LOW-TROPHIC AQUACULTURE IN OFFSHORE WIND FARMS

THEMATIC ROADMAP

Advancing Eco-friendly Productivity



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Advancing Eco-friendly Productivity

Introduction

Eco-friendly productivity in offshore low-trophic aquaculture is not achieved through production alone. It depends on how aquaculture is designed, sited, operated, monitored and verified within offshore wind farms.

> In this thematic roadmap, eco-friendly productivity is understood as a practical direction of travel: from reducing negative impacts towards systems that can support ecological functions and, where evidence is strong enough, contribute to more restorative outcomes.

Low-trophic aquaculture is often promoted as inherently sustainable, but positive ecological outcomes can not be assumed simply because production is low-trophic or co-located with renewable energy. Ecological performance depends on site conditions, species selection, production intensity, infrastructure design, harvesting practices, monitoring and governance, as well as site-specific ecological carrying capacity: whether nutrient extraction and use stay within local ecosystem limits, which vary by region depending on nutrient availability, water exchange and ecological conditions.

This thematic roadmap treats eco-friendly productivity as an evidence-based concept, drawing on the Environmental Footprint Assessment, ecosystem-services feasibility screening, governance and certification mapping, and an analysis of wider ecosystem pressures and responses.

It connects ecological ambition with practical implementation and makes clear that stronger claims, such as habitat support, water-quality regulation, biodiversity benefits or restorative effects, require stronger evidence. Rather than prescribing one fixed model, this roadmap offers guidance for moving from responsible pilot activity towards eco-friendly productivity that is credible, verifiable and governable.

Why This Matters

Offshore wind farms are becoming a major part of Europe's marine space, with growing interest in combining energy production with low-trophic aquaculture. Such systems may improve space efficiency, support sustainable biomass production, and contribute to ecological functions such as nutrient uptake, habitat formation or support for marine life.

However, these outcomes remain conditional. Eco-friendly results do not automatically follow from multi-use: a mussel or seaweed system may reduce certain pressures while raising new operational, ecological or governance questions, depending on spatial planning, stocking density, infrastructure and harvesting. Excessive production intensity or unsuitable locations can affect nutrient availability and wider ecosystem functioning, and effects are highly site-specific.

Conventional sustainability approaches, focused on efficiency, impact reduction and compliance, are necessary but not always sufficient where ecological baselines have already shifted: doing less harm shouldn't be confused with demonstrating a positive contribution. There is also a governance gap, since certification schemes are generally better suited to recognising compliance than verifying restorative outcomes, risking overclaiming that can undermine trust.

Eco-friendly productivity is therefore more than a production activity. It needs a system-level view linking ecological performance, operational design, monitoring, governance and verification. The strongest evidence found relates to operational design, monitoring, risk mitigation, material suitability, circularity, decommissioning and stakeholder engagement. Wider claims about ecosystem services, nutrient cycling, water quality and restoration remain more conditional and need stronger, site-specific evidence.



Six Pathways for Eco-Friendly Productivity

1. **Establish a credible evidence base:** start from a clear ecological baseline. Structure evidence through indicators, confidence levels and transparent treatment of uncertainty; keep claims proportionate where evidence is limited.

2. **Move from reducing impacts to increasing benefits:** reducing harm, through better materials, responsible harvesting and equipment retrieval, is good practice but mainly demonstrates responsible operation. Stronger claims need evidence that systems actively support ecological functioning.

3. **Design for ecosystem-service outcomes:** consider potential outcomes (biomass production, nutrient regulation, habitat support, cultural value) during system design, not as an after-the-fact claim. Define expected benefits, possible negative effects and monitoring approaches before deployment.

4 **Strengthen monitoring, harmonisation and adaptive management:** assess operational performance and ecological outcomes over time using appropriate indicators. Sensors, cameras and biological sampling support evidence generation but do not by themselves demonstrate benefit; harmonised protocols improve comparability across sites.

5 **Keep valuation proportional to the evidence:** biomass production is easier to quantify than biodiversity or habitat support, which may be better represented through qualitative indicators. Apply monetary valuation only where evidence is robust; it should never replace ecological assessments.

6 **Embed evidence in governance and verification:** evidence should inform licensing, monitoring, reporting and certification, with ecolabels following robust assessment rather than preceding it. Mitigation-focused schemes may need a purpose-built framework for verified restorative claims.

Together, these pathways show eco-friendly productivity as a staged process, moving from responsible design towards more ambitious claims only where ecological performance can be demonstrated within site-specific limits.



The Way Forward

The next step is repeatable, verifiable practice: define ecological objectives early, agree shared indicators, monitor over seasonal and multi-annual timescales, build in adaptive measures, and communicate uncertainty clearly.

For policymakers, the priority is connecting ecological ambition to licensing and verification requirements. For industry, it is translating these into practical offshore operations. For researchers, it is improving methods to detect and attribute ecological effects in dynamic offshore environments.

Eco-friendly productivity can bridge science, policy and industry, but only if it stays evidence-based and transparent: establish baselines, monitor consistently, adapt when needed, and make stronger claims only when the evidence supports them.

ULTFARMS Policy Brief
Restoration & Nature Inclusive Design

Roadmap for Eco-friendly Productivity - *An integrated synthesis of D7.4*

Across D7.4, eco-friendly productivity is most credibly supported by evidence on offshore design, monitoring, risk mitigation and circularity, while wider ecosystem-service and restorative/regenerative outcomes remain conditional on stronger, longer-term, verifiable evidence.

A. What the roadmap may collectively enable

Evidence-conditioned environmental outcomes

- Responsible offshore / exposed production
- Eco-friendly productivity
- Ecosystem-service contribution
- Restorative / regenerative claims

B. Roadmap prerequisites

Values-based regenerative ambition

- Bottom-up ambition from stakeholder values and shared vision
- Regenerative principles and end-goals
- Social acceptance and motivation

Evidence-based differentiation

- Assessment of what can credibly be claimed
- Confidence, uncertainty and evidence gaps
- Pilot experience and *in-situ* insights

Governance, verification and certification architecture

- Top-down instruments, voluntary standards and labelling frameworks
- Existing ecolabel limits, auditability, and certification readiness
- Market implementation and feasibility

C. Evidence base for the roadmap

Literature review and input from external experts

- Scientific literature and targeted meetings with external experts
- Cross-project insights (UNITED, OLAMUR)

Pilot-generated evidence

- Reporting, field data and pilot lead input
- Operational and ecological evidence

Environmental Footprint Assessment

- Structured scoring framework
- Confidence and uncertainty tracked

DAPSI(W)R(M) system structuring

- Drivers to responses systematically mapped in matrix
- Causal pathways framed

Ecosystem services mind map and feasibility

- Interdependencies and trade-offs identified
- Assessment and ESs valuation feasibility summarised

Governance, standards and certification mapping

- Operational binding and non-binding instruments
- Verification and eco-label implementation pathways mapped

D. Integrated synthesis of D7.4 results

Strongest evidence base

- Operational design, monitoring and risk mitigation are consistently evidenced
- Materials, circularity, retrieval and decommissioning are well documented
- Stakeholder participation and demonstration value are consistently supported

Evidence base requiring substantiation

- Carbon, nutrient and wider regulating-service effects remain unevenly quantified
- Turbidity, water quality and habitat function warrant stronger causal evidence
- Long-term ecosystem effects and valuation robustness remain insufficiently verified

E. Six integrated operational roadmap pathways

1. Credible evidence and assessment basis

- Site-specific baselines, structured indicators & boundaries
- Communicate confidence and uncertainty transparently

2. From eco-efficiency to eco-effectiveness

- Distinguish reduced harm from ecological contribution
- Require site-specific evidence and ecological limits for progression

3. Design for ecosystem-service outcomes

- Define service objectives before deployment
- Link design choices to ecological functions

4. Monitoring, harmonisation and adaptive management

- Integrate monitoring into design and operations from outset
- Improve cross-pilot comparability, documenting interventions

5. ES valuation balanced & proportional to evidence

- Prioritise what can be measured accurately
- Avoid false precision

6. Implementation, governance, verification and certification

- Treat certification as an outcome, not a starting point
- Translate evidence into auditable governance pathways
- Consider a purpose-built framework where existing schemes remain mitigation-focused

F. Co-design foundation

Co-design underpins all evidence interpretation and roadmap development

Pilot engagement, expert consultation, iterative learning, context-specific adaptation and shared ownership and accountability.

Further Reading

ULTFARMS Deliverables

- D7.3 Sustainability goals of business models
- D7.4 LTA aquaculture in OWF and eco-friendly approach

ULTFARMS Scientific Publications

- *Nature Inclusive Design in Marine Infrastructure (abbr.)* - ICES Journal of Marine Science

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