ROADMAP TO SCALING UP *OSTREA EDULIS* HATCHERY PRODUCTION IN EUROPE

Endangered Landscapes & Seascapes Programme

University of Portsmouth

ZSL Zoological Society of London

Blue Marine Foundation

Native Oyster Network UK & Ireland

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CONTENTS

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Cover image: Bangor University (spat on shell at the Bangor University hatchery)

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EXECUTIVE SUMMARY

European native oyster (*Ostrea edulis*) reefs were once widespread but have been functionally lost across most of their historical range following centuries of exploitation. As countries now implement ambitious environmental policies, including the Kunming–Montreal Global Biodiversity Framework, EU Nature Restoration Regulation and the 2025 Environment Improvement Plan for England, demand for oyster seed for restoration is projected to increase substantially in the coming decades. Current hatchery produced seed demand and supply is, however, insufficient, inconsistent, and inadequately suited to meet these policy targets.

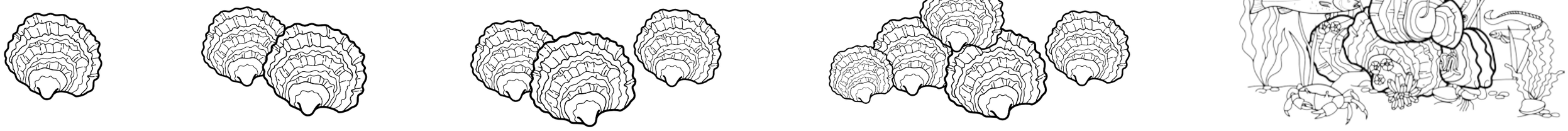
This roadmap provides a co-developed, evidence-based strategy to scale up European hatchery production to meet future restoration and regenerative aquaculture demands. Co-developed through a workshop with European oyster hatchery representatives and subsequent input from >100 stakeholders across governments, regulators, hatcheries, research institutions, NGOs, and industry, it sets out clear actions, timelines, and roles required to deliver a resilient and coordinated seed supply chain by 2040.

Large-scale restoration of *O. edulis* is now recognised as essential for achieving legal environmental commitments, enhancing biodiversity, supporting climate resilience, and delivering a regenerative Blue Economy. Delivering these outcomes demands urgent, coordinated support to scale hatchery production that effectively links restoration and commercial seed production sectors. This roadmap sets out the strategy to achieve that , by ensuring long-term market certainty, regulatory clarity, investment incentives, and research and skills development frameworks. Together, these actions will unlock the production capacity necessary to restore keystone European ecosystems and accelerate development of regenerative aquaculture.

Roadmap to scaling up *Ostrea edulis* hatchery production in Europe

VISION 2040: Hatchery production of *Ostrea edulis* is increased to meet the tailored demands of Europe-wide restoration and regenerative aquaculture efforts. Product requirements and appropriate sourcing is clearly understood across both supply and demand, with a wide range of broodstock genotypes available for purchase. Clear, consistent and feasible regulation is in place for the movement of oysters from/to restoration areas, shaped by scientific advancement. This is supported by a skilled workforce available for European native oyster hatcheries to deliver at scale.

	BY 2027	BY 2028	BY 2029	BY 2030	BY 2040
RECOMMENDATION 1 **Increase confidence in the demand for native oysters**	Raise awareness of the need for large scale oyster restoration ACADEMIA · PRODUCER ORGANISATIONS · RESTORATION NETWORKS · PRACTITIONERS		Scaled up restoration efforts enable quantification of biodiversity and ecosystem service benefits GOVERNMENT · PRACTITIONERS · ACADEMIA · PRIVATE SECTOR		Large-scale restoration is commonplace ACADEMIA · PRACTITIONERS · PRODUCER ORGANISATIONS · PRIVATE SECTOR
			Monitor post deployment survival and growth to evidence viability of restoration and aquaculture of *O. edulis* GOVERNMENT · PRACTITIONERS · HATCHERIES · PRIVATE SECTOR		
RECOMMENDATION 2 **Secure diverse investment for market growth**	Develop a business case and secure investment for seed production PRIVATE SECTOR · PRACTITIONERS · GOVERNMENT · HATCHERIES		Co-develop programme of support within government blue investment strategies GOVERNMENT · PRODUCER ORGANISATIONS · PRIVATE SECTOR		Marine natural capital markets include oyster reef restoration and regenerative aquaculture GOVERNMENT · PRODUCER ORGANISATIONS · ACADEMIA · PRIVATE SECTOR
					O. edulis is widely adopted in regenerative aquaculture. PRODUCER ORGANISATIONS · PRIVATE SECTOR
RECOMMENDATION 3 **Develop a decision support tool for practitioners to identify suitable seed product and sources**	Map current oyster on-growing network and capacity ACADEMIA · HATCHERIES · RESTORATION NETWORKS · PRODUCER ORGANISATIONS		Monitor increase in on-growing capacity PRACTITIONERS · RESTORATION NETWORKS · PRODUCER ORGANISATIONS		
	Collate Europe-wide maps of notifiable diseases, including areas of unknown disease status ACADEMIA · REGULATORS · PRACTITIONERS · RESTORATION NETWORKS	Online tool developed for projects to identify suitable seed supply PRODUCER ORGANISATIONS · PRACTITIONERS · REGULATORS · RESTORATION NETWORKS			Updates to online tool ACADEMIA · HATCHERIES · REGULATORS
RECOMMENDATION 4 **Address critical knowledge gaps of *Ostrea edulis* genetics, develop effective disease screening tools**	Secure research funding to address knowledge gaps and optimise disease screening technology ACADEMIA · GOVERNMENT · REGULATORS · HATCHERIES		Undertake research on genetic structure of native oysters across Europe ACADEMIA · HATCHERIES · REGULATORS		Understand the risk profile of utilising certified Bonamia free oyster seed from Bonamia positive areas ACADEMIA · HATCHERIES · REGULATORS
			Develop non-destructive testing methods acceptable for regulated movement of bivalves for restoration ACADEMIA · HATCHERIES · REGULATORS		Review disease monitoring practices and regulations on the use of disease resistant or tolerant oysters REGULATORS · GOVERNMENT · PRODUCER ORGANISATIONS · ACADEMIA
			Understand the impact of provenance, genetic diversity and disease resistance on oyster survival and fitness ACADEMIA · PRACTITIONERS · REGULATORS		
			Advance physiological understanding and biotechnology to enhance larval survival and fitness in hatcheries ACADEMIA · HATCHERIES		
RECOMMENDATION 5 **Develop accessible guidance on the movement of oysters for restoration purposes**	Summarise the current legal requirements and restrictions on movements both within and between countries and identify uncertainty ACADEMIA · GOVERNMENT · RESTORATION NETWORKS · PRODUCER ORGANISATIONS · HATCHERIES		Develop clear pan-European guidance, that addresses identified regulatory uncertainty REGULATORS · ACADEMIA · PRODUCER ORGANISATIONS · PRIVATE SECTOR		
RECOMMENDATION 6 **Develop skills pipeline for hatcheries**	Map out existing skill gaps in European hatcheries GOVERNMENT · PRODUCER ORGANISATIONS · EDUCATION SECTOR · HATCHERIES		Expand training programmes in low trophic aquaculture and regenerative aquaculture GOVERNMENT · PRODUCER ORGANISATIONS · EDUCATION SECTOR · HATCHERIES		



INTRODUCTION

VISION 2040: Hatchery production of *Ostrea edulis* is increased to meet the tailored demands of Europe-wide restoration and regenerative aquaculture efforts. Product requirements and appropriate sourcing is clearly understood across both supply and demand, with a wide range of broodstock genotypes available for purchase. Clear, consistent and feasible regulation is in place for the movement of oysters from/to restoration areas, shaped by scientific advancement. This is supported by a skilled workforce available for European native oyster hatcheries to deliver at scale.

The vision and roadmap for delivery has been identified and co-developed with the European native oyster *Ostrea edulis* production and restoration communities. Through a series of workshops and targeted outreach, questionnaires and formal consultation, >100 stakeholders have contributed to the co-design of this roadmap. A strategic roadmapping methodology was followed[1], with the wider restoration community informing the understanding of the current state and the vision, and hatchery managers, disease experts and industry representatives identifying the steps necessary to achieve the vision. A consultation on the draft roadmap between 27th November 2025 - 6th January 2026 was launched at the NORA6 conference in Cartagena and all responses considered in developing the final version.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1 Phaal R., 2017. Strategic Roadmap Template with Facilitation Guidance https://engage.ifm.eng.cam.ac.uk/roadmapping-templates/ Accessed on October 18 2024

VISION 2040:

Hatchery production of *Ostrea edulis* is increased to meet the tailored demands of Europe-wide restoration and regenerative aquaculture efforts.

CONTEXT AND MOTIVATION

Native oyster reefs were once widespread along European coasts, but suffered more than two centuries of overexploitation and were collapsed by the early 1900s[2]. Recent efforts to improve the degraded status of European seas and coasts has included increased interest in actively restoring native oyster reefs. As the ecosystem is Collapsed[3], oyster populations at many locations are extirpated or present at levels below which populations are self-sustaining and reef building. With the anticipated growth in restoration efforts required to meet England's Environment Improvement Plan and the European Commission's Nature Restoration Regulation, many more oysters will need to be available for restoration in the coming decades.

In locations currently still supporting sustainable populations, harvest from managed fisheries or spatting ponds may support local or small scale restoration efforts. For locations where local populations are much diminished or absent or unable to support restoration without diminishing the wild stock, and/or where spatting ponds may be logistically difficult to establish, hatchery production of oysters may provide the most appropriate source of oysters for restoration. Currently, however, restoration projects widely report a lack of availability of oyster seed for restoration efforts. Furthermore, though projects stated a preference for oysters of a particular size, settlement substrate or genetic heritage, as recommended in the Native Oyster Restoration Alliance Berlin Recommendations[4], restoration practitioners reported difficulties in sourcing oysters that meet these specific requirements. Questionnaires completed by restoration practitioners (N=21) highlighted that the interest in spat on substrate and larvae is increasing. While many projects to date have worked with adult or subadult oysters, spat on shell or rock substrate and remote setting of hatchery produced larvae will become increasingly important as we move to larger scale restoration as project managers look to mitigate the biosecurity risk associated with translocating adult oysters[5]. Several oyster hatcheries have been investing and experimenting with larval production and transport, novel substrate materials and broodstock, but highlight that challenges remain regarding the volume and consistency of orders, and a lack of clarity regarding which oyster products will be demanded in the medium and long term.

2 Thurstan, R.H., McCormick, H., Preston, J., Ashton, E.C., et al., 2024. Records reveal the vast historical extent of European oyster reef ecosystems. *Nature Sustainability* 7:1719–1729 https://www.nature.com/articles/s41893-024-01441-4

3 Zu Ermgassen, P.S., McCormick, H., Debney, A., Fariñas-Franco, J.M., Gamble, C., Gillies, C., Hancock, B., Laugen, A.T., Pouvreau, S., Preston, J. and Sanderson, W.G., 2025. European native oyster reef ecosystems are universally collapsed. *Conservation Letters*, 18(1), p.e13068.

4 Pogoda, B., Brown, J., Hancock, B., Preston, J., Pouvreau, S., Kamermans, P., Sanderson, W. and Von Nordheim, H., 2019. The Native Oyster Restoration Alliance (NORA) and the Berlin Oyster Recommendation: bringing back a key ecosystem engineer by developing and supporting best practice in *Europe. Aquatic Living Resources*, 32, p.13.

5 Zu Ermgassen, P., Gamble, C., Debney, A., Colsoul, B., Fabra, M., Sanderson, W. G., Strand, Å., & Preston, J. (Eds.), 2020. European Guidelines on Biosecurity in Native Oyster Restoration. Zoological Society of London. https://nativeoysternetwork.org/resources

This roadmap seeks to identify the steps required for hatcheries across Europe to scale up production of oyster seed to meet the specific demand and anticipated volume from future ecosystem restoration activities.

STAKEHOLDER GROUPS	DESCRIPTION
Academia	Organisations concerned with the pursuit of research, education, and scholarship, e.g. universities/higher education institutions, consultancies.
Producer organisations	Organisations with aquaculture industry membership, that may collectively represent the views of its members, e.g. Aquaculture Advisory Council, European Molluscs Producers' Association, Shellfish Association of Great Britain.
Hatcheries	A facility that produces bivalve larvae and spat under controlled conditions. Referring to both commercial hatcheries and research hatcheries.
Restoration networks	Communities of practice that promote restoration, e.g.: Native Oyster Restoration Alliance, Native Oyster Network UK & Ireland, Seascape Network, Society for Ecological Restoration Europe.
Practitioner	Those undertaking oyster reef restoration, they may be contractors, local community groups, Non-Governmental Organisations or others.
Government	Referring to government departments responsible for formulating and implementing policies.
Regulators	Including regulatory and supervisory bodies responsible for monitoring and licencing shellfish related activities.
Education sector	Vocational colleges, apprenticeships and further education institutes.
Private sector	Corporates and financial institutions, industry.

SIX RECOMMENDATIONS TO SCALING UP *O. EDULIS* HATCHERY PRODUCTION IN EUROPE

BARRIER	RECOMMENDATION
Limited and inconsistent demand for oyster seed from current restoration efforts and regenerative aquaculture. Limited supply of restoration appropriate products from producers.	**Recommendation 1** Increase confidence in the demand for native oysters
Lack of investment pipeline to scale up hatchery production.	**Recommendation 2** Secure diverse investment for market growth
Lack of clarity in the restoration community about seed sourcing options and planning timescales.	**Recommendation 3** Develop a decision support tool for practitioners to identify suitable seed product and sources
Limited understanding of long-term ecological impact of source broodstock on genotypes and disease status.	**Recommendation 4** Address critical knowledge gaps of *Ostrea edulis* genetics, develop effective disease screening tools
Lack of guidance on oyster movement applicable to restoration activities.	**Recommendation 5** Develop accessible guidance on the movement of oysters for restoration purposes
Lack of skilled technicians to support scaling up of hatchery production.	**Recommendation 6** Develop skills pipeline for hatcheries

RECOMMENDATION 1

Increase market confidence in the demand for native oysters

YEAR	ACTIONS	ACTORS
By 2028	Raise awareness of the need for large scale oyster restoration	Academia, Producer organisations, Restoration networks, Practitioners
By 2030	Monitor post deployment survival and growth to evidence viability of restoration and aquaculture of *O. edulis*	Government, Practitioners, Hatcheries, Private Sector
	Scaled up restoration efforts enable quantification of biodiversity and ecosystem service benefits	Government, Practitioners, Academia, Private Sector
By 2040	Large-scale restoration is commonplace	Academia, Practitioners, Producer organisations, Private sector

Inconsistent demand for *O. edulis* seed was highlighted by hatchery managers as a reason why hatcheries are often unable to meet the specialised demand for oyster seed from oyster restoration projects. Furthermore, hatchery managers reported struggling to find investment for scaling up, due to a lack of confidence in the future market size. Educating potential investors as to the likely growth in demand of oyster seed, as well as increasing the evidence base for future market growth, were seen as key steps to increasing market confidence. Drivers of demand include the scale up in production that will be required to meet key environmental policy targets for habitat restoration (UK) and through the expansion of a regenerative aquaculture sector.

Increased market confidence can be achieved through larger and more consistent orders being placed, as will be necessary when restoration is undertaken at a large scale. Large scale deployments both in the inshore and offshore areas will be necessary for ecosystem scale recovery, as mandated in the Nature Restoration Regulation and in the Environmental Improvement Plan (England) and Wales Native Oyster Action Plan. Offshore Wind Farm Operators have the potential to contribute significantly to scaling up restoration efforts in offshore areas, by including oyster restoration and aquaculture features in nature positive design and installation measures (e.g. spat on scour protection) if undertaken as part of the installation.

© ASML Ltd. for Marine Conservation Society (Bangor University produced spat on shell in the Milford Haven waterway, Pembrokeshire, Wales)

Increased and consistent demand may also be achieved through growth in the demand for *O. edulis* seed from aquaculture. Currently the vast majority of aquaculture producers focus on the intertidal non-native Pacific oyster species (*Magallana gigas*, formerly *Crassostrea gigas*). This shift was initially driven by declines in *O. edulis* due to overexploitation and disease resulting in the need to look for an alternative commercial oyster. There is currently low demand for *O. edulis* seed from commercial growers due to its disease susceptibility, slower growth and lower market demand. Evidencing the post deployment growth, mortality and ecosystem service benefits from native oysters deployed in a variety of settings, including commercial aquaculture, both inshore and offshore, will provide key data for adaptive management of restoration efforts and for developing appropriate commercial systems for the predominantly subtidal native oyster. Research and innovation to optimise *O. edulis* aquaculture technology is needed to demonstrate the viability and quantify the benefits of a regenerative commercial *O. edulis* market.

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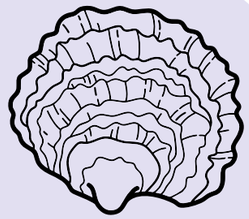
Regenerative Aquaculture



Regenerative aquaculture can span a range of activities from impact reduction to conservation action, but is commonly used to refer to aquaculture that has direct ecological benefits to the environment, with the potential to generate net positive environmental outcomes[6]. In the context of growing *O. edulis* for food production, there is significant scope for positive interactions between aquaculture and restoration. These include water quality improvements as a result of shellfish aquaculture and increased broodstock biomass in the system that could, if appropriately sited and representative of appropriate genetic provenance, have the potential to benefit wild populations through increased larval production. While a framework for assessing the potential wider ecological benefits of and best practice associated with regenerative aquaculture is currently lacking, regenerative aquaculture has a key role to play in a regenerative, sustainable Blue Economy[7].

6 Alleway, H. K., Waters, T. J., Brummett, R., Cai, J., et al., 2023. Global principles for restorative aquaculture to foster aquaculture practices that benefit the environment. *Conservation Science and Practice*, 5, e12982. https://doi.org/10.1111/csp2.12982

7 Le Gouvello, R. and Simard, F., 2024. Towards a regenerative blue economy. *Mapping the Blue Economy, International Union for Conservation of Nature.*

RECOMMENDATION 2

Secure diverse investment for market growth

YEAR	ACTIONS	ACTORS
By 2028	Develop a business case and secure investment for seed production	Private sector, Practitioners, Government, Hatcheries
By 2029	Co-develop programme of support within government blue investment strategies	Government, Producer organisations, Private sector
By 2040	*O. edulis* is widely adopted in regenerative aquaculture	Producer organisations, Private sector
	Marine natural capital markets include oyster reef restoration and regenerative aquaculture	Government, Producer organisations, Academia, Private sector

An increase in *O. edulis* seed production is necessary to meet legally mandated restoration targets and growth in regenerative aquaculture, yet confidence in growth of demand is still lacking due to the inadequate funding model currently in place for restoration across Europe[8]. Marine restoration in Europe is largely funded by government, philanthropic and research grants that are typically limited to a few years in duration, making it challenging for restoration projects to commit to long term planning of orders. Diversifying investment into *O. edulis* seed production to include private finance may add much needed stability and confidence for scaling up production and meeting the specific demands of restoration efforts.

In addition to increasing the market confidence in the demand for *O. edulis* seed (Recommendation 1), diversifying the sources of investment into seed production is critical for ensuring stability and growth in production. Both government support and development of natural capital markets can play a role. Government schemes can provide capital investment for infrastructure and help reduce risk of private investment. Natural capital markets require sufficient confidence in the return on investment. In this instance that requires the ecosystem services arising from scaled up oyster habitat restoration to be quantified, the contextual drivers of variation in ecosystem services delivery to be understood (e.g. nutrient removal may be dependent on sediment composition and proximity to other biogenic habitats), and regulatory drivers to ensure demand for resulting credits. The steps required for developing a high integrity natural capital markets have been laid out in a recent report[9].

There are excellent examples of government investment resulting in market growth in hatchery production from both Europe and the U.S.A., that illustrate the critical role that long-term government investment and blended finance can play in ensuring growth and success of hatchery production. In the Chesapeake Bay, USA, long-term federal and State support for the Horn Point Oyster Hatchery has resulted in a state of the art facility that produces hundreds of millions of eastern oyster (*Crassostra virginica*) spat a year, primarily for restoration purposes, but also for aquaculture. The development of this hatchery has been critical to the success of restoring Chesapeake Bay tributaries, as was legally mandated in 2014.

Norwegian National Cod Breeding Programme Case Study

There are a number of similarities between the current situation for hatcheries producing *O. edulis* seed and hatcheries that produced cod, *Gadus morhua*, in the early 2000s. In the early 2000s hatchery production of cod faltered due to a lack of profitability resulting from a combination of low prices and high mortalities during production. Over the period 2008-2013, the cod farming industry collapsed. The industry has, however, subsequently turned around following the decades-long efforts of the Norwegian National Cod Breeding Programme; a programme launched in 2003 and funded by the Norwegian Ministry of Trade, Industry and Fisheries, that invested in the research required to improve cod yields from hatchery production. Following more than a decade of government support for the breeding programme, hatchery production of cod made a breakthrough in 2015, achieving higher survival, growth and disease resistance. Re-established cod farms are now moving into profitability as a result.

Horn Point Hatchery Case Study

As part of the 2014 Chesapeake Bay Watershed Agreement, Maryland State committed to restoring oyster reefs in five Chesapeake Bay tributaries by 2025. The Horn Point Hatchery in Cambridge, Maryland is the largest hatchery on the east coast of the USA, and has played a pivotal role in this effort, producing hundreds of millions of spat a year for restoration over this period[10]. The establishment and maintenance of this large facility has been made possible through the consistent support of both agencies, in particular NOAA and the State of Maryland. The large-scale and long-term commitment of the Federal and State governments to undertaking restoration to meet legally mandated restoration goals, has supported the state of the art facilities and specialised technicians required to consistently produce such large numbers of oyster spat. As an indication of the level of investment in restoration (including deployment, which has been largely undertaken by the US Army Corps of Engineers), between 2014 and 2025, Chesapeake Bay Programme partners spent approximately $108 million on oyster reef construction.

8 United Nations Environment Programme, 2023. State of Finance forNature: The Big Nature Turnaround – Repurposing $7 trillion to combat nature loss. Nairobi. https://doi.org/10.59117/20.500.11822/44278

9 Finance Earth Report. High Integrity Marine Natural Capital Markets in the UK – A roadmap for Action. Commissioned by The Crown Estate & Blue Marine Foundation.

10 https://hatchery.hpl.umces.edu/about

RECOMMENDATION 3

Develop a decision support tool for practitioners to identify suitable seed product and sources

YEAR	ACTIONS	ACTORS
By 2027	Collate Europe-wide maps of notifiable diseases, including areas of unknown disease status	Academia, Regulators, Practitioners, Restoration networks
	Map current oyster on-growing network and capacity	Academia, Hatcheries, Restoration networks, Producer organisations
By 2028	Online tool developed for projects to identify suitable seed supply	Producer organisations, Practitioners, Regulators, Restoration networks
By 2030	Monitor increase in on-growing capacity	Practitioners, Restoration Networks, Producer organisations
Continuous to 2040	Updates to online tool	Academia, Hatcheries, Regulators

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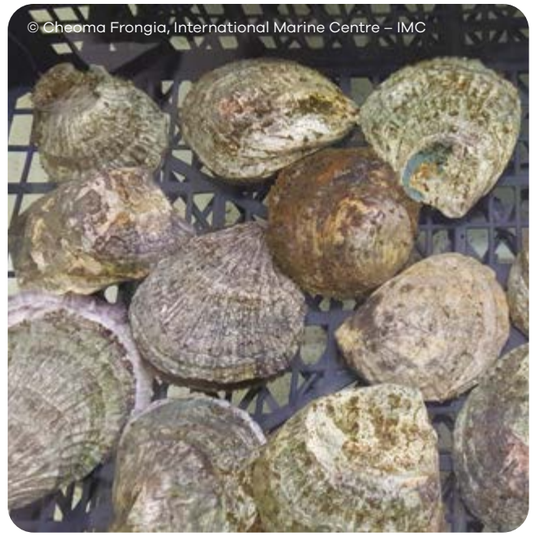
Both hatchery managers and restoration practitioners identified inefficiencies regarding decision making and communication of suitable oyster products for restoration. Overcoming these inefficiencies would allow restoration practitioners to make informed decisions about their oyster suppliers and allow hatcheries to adapt and inform their business plans accordingly.

The near-term actions seek to make accessible currently available information on the geographic distribution of disease status designations across European and UK waters. This includes disease free, notifiable disease control areas and seas currently designated as 'unknown' areas. Mapping onto this the existing on-growing areas/facilities will enable projects to align the appropriate supply sources and ongrowing areas in relation to the disease status of the receiving areas and broodstock used to produce the seed. It will also identify knowledge gaps regarding disease status designations and regulatory gaps relating to shellfish translocation (e.g. to areas of unknown status offshore), as well as gaps in broodstock availability.

To ensure that decisions continue to be informed by the most current science, it is critical that the decision support tool is maintained and consistently updated to reflect any changes in the scientific understanding of genetic population structure, the genetic basis of disease resistance and monitoring and disease regulation.



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Broodstock Sourcing

Hatchery production of seed from locally sourced, adapted stock is often desired as it may increase likelihood of restoration success and maintains genetic diversity in the receiving areas. It is, however, currently often not appropriate or possible for hatcheries to breed from local wild stock due to biosecurity or regulatory barriers. Furthermore, it is important to ensure that broodstock harvest does not negatively impact wild stocks. The lack of diversity in broodstock currently available in hatcheries may also be a factor that limits demand, as restoration projects struggle to access genetically suitable seed. Having a clear overview of the relatedness of stocks across Europe and a genetic breeding programme across European hatcheries may overcome this need for relying on using local stock. This barrier to demand is discussed further in recommendations 4 & 5.

RECOMMENDATION 4

Address critical knowledge gaps of *Ostrea edulis* genetics, and develop effective disease screening tools

Year	Actions	Actors
By 2027	Secure research funding to address knowledge gaps and optimise disease screening technology	Academia, Government, Regulators, Hatcheries
By 2030	Undertake research on genetic structure of native oysters across Europe	Academia, Hatcheries, Regulators
	Develop non-destructive testing methods acceptable for regulated movement of bivalves for restoration	Academia, Hatcheries, Regulators
	Understand the impact of provenance, genetic diversity and disease resistance on oyster survival and fitness	Academia, Practitioners, Regulators
	Advance physiological understanding and biotechnology to enhance larval survival and fitness in hatcheries	Academia, Hatcheries
By 2040	Understand the risk profile of utilising certified Bonamia free oyster seed from Bonamia positive areas	Academia, Hatcheries, Regulators
	Review disease monitoring practices and regulations on the use of disease resistant or tolerant oysters	Regulators, Government, Producer organisations, Academia


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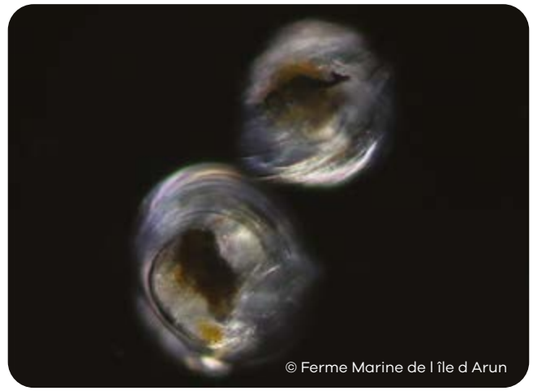
Significant knowledge gaps relating to disease monitoring technology, the mechanisms of disease resistance or tolerance, and the impact of provenance, genetic diversity and disease resistance status on oyster survival remain. These knowledge gaps are currently preventing informed decision making on the disease risks related to the introduction of non-local broodstock into hatcheries and of utilising hatchery reared stock in restoration, both with regards to regulated and non-regulated diseases. Further research is also needed to inform our understanding of the cost effectiveness of restoration actions in areas of unknown disease status with regards to the use of bonamia free certified oysters originally from bonamia positive areas, such as was recently agreed in The Netherlands. Currently we do not fully understand the cellular mechanisms behind disease immunity. It is important to be able to distinguish whether oysters are resistant (resists infection or reduced susceptibility to infection) or tolerant (retention of fitness and reduced virility when infected)[11], as this has implications for both spread of disease and the fitness and survival of oysters used in restoration. Furthermore, the role of genetic diversity and disease resistance in the broodstock on oyster seed survival, and whether disease tolerance genetic markers will persist in areas free from disease is currently unknown but critical for informing restoration decision making and for assessing cost effectiveness.

Existing disease regulation and monitoring is designed to meet the needs of the food production industry. Restoration efforts, however, present a number of unique scenarios. Restoration is currently planned in many areas with limited broodstock available. In these areas, there is interest in adopting disease monitoring protocols that are less reliant on histology, which requires sacrificing many individuals (up to 150 individuals). Optimisation of non-destructive techniques that sufficiently address the risk of disease are required to effectively screen prior to oyster movements. Such methods may also be utilised for restoration projects in areas where oysters are currently locally extinct and therefore cannot be tested for their disease status.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It is recommended that the foundations are laid now for a long term collaboration between regulators, government, industry organisations and academia to review current disease monitoring practices of both *O. edulis* and other species that may act as reservoirs of *O. edulis* diseases. It is further recommended that these actors reflect on how regulations can account for the fast developing technologies for detecting disease and the growing knowledge base related to the use of disease resistant or tolerant oysters.

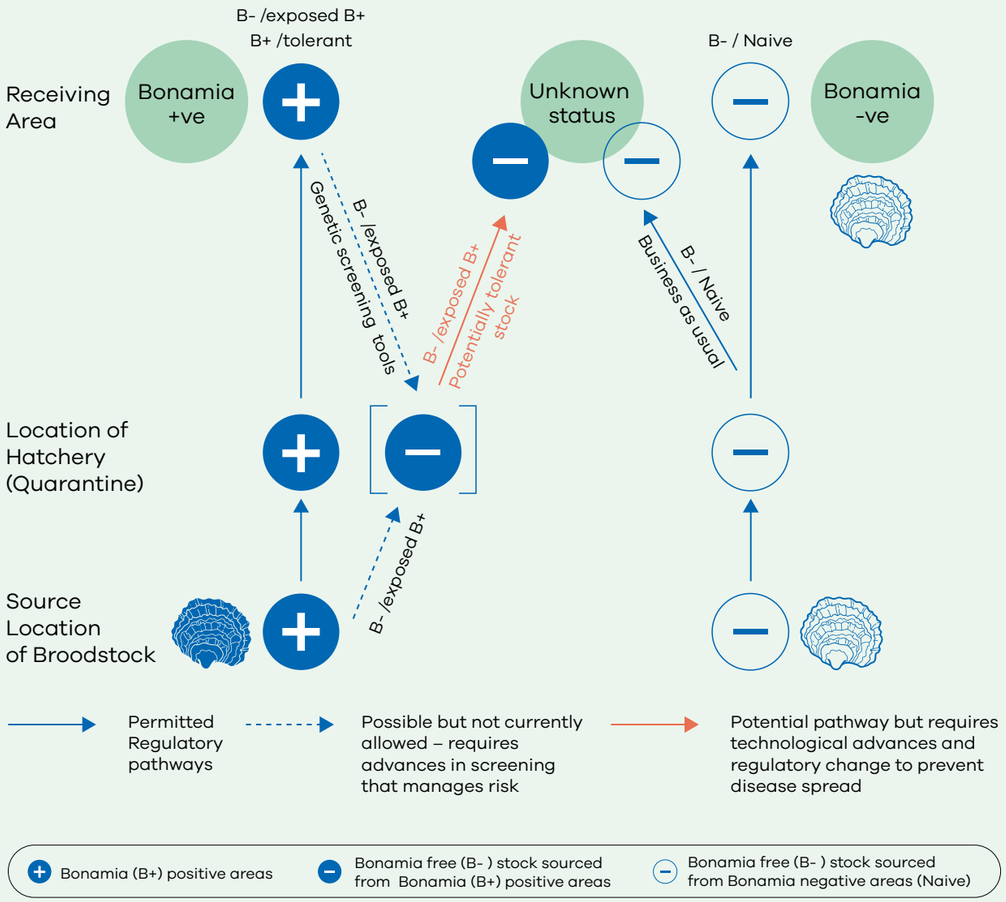
Additionally, research into hatchery protocols and *O. edulis* reproduction and larval metamorphosis should be undertaken to further optimise survival and fitness of larvae and spat produced in hatcheries. Optimisation of larval survival and fitness could increase the productivity and efficiency of hatcheries and therefore increase market confidence.

11 Holbrook, Z., Bean, T. P., Lynch, S. A., & Hauton, C. (2021). What do the terms resistance, tolerance, and resilience mean in the case of *Ostrea edulis* infected by the haplosporidian parasite Bonamia ostreae. Journal of Invertebrate Pathology, 182, 107579. https://doi.org/10.1016/j.jip.2021.107579

Moving into unknown territory

Areas of unknown disease status occur where restoration is planned in areas where *O. edulis* is locally extinct and it is therefore not possible to test individuals for disease. These areas are currently considered as a precautionary measure to be *de facto* disease free. Yet the proximity of some of these areas to disease positive areas raises the question of whether using disease naïve oysters is a reasonable approach. The government of the Netherlands has therefore been exploring seed production from oysters that have been individually tested to be disease free but originally from disease positive areas, with the expectation that the seed produced are more likely to be genetically moreresistant or tolerant to bonamia if it should arrive in the newly restored site.

Figure 1: Current and potential future framework for sourcing and movement of oysters to Bonamia +ve, -ve and areas of unknown disease status.



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RECOMMENDATION 5

Develop accessible guidance on movement of oysters for restoration purposes

YEAR	ACTIONS	ACTORS
By 2027	Summarise the current legal requirements and restrictions on movements both within and between countries and identify uncertainty	Academia, Government, Restoration networks, Producer organisations, Hatcheries
By 2030	Develop clear pan-European guidance, that addresses identified regulatory uncertainty	Regulators, Academia, Producer organisations, Private sector

While clear guidance exists within the aquaculture sector regarding the movement of shellfish, oyster reef restoration presents some novel situations, such as the introduction of oysters into waters of unknown disease status and the production of disease tolerant oysters intended for deployment in such areas. Furthermore, in some locations oyster reef restoration is subject to additional biosecurity regulation, in particular regarding the risk of introducing Invasive Non-Native Species. Therefore, despite international alignment on the movement of oysters in relation to disease status, national level differences in interpretation have resulted in projects and hatcheries finding it challenging to efficiently navigate the regulations.

Development of clear and accessible pan-European guidance, that accounts for national level differences in interpretation, would assist both restoration practitioners and oyster producers by reducing the administrative burden of interpreting complex regulations.

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RECOMMENDATION 6

Develop skills pipeline for hatcheries

YEAR	ACTIONS	ACTORS
By 2027	Map out existing skill gaps in European hatcheries	Government, Private sector, Education sector, Hatcheries
By 2030	Expand training programmes in low trophic aquaculture and regenerative aquaculture	Government, Producer organisations, Education sector, Hatcheries

With the anticipated growth in demand for oyster seed, both existing and newly established hatcheries will require a workforce skilled in bivalve production to provide increased capacity and supply. As demand for oysters increases to meet both ecological restoration targets and increased regenerative aquaculture production, this will be reflected in the diversity of product requirements to meet different sector needs. For example, commercial growers of oysters destined for the food market will likely have nutritional profile requirements and favour rapid growth. In contrast the restoration market stock requirements will be driven by disease resistance, biosecurity concerns and other genetic characteristics. Mapping of skills gaps in aquaculture is already identified as a need in the "Strategic Plan for farming Scotland's seas"[12] and was identified more widely across the group as a key need.


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Skills gaps are best met through a combination of academic and non-academic routes. In training, partnership with commercial entities are key to both affordability and experiential learning. Therefore vocational routes to upskilling on production related skills should form a key part of the skills pipeline. The high running and maintenance requirements of hatchery facilities make partnership with commercial entities a critical element of course development. The practical skills gained would have relevance throughout low trophic aquaculture production, and are therefore key to strengthening the growing sustainable Blue Economy in Europe[13].

12 Scotland Food and Drink, 2016. Aquaculture Growth to 2030. A strategic plan for farming Scotland's seas. https://www.hie.co.uk/media/6164/aquaculture-growth-to-2030.pdf

13 Borriello, A., Calvo Santos, A., Feyen, L., Ghiani, M., et al., The EU blue economy report 2025, Office des publications de l'Union européenne, 2025. Commission européenne, Direction générale des affaires maritimes et de la pêche, https://data.europa.eu/doi/10.2771/2333701

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CONTRIBUTORS

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© ASML Ltd. for Marine Conservation Society (Bangor University produced spat on shell in the Milford Haven waterway, Pembrokeshire, Wales)

ANNEX 1

Methods

This roadmap was developed following the S-Plan process as outlined in Kerr et al. (2019), supported by the Strategic Roadmap Template with Facilitation Guidance (Phaal 2017).

The vision and current state were informed through an online workshop with the Native Oyster Restoration Alliance Production Working Group (6th March 2025), and through a workshop at the Native Oyster Network UK and Ireland meeting in Galway, Ireland, hosted by the Marine Institute (1st-3rd April 2025), as well as through responses from two questionnaires; one aimed at hatcheries that had recently or were currently producing *Ostrea edulis* seed for restoration efforts in Europe, and one aimed at restoration practitioners. Additionally, input was sought from key stakeholders including Cefas, Fish Health Inspectorate, Marine Scotland, Nature Scot and DG Mare through targeted emails and meetings.

A one and a half day workshop was hosted at the Zoological Society of London (6-7th October 2025) to develop the draft roadmap. Representatives from all commercial hatcheries that had recently or were currently producing *O. edulis* seed for restoration purposes were invited, as well as representatives from several research hatcheries or institutes, industry organisations and disease and aquaculture vocational training experts. Workshop participants first discussed the vision and then brainstormed to identify themes relevant to the aims of the roadmap and subsequently voted to identify key themes to be discussed in specific breakout groups. The actions and actors identified in the break out groups were reviewed in plenary before all themes were integrated into a coherent roadmap, again at the plenary level.

The proposed roadmap resulting from the workshop was presented and launched for public consultation at the Native Oyster Restoration Alliance 6 conference in Cartagena, Spain (24-27th November 2025). Key stakeholders were additionally sent the roadmap for consultation. Following the period of public consultation, the responses were taken into consideration in drafting the final report, which was reviewed by the ZSL workshop participants before publication.

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