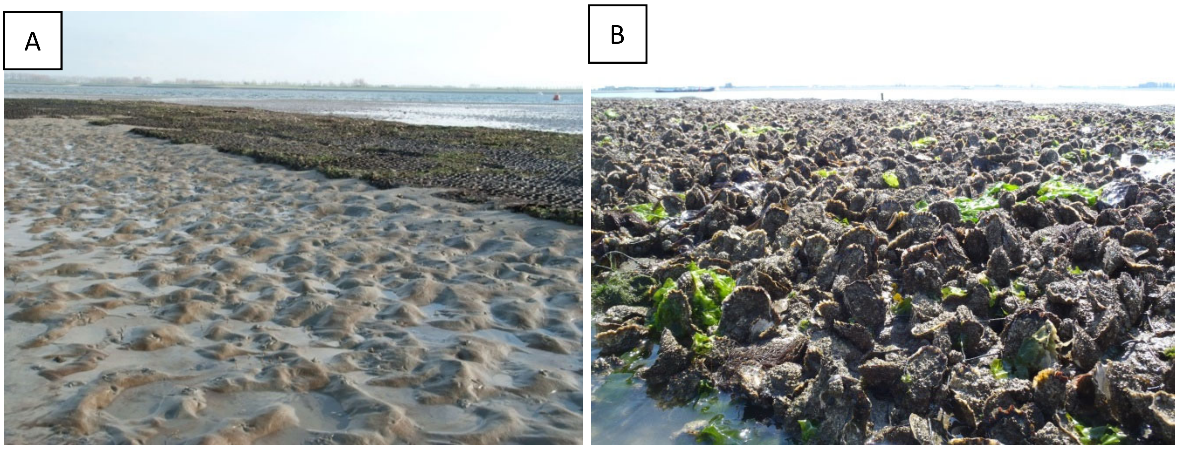


Examples of reefs constructed for shoreline
protection and erosion control. A, Reefs constructed for shoreline protection at Swift Tract

Alabama, USA (M-K Brown); B, Swift Tract reef demonstrating wave attenuation (M-B Charles); C, Reef grown on concrete domes for shoreline protection, Tampa Bay, Florida, USA (B. Hancock); D, Concrete domes with 3 years of oyster growth, Tampa Bay, FL, USA (B. Hancock).

The theoretical case for oyster reefs as a cost-effective means for shoreline protection is strong; however, the question remains as to how this is reflected in practice and whether oyster reefs could provide shoreline protection in Europe. Empirical evidence is growing, with cases across several continents, but it is thus far limited to case studies with C. virginica and C. gigas (Ysebaert et al. 2018; Preston et al. 2020). This unfortunately means that all work on European native oysters for coastal protection would have to proceed first on a theoretical basis, without empirical proof of concept. Nevertheless, there are some general lessons learned from the empirical evidence base which can help inform project planning in Europe for native oyster restoration:

1. Reef position in relation to shoreline and water depth is critical. In 2010, three intertidal oyster reefs (C. gigas) were constructed in the Netherlands to test the impacts of reefs on coastal erosion. These pilot reefs showed that wave energy attenuation depends on distance to the water surface from reefs (tidal range), wave height, and reef height/width. Reefs in the near-shore environment, where reefs are closest to the surface have the highest attenuation benefit and therefore the highest protection benefit. Where bed slope is steep, the reef is too deep, or the tidal range too large, the protection benefits of reefs are greatly reduced (Ysebaert et al. 2018). This means benefits also differ by species, depending on where species form reefs (Preston et al. 2020). Only nearshore intertidal reefs will provide significant protection benefits.



A, Reef consisting of gabions filled with oyster shells constructed for erosion control of an intertidal mudflat of Viane, Oosterschelde, The Netherlands (T. Ysebaert), Reef at Viane after 3 years of oyster growth, Oosterschelde, The Netherlands (B. Walles).

2. Biological considerations are just as important as engineering considerations. It is critical that restored reefs are designed to meet both ecological and engineering objectives. Oyster reefs rely on specific ecological conditions in order to grow. If these conditions are not met (e.g., the waters are too polluted, not enough oyster spat is present, the reef is not sited appropriately for the species), then a proper reef structure of multiple generations of oysters will not grow (Morris et al. 2019). Without a properly established reef structure, the full protection benefits will not be realized.

3. Secondary environmental conditions of the restoration site must be accounted for. La Peyre et al. (2015) showed that both the oceanic conditions and immediate spatial conditions influence success in reef restoration projects for shoreline protection. A reef needs space to expand horizontally as well as vertically, in order to maintain its position relative to the shoreline. If the shoreline recedes too far from the reef, the protection benefits of the reef are diminished. Artificial bases for reefs should therefore be designed with horizontal growth in mind as well.

7 SUMMARY

There is increasing recognition of the critical role of oyster reefs in coastal communities through stabilising shorelines, improving water quality, increasing marine biodiversity, supporting coastal economies and fisheries, and sustaining generations-old cultural practices. In Europe in particular, the potential for restoration is immense, as nearly 99% of the originally abundant native oyster reefs across the European coast have been lost. Momentum for restoration is gaining and shellfish reefs now have a policy foundation to support their protection and restoration under various frameworks and agreements, such as the Ramsar Convention on Wetlands in 2012, the Habitats Directive, Natura 2000, and the Oslo-Paris-Commission. Much of the work on protection and restoration of native oysters in Europe is now led by The Native Oyster Restoration Alliance (NORA) Network, which acts as a primary platform in Europe for relevant stakeholders in native oyster production and protection to connect, share expertise, and coordinate work. To guide these efforts in meeting the large scale of restoration needed in Europe, this report highlights key learnings from best-practice cases of large-scale oyster reef restoration from the US and Australia and key learnings from best practice on how to finance large-scale oyster restoration.

In the case of the Chesapeake Bay, the report highlights the presence of a strong national policy framework as the foundation for successful restoration. A strong policy framework can set the impetus for coordinated action across public and private sector actors to set and meet restoration targets in a degraded habitat. The Chesapeake Bay case set a milestone for future large-scale restoration efforts to follow in how it defined conditions of restoration and set science-based targets. The clear mileage/acreage goals set for restoration enabled and encouraged stakeholders in the region to develop projects of scale, as these would be the only kind able to meet the set targets. They also demonstrate an attractive return-on-investment from the work. These metrics and the process followed to capitalize on existing policy frameworks in the Chesapeake Bay could be replicated where other appropriate policy frameworks are in place.

In the case of Australia, the primary driver of success was the presence of a strong champion for oyster restoration which took responsibility for leading action and connecting disparate or even opposing stakeholders for shellfish restoration in the absence of government leadership. Key to their success was their creativity and flexibility to find policy levers to capitalize on in furthering this work. The use of the valuation of ecosystem services of oyster reefs presents an approach which could be replicated elsewhere where business interests or economic stimulus are a priority.

In cases where there is not a strong policy framework in place which supports oyster reef restoration or where stimulus spending is not a current government priority, the report presents piloted and emerging alternative approaches to support oyster reef restoration at scale through private and blended financing approaches. The case of the emerging nutrient trading scheme in the Chesapeake Bay could be considered for replication in Europe's highly nutrient-polluted marine ecosystems. The emerging practice of siting oyster reefs on the base of offshore windfarms in the North Sea similarly could be considered for further expansion in Europe as it presents a promising means for businesses to profit from the restoration of oyster reefs. In the longer term, the report also suggests that the value of coastal protection provided by oyster reefs will likely become an ever-larger motivator for large scale restoration.

Looking to the future, the NORA network and the broader European community for native oyster restoration has a solid foundation of science and experience which it can draw upon from the past successes highlighted in this report and from the numerous strategies presented for funding and motivating large scale oyster reef restoration. With this context in mind, the authorship of this report recommends readers turn to the NORA network and publications to develop projects that begin scaling the restoration of Europe's lost and degraded native oyster habitat.

A developing European native oyster (O. edulis) habitat in Maine, US, following introduction (C. Coffin).

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