Training programme for the workers of the bivalve mollusc aquaculture sector

Work Package: 4
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OPTIMA
Good Practices in Molluscs Aquaculture

MODULE 2

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1. Short description	Module 2 explores the environmental role and sustainability of bivalve mollusc aquaculture, focusing on ecosystem services, environmental impact, and climate change adaptation strategies.
2. Objectives of the module	This module examines ecosystem services, the environmental impact of bivalve aquaculture, climate change effects, and key adaptation and mitigation strategies.
3. Learning outcomes	Participants will understand the environmental and economic value of bivalve farming, its low environmental impact, and strategies to address climate change challenges in aquaculture.
4. Prerequisites	Not applicable
5. Duration	240 minutes (150 face to face online, 90 e-learning)

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2. Ecosystem Services, Environmental monitoring, risk management and climate resilience

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2.1 Ecosystem services: defi nition, typology and EU policy on the matter

2.1.1 Understand what ecosystem services are

Bivalve mollusc aquaculture provides important ecosystem services, contributing to coastal ecosystem health through habitat protection and the regulation of key biogeochemical cycles.

Bivalves play a crucial role in:

- Seawater filtration
- Carbon and Nutrient Cycle
- Creation of habitats and nursery areas
- Coastal erosion protection

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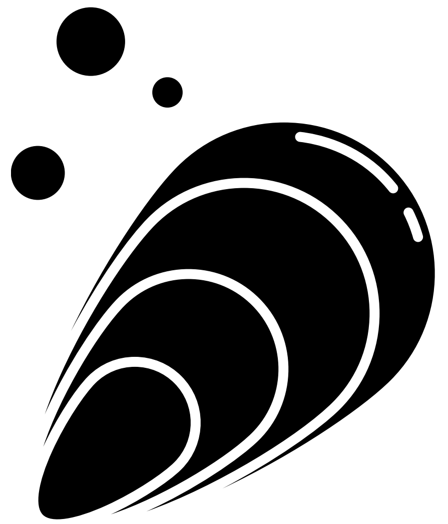
Seawater filtration

Bivalve molluscs provide an important ecosystem service through their ability to **filter large volumes of seawater.**

By feeding on phytoplankton, organic matter, and detritus, **they improve water quality through natural biological filtration.**

Main benefits include:

- **Reduced water turbidity**
- **Lower nutrient levels** (nitrogen and phosphorus)
- **Reduced eutrophication and harmful algal blooms**



Their filtration activity also **improves water clarity**, **supporting the growth of seagrasses and other marine plants**; this contributes to healthier and more productive marine ecosystems.
This service also benefits aquaculture by improving sustainability and **reducing the need for artificial water treatment.**

For example, a single *Mytilus edulis* can filter up to 25 liters of water per day (Smaal and Poutiers, 2003).

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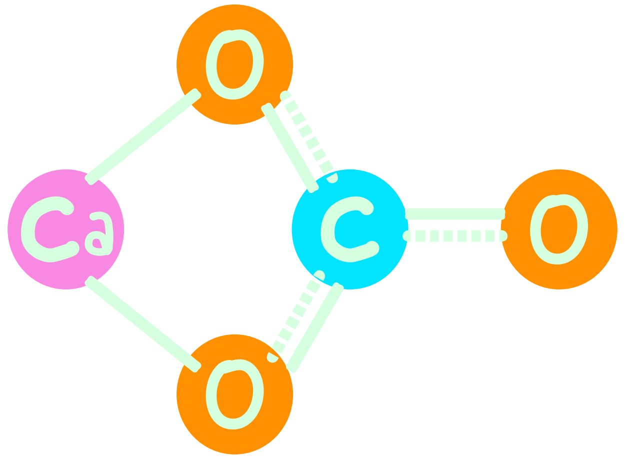
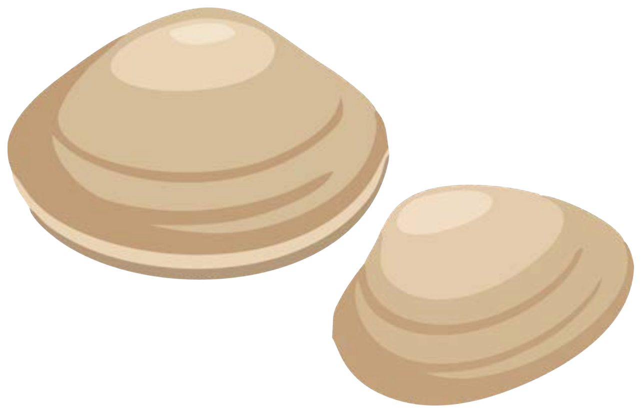
Carbon and Nutrient Cycle

Bivalve molluscs play an important role in the carbon cycle by **absorbing CO_2 from seawater and storing it in their shells as calcium carbonate ($CaCO_3$).**
They also contribute to organic carbon storage through **biomass accumulation and sediment deposition.**



Although shell formation releases some CO_2, the **overall impact of bivalve farming on carbon sequestration is generally positive.**

Bivalves also help regulate the nutrient cycle by **removing excess nitrogen and phosphorus from the water through filtration.**
This **reduces eutrophication, improves water quality**, and supports healthier marine ecosystems.
Their environmental benefits can be **further enhanced in Integrated Multi-Trophic Aquaculture (IMTA) systems.**



➔**Sustainable bivalve aquaculture supports both food production and environmental protection.**

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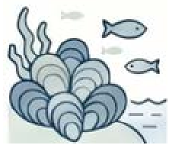
Creation of habitats and nursery areas



Bivalve farms **create habitats that provide shelter and food for many marine species.**

Structures such as ropes, nets, and poles **increase habitat complexity and support both surface and sediment-dwelling organisms.**

This helps **enhance local biodiversity** and **provides nursery areas** for juvenile fish and invertebrates.

Additional benefits include:

- Nutrient cycling
- Sediment stabilization
- Improved ecosystem resilience.

→Bivalve aquaculture **supports biodiversity and the ecological health of coastal ecosystems.**

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Coastal erosion protection

Bivalve farms **help stabilize sediments and reduce coastal erosion.**
Farming structures can **act as natural barriers,** reducing wave energy and **protecting coastlines from storm surges**. This **improves coastal stability** while also supporting **water quality and biodiversity.**

→Bivalve aquaculture contributes to the **protection and resilience of coastal ecosystems.**

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Bivalve Aquaculture: Ecosystem Services & EU Strategy

Essential Ecosystem Services

Biological Water Depuration

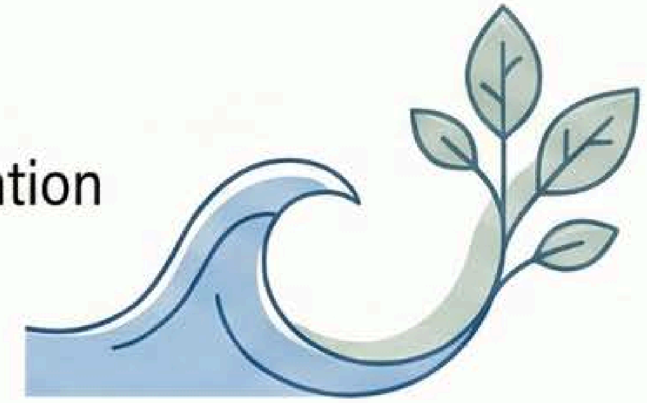
A single blue mussel can filter up to 25 liters of seawater per day.

Carbon & Nutrient Sequestration

Bivalves sequester CO_2 into shells and remove excess nitrogen and phosphorus from the water.

Habitat & Coastal Protection

Farms act as nursery areas for biodiversity and natural barriers against coastal erosion.



EU Strategic Guidelines (2021–2030)

The Green Transition

Promoting low-carbon, resource-efficient practices aligned with the European Green Deal.

Resilience & Competitiveness

Enhancing efficiency and simplifying regulations to support economic growth in coastal regions.

Social Acceptance

Improving transparency and standards to build consumer confidence in sustainable aquaculture.

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2.1.2 Understanding the positive impact ecosystem services have on the marine environment

In 2021, the **Aquaculture Advisory Council (AAC) highlighted the important ecosystem services provided by European aquaculture.**
Within the framework of the European Union Green Deal and Biodiversity Strategy 2030, **aquaculture is recognized as a key contributor to**:

- **Biodiversity protection**
- **Ecosystem enhancement**
- **Sustainable food production**

Aquaculture Advisory Council

➔The AAC especially e**mphasizes the value of bivalve mollusc farming for its environmental benefits.**

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Key recommendations include:

- Recognizing **bivalve farming** as **part of natural and cultural heritage**
- Improving **regulatory protection**
- **Supporting research on ecosystem services**
- Increasing **public awareness** of sustainable aquaculture

→Bivalve farms are recognized not only for food production but also for supporting coastal resilience and ecological stability.

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2.1.3 Understand the EU's strategic guidelines for aquaculture (2021-2030)

The EU Strategic Guidelines for Aquaculture (2021–2030), developed by the European Commission**, provide a common framework to support the sustainable development of the aquaculture sector across EU Member States.**

The main objective of the guidelines is to build an aquaculture sector that balances **environmental sustainability**, **economic growth**, and **social responsibility**.
The sector should be productive and competitive while reducing environmental impact and ensuring long-term resilience.

The guidelines also aim to promote an aquaculture system that is **transparent** and **socially accepted**.
Innovation, **research**, and **knowledge development** are considered **essential for supporting long-term sustainability and sector growth.**

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The **guidelines are built around four core priorities** that shape the future direction of EU aquaculture.

Priority 1

Improve competitiveness and resilience by increasing **efficiency**, **simplifying administrative procedures**, and improving **access to suitable sites and water resources**.

Priority 2

Focus on the **green transition**, encouraging low-carbon, resource-efficient practices and improving **adaptation to climate change.**

Priority 3

Strengthen social acceptance and consumer confidence through better transparency, improved labelling, and high standards of food safety and animal welfare.

Priority 4

Focus on **knowledge, innovation, and digitalisation**, promoting investment in research, new technologies, data systems, and workforce skills.

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To support these priorities, the guidelines identify a range of **key action areas that Member States are encouraged to address** and these include:

- improving **access to space** through marine spatial planning
- **simplifying regulations and licensing**
- **enhancing environmental performance in aquaculture operations**
- **animal health and welfare**
- **market development**
- **public awareness**
- **communication**
- **technological innovation**

Although **the guidelines are not legally binding**, they provide a strategic framework for coordinated action across the EU. ➔ **Member States are expected to implement them through National Aquaculture Plans.**
Financial support is **provided through EU funding mechanisms,** especially the European Maritime, Fisheries and Aquaculture Fund, which supports sustainability, innovation, and sector growth.

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2.2 Impact of bivalve mollusc aquaculture: carbon Footprint analysis and Life Cycle Assessment

2.2.1 Understand what the potential impacts of bivalve mollusc farming are and how can these potential impacts be mitigated

Life Cycle Assessment (LCA)

Is an important tool **used to evaluate the environmental impact of a product or activity throughout its entire life cycle,** from the production of raw materiald to the final disposal of waste.
→ It **helps assess the ecological footprint of bivalve mollusc aquaculture and identify ways to improve sustainability.**

Two main LCA approaches are commonly used:

The **cradle-to-grave** approach **evaluates the entire life cycle**. In bivalve aquaculture, this includes juvenile production, farming, harvesting, distribution, consumption, and waste management.

The **cradle-to-gate** approach **focuses only on the stages before the product leaves the farm**. It mainly includes juvenile production, farming, and harvesting.

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In both cases, LCA helps to:

- **Measure the carbon footprint** by calculating greenhouse gas emissions generated during production and distribution.
- **Evaluate resource use** (consumption of water, energy, and raw materials).
- **Identify environmental impacts** (eutrophication, ocean acidification, and pollution).
- **Compare different farming practices and identify the most sustainable** production methods.

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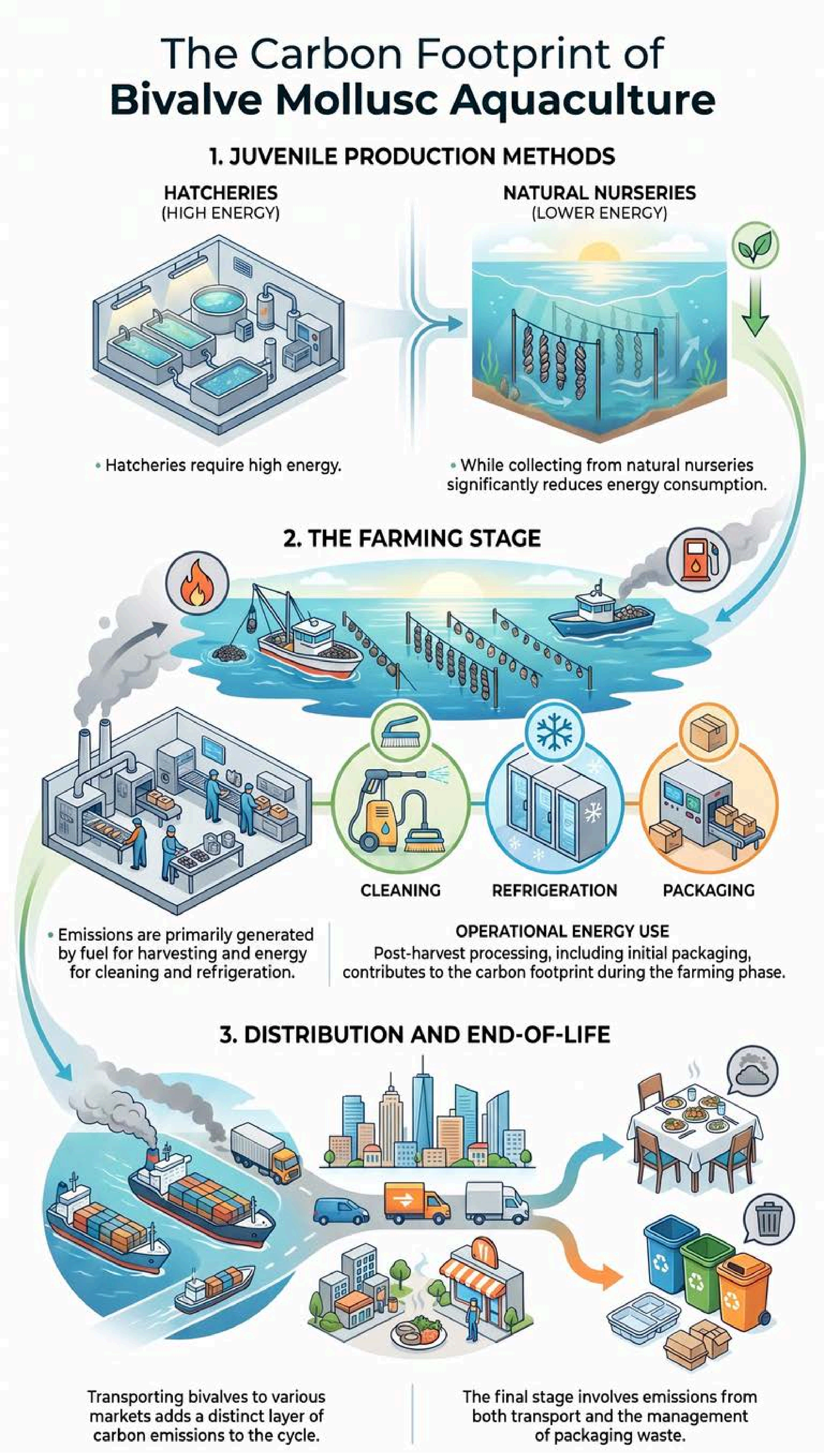

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The life cycle of bivalve mollusc aquaculture includes several phases, each with a specific contribution to the carbon footprint:

- **Juvenile production**, which may occur in hatcheries requiring energy, or through collection from natural nursery areas, reducing energy use.
- The **farming stage**, which mainly generates emissions through fuel consumption for harvesting and energy used for cleaning, packaging, and refrigeration.
- **Distribution and consumption** also contribute to the overall carbon footprint through transport and packaging disposal.

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2.2.2 Know better the Carbon Footprint and the LCA

Assessing the **carbon footprint** of marine bivalve aquaculture **requires** analysing **both CO_2 emissions from farming activities and the metabolic CO_2 balance of the farmed species** and the estimates are also influenced by **site-specific environmental conditions** and the **farming methods** used..

Studies show that **bivalve aquaculture** has a **much lower carbon footprint than other animal production systems**, such as cattle or pig farming.
This is mainly because **bivalves are fast-growing** and have **low energy requirements**, since they feed naturally by filtering seawater.

Bivalves may **also contribute to carbon sequestration by absorbing calcium carbonate from seawater to build their shells.**
After death, the shells can settle on the seabed and store carbon for long periods, potentially helping reduce atmospheric CO_2 levels.

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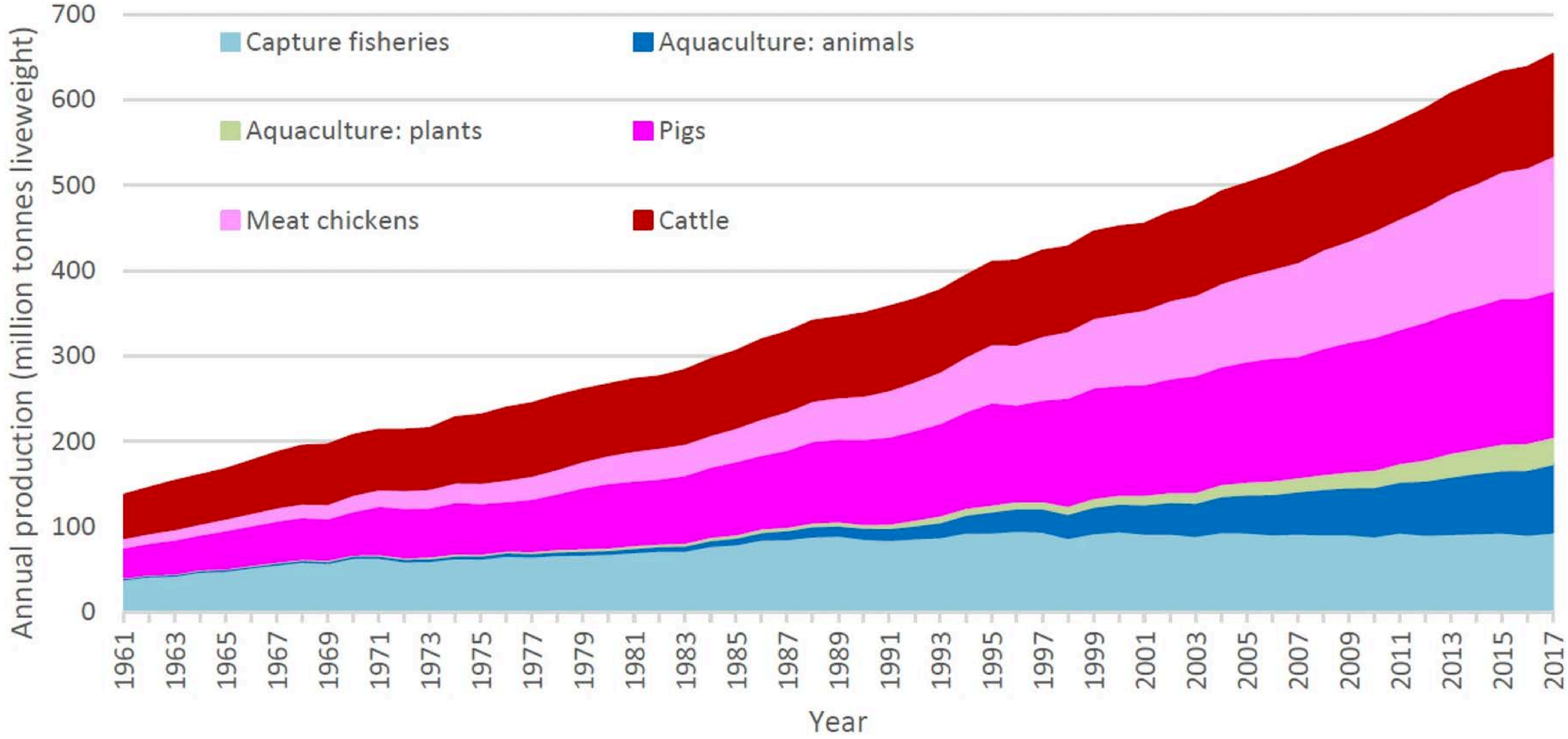

MacLeod, M.J., Hasan, M.R., Robb, D.H.F. et al., 2020. Quantifying greenhouse gas emissions from global aquaculture. Sci Rep 10, 11679

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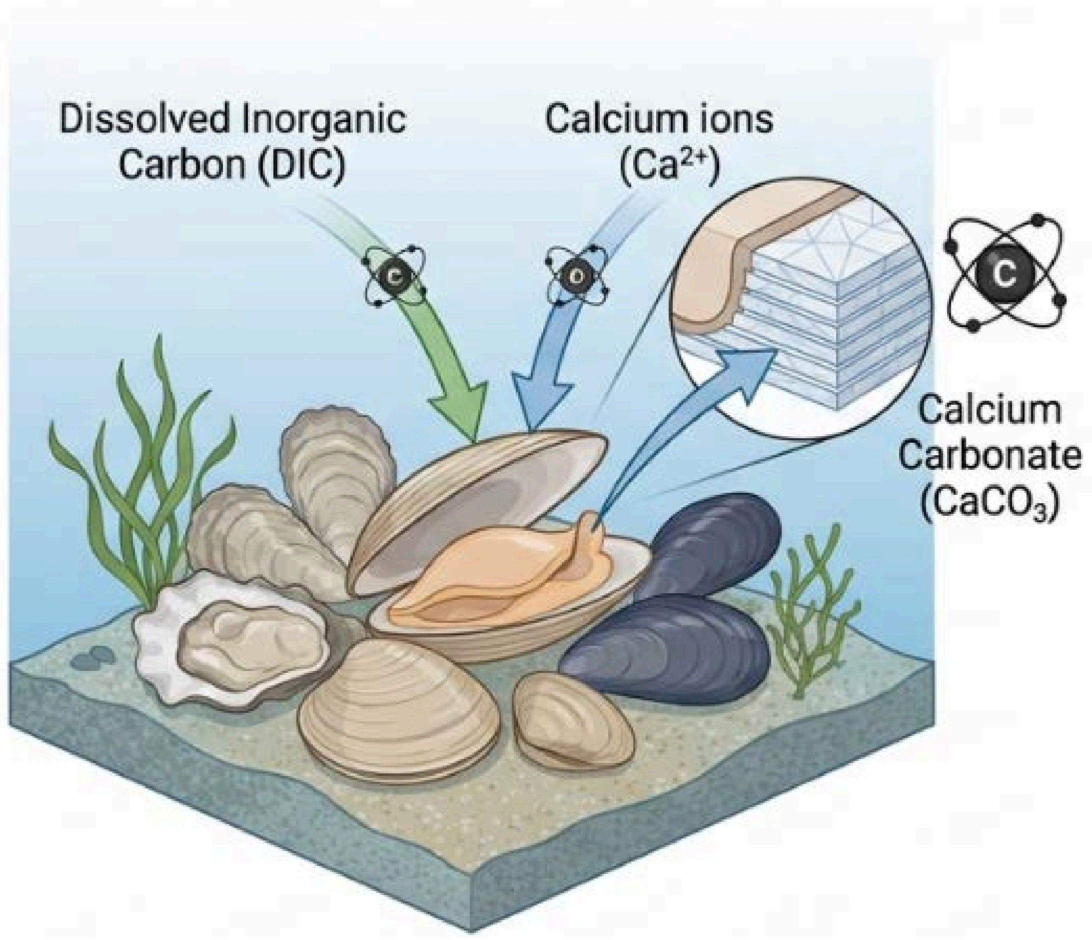
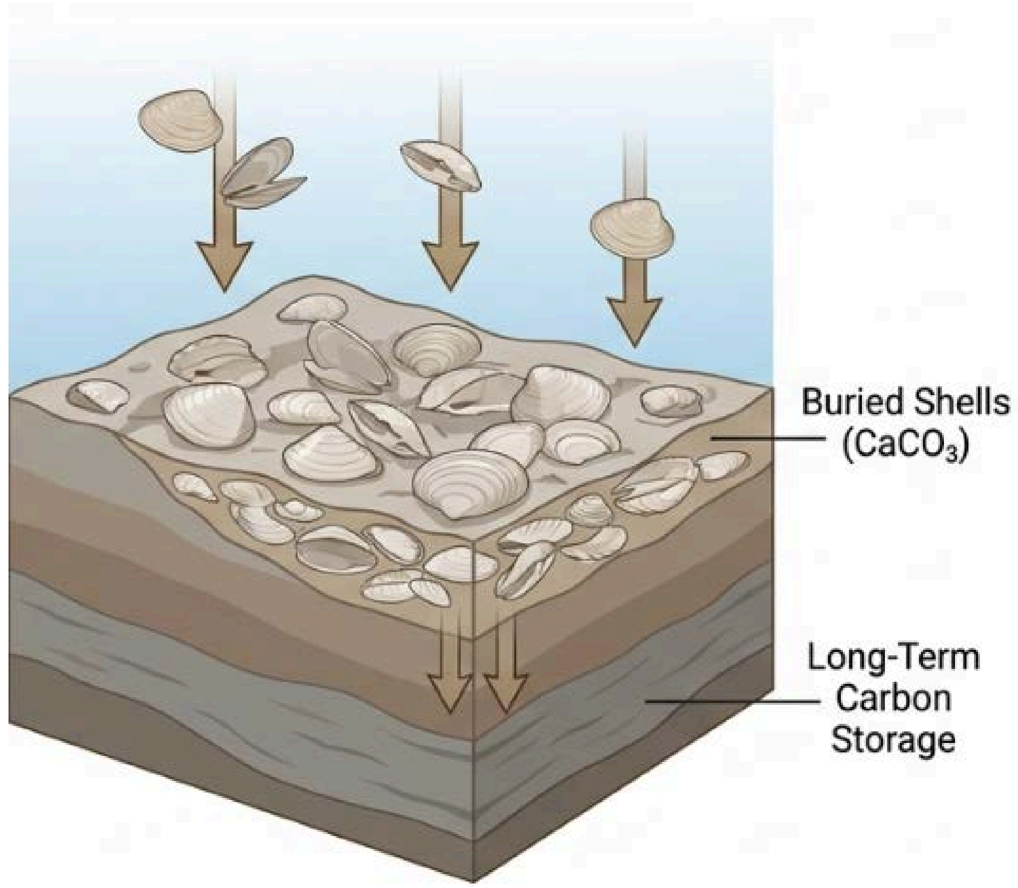
Bivalve molluscs sequester carbon mainly through:

Biomineralization, using calcium carbonate to build shells

Sedimentation, as shells accumulate on the seafloor after death





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Bivalve molluscs sequester carbon mainly through:

- **Species**
- **Environmental conditions**
- **Farm management**
- **Farming system**
- **Location**
- **Waste management**

Bivalve aquaculture has a **very low carbon footprint compared to many other food production systems**.

Greenhouse gas emissions are particularly low for mussel and oyster farming.

The main source of emissions comes from <u>fuel consumption for boats, tractors, and farm operations</u>, especially diesel use, which represents the largest share of emissions.

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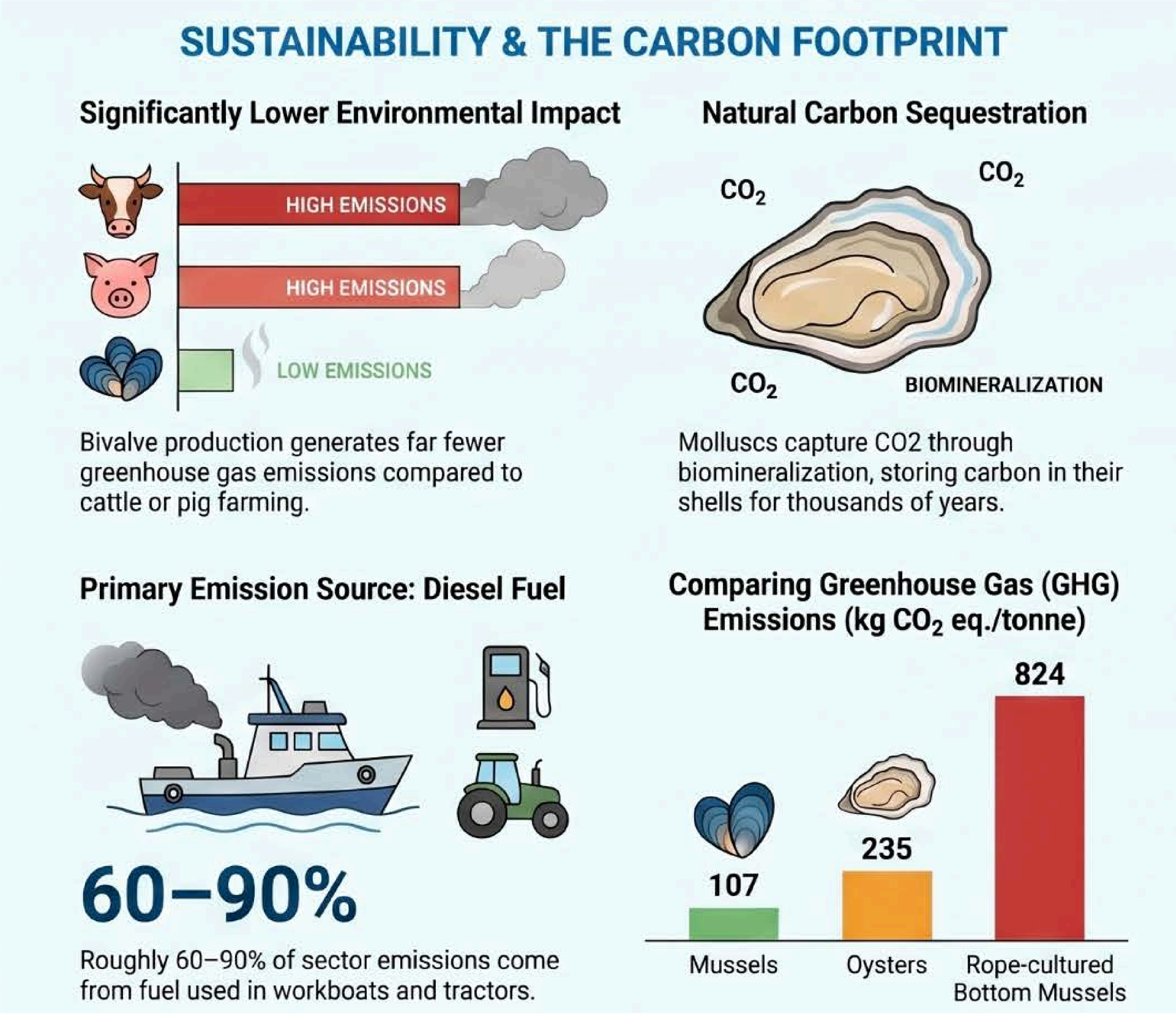

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Further reductions of the carbon footprint can be achieved through:

- **Optimizing energy consumption**
- **Minimize waste production, reuse materials and products for as long as possible and recycle those that are no longer usable.**
- **Recovery and valorisation of by-products** (e.g. shells)
- **Optimizing logistics**
- **Integrated aquaculture**

→ **Aquaculture products generally have a small carbon footprint, making them valuable for supporting carbon reduction targets and improving food security.**

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Carbon footprint assessment remains complex because estimates vary depending on the processes included, the scale of analysis, and site-specific conditions.

Research shows that carbon footprint estimates can change significantly depending on farming practices, such as seeding time and harvest size.
Including carbon stored in mussel waste buried in sediments can further reduce estimated carbon footprints.

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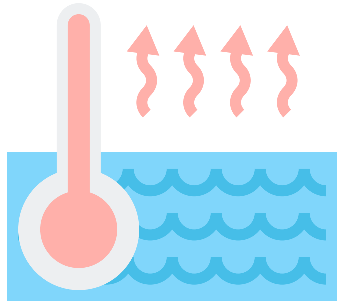
2.3 Assessment of the impact of climate change on bivalve production

2.3.1 Understand the impacts of climate change on aquaculture systems (temperature, salinity changes, oxygen depletion, extreme weather events)

Climate change has major impacts on aquaculture, affecting environmental conditions essential for the growth and survival of fish, shellfish, and seaweed.

- **Rising water temperatures** increase metabolism and may initially improve growth, but excessive heat causes thermal stress, reduced growth, weaker immune systems, and higher mortality.
  Warmer waters also increase the spread of diseases and parasites, making farmed species more vulnerable to outbreaks.



- **Changes in salinity,** especially in coastal and estuarine areas, create stress for aquatic organisms and can negatively affect growth and survival.
  Sudden or extreme salinity changes can cause serious losses, particularly in species with low tolerance.

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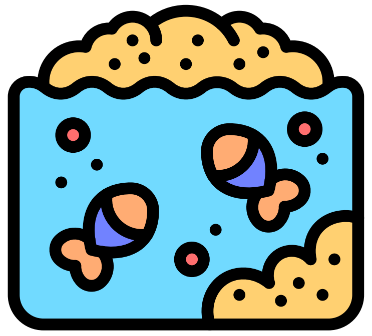
- **Oxygen depletion (hypoxia)** is becoming **more common due to higher temperatures and nutrient pollution.**
  Warmer water contains less oxygen, while eutrophication and algal blooms further reduce oxygen availability.
  Low oxygen levels limit feeding and growth, increase disease risk, and in severe cases cause mass mortality.



- **Extreme weather events**, such as storms and floods, also threaten aquaculture by damaging infrastructure and disrupting farm operations.
  These events can worsen water quality by introducing pollutants, sediments, and pathogens.

→ **Climate change reduces productivity, increases costs, and creates greater uncertainty, making adaptation essential for sustainable aquaculture.**

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2.3.2 Solutions against climate change impacts on bivalve mollusc aquaculture

- Bivalve molluscs contribute to the carbon cycle by **absorbing CO_2 from seawater and storing it in their shells through biomineralization**, or **in the sediment through sedimentation**, helping to store carbon and reduce atmospheric CO_2 levels.

Although shell formation releases some CO_2, the **overall impact of bivalve farming on carbon storage is generally positive**, especially with good environmental management.
Studies show that **mussel farming** can sequester significant amounts of blue carbon, **combining food production with environmental benefits.**

→ **Expanding bivalve aquaculture could serve as a nature-based solution to help mitigate climate change and support carbon sequestration efforts.**

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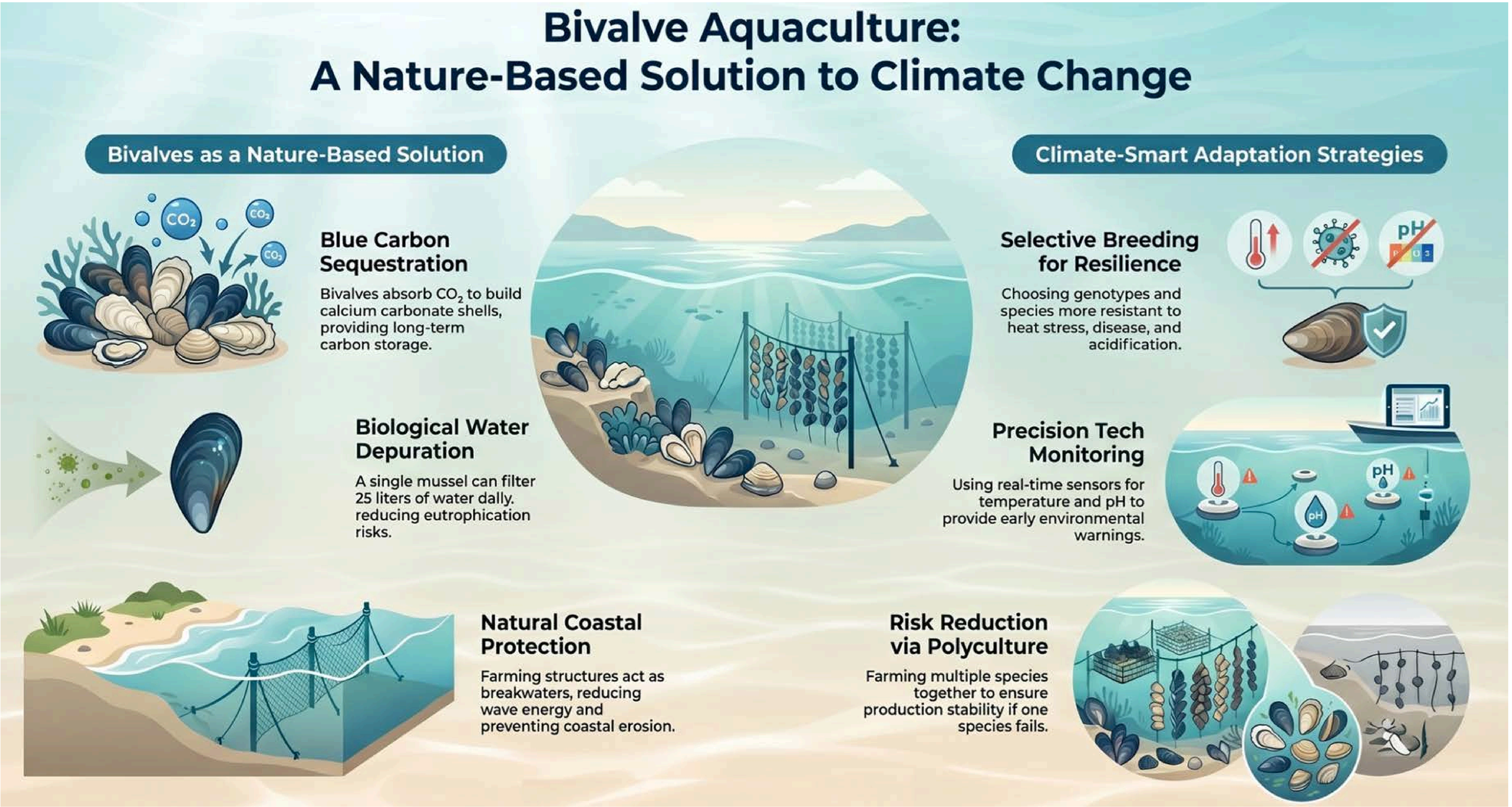

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2.4 Understanding the various farm-level strategies to adapt to and mitigate climate change, including species selection and technological innovations

2.4.1 Understanding how to fi ght the damage caused by climate change to bivalve aquaculture (product movement, selection of genotypes or species more resistant to temperature, polyculture to avoid product loss)

Aquaculture farmers are adopting different strategies to adapt to and mitigate climate change impacts:

- **Species and genotype selection**: choosing or breeding species that are more resistant to higher temperatures, salinity changes, low oxygen, disease, and acidification.
  In bivalve aquaculture, **selective breeding helps improve resistance** in species such as mussels and oysters, supporting productivity **under changing environmental conditions.**

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- **Site selection and relocation:** moving farms to areas with better water quality, more stable salinity, and suitable temperatures.
  In bivalve farming, relocating farms can reduce exposure to harmful algal blooms, hypoxia, and extreme warming.

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  In bivalve farming, relocating farms can reduce exposure to harmful algal blooms, hypoxia, and extreme warming.

- **Product movement strategies**: transferring stock between sites or water depths to avoid unfavorable conditions such as heatwaves or poor water quality.

- **Polyculture**: multiple species are farmed together to reduce risk and improve resilience.
  In bivalve systems, combining shellfish with species like seaweed can improve water quality by absorbing excess nutrients and reducing eutrophication.

→ **These farm-level strategies are essential to improve resilience and ensure sustainable aquaculture production under climate change.**

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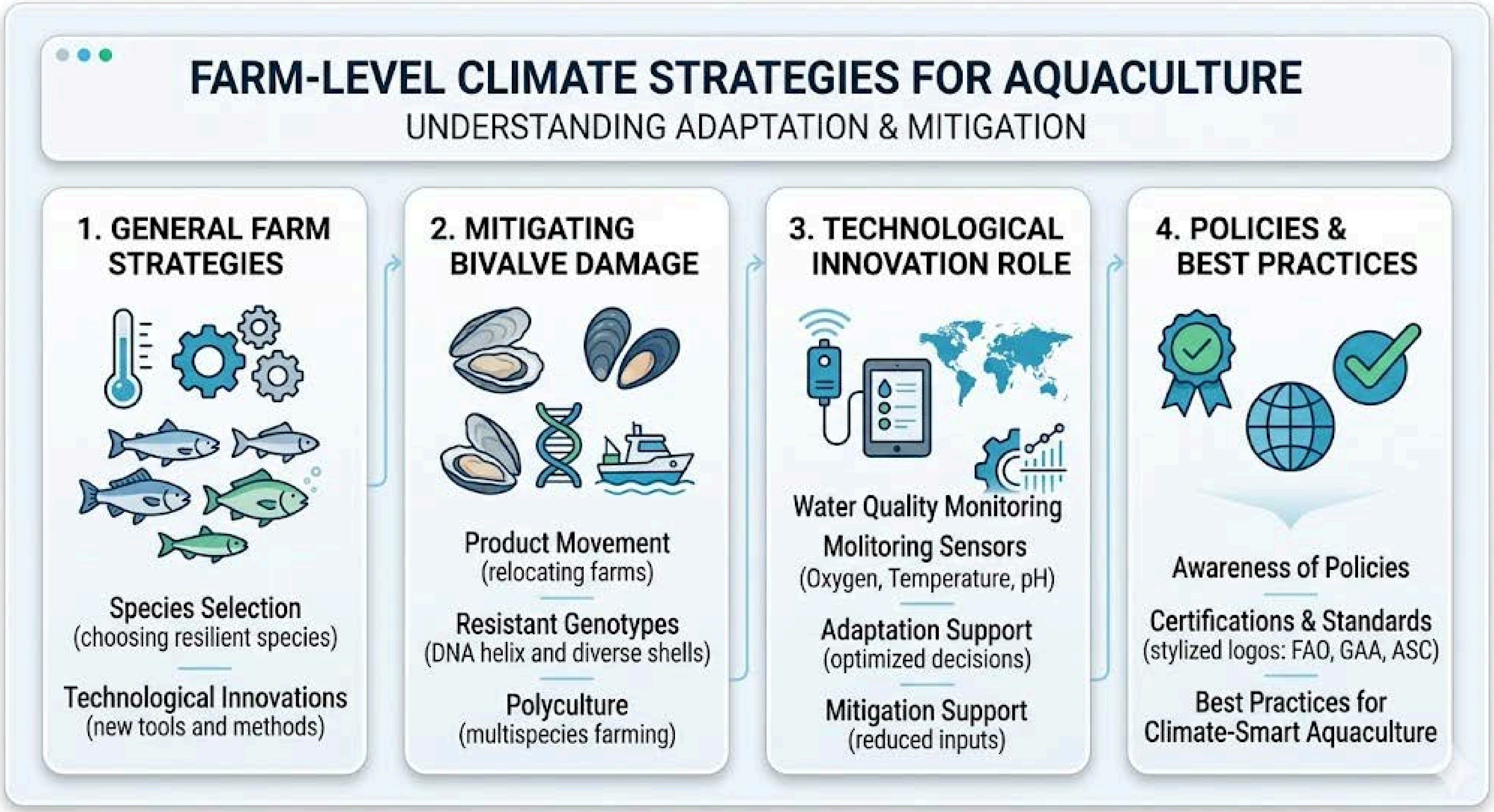

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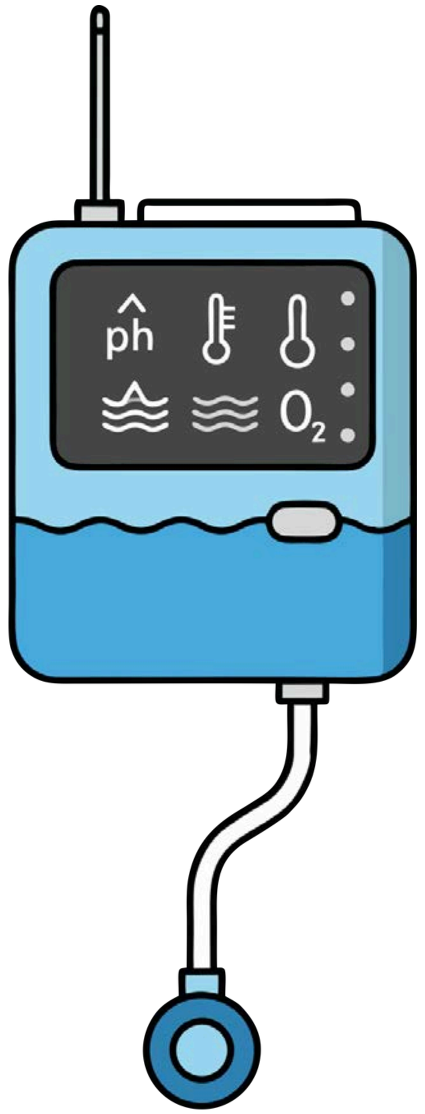
<u>2.4.2 Recognizes the role of technological innovations (water quality monitoring sensors) in adaptation and mitigation</u>

Water quality monitoring sensors are becoming essential tools for helping aquaculture adapt to and mitigate the effects of climate change.

→ <u>In shellfish aquaculture</u>, these technologies are <u>especially important because bivalves are highly sensitive to environmental changes and are difficult to move once deployed.</u>



Real-time sensor networks monitor key parameters such as **temperature**, **dissolved oxygen**, **salinity**, **pH**, and **chlorophyll**.
These sensors **help farmers detect environmental stress early**, including <u>warming events</u>, <u>low oxygen</u>, and <u>salinity changes</u>, allowing **quicker responses**, and **supporting adaptation strategies** such as <u>adjusting stocking density</u>, <u>delaying harvest</u>, or <u>relocating shellfish to safer areas</u>.

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Sensors are also crucial for **monitoring eutrophication and harmful algal blooms (HABs)**, reducing risks to stock, consumer health, and farm productivity.

Sensor data can also be **integrated into digital platforms and predictive models, improving decision-making** and helping farmers prepare for heatwaves, storms, and seasonal environmental changes.

In shellfish **hatcheries**, accurate monitoring of temperature, salinity, and pH is essential for larval development, **improving survival rates and supporting the production of stronger juveniles.**

From a mitigation perspective, sensors **improve farm efficiency** by optimizing stocking densities and harvest timing, **reducing waste accumulation and preventing excessive pressure on local resources.**

In **integrated aquaculture** systems, such as shellfish combined with seaweed, sensors help **monitor nutrient removal** and support more sustainable production.

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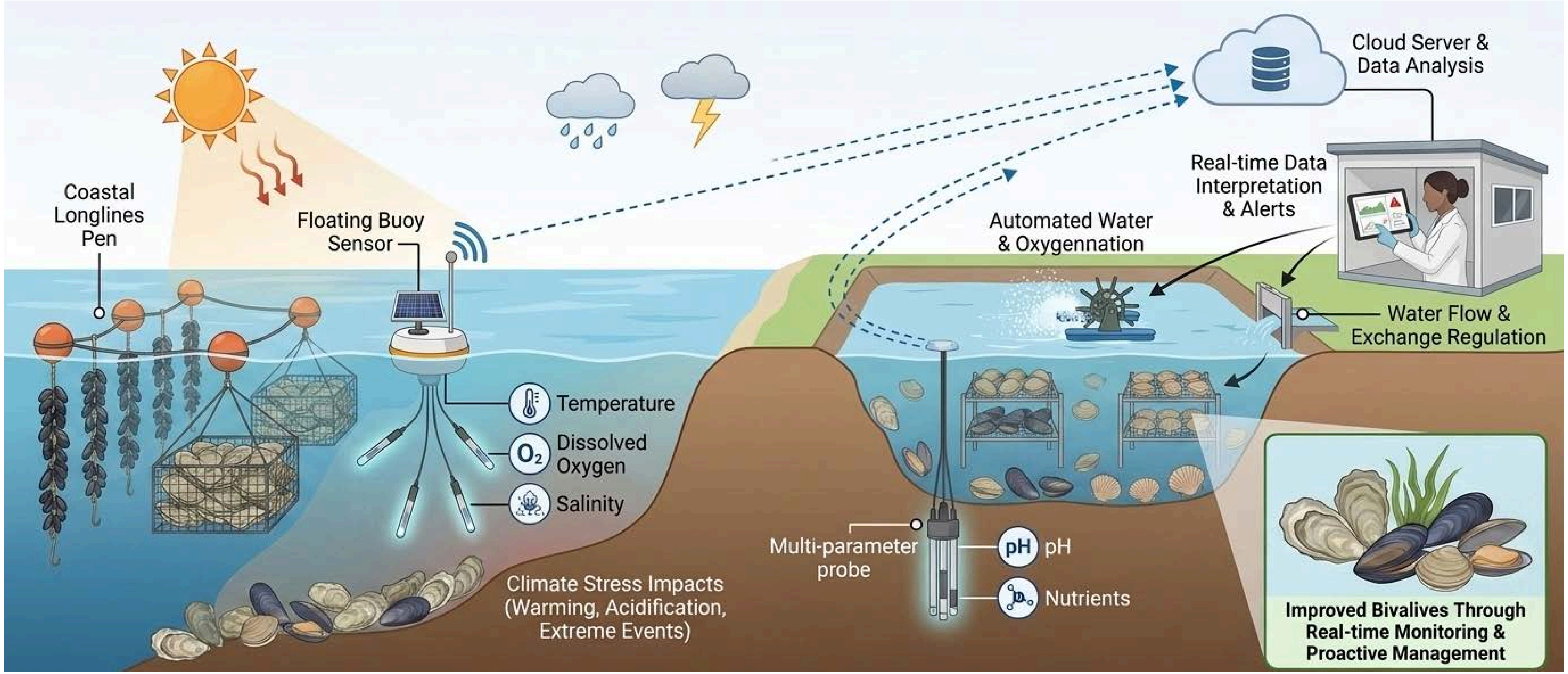

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Examples in shellfish mollusc aquaculture include:

- **Smart buoy systems** with live data transmission
- **Fixed sensor arrays on mussel longlines**
- **Hatchery monitoring systems**
- **Early warning networks for harmful algal blooms,**

Water quality monitoring technologies improve resilience, reduce risks, and support more sustainable and efficient shellfish aquaculture.

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2.4.3 Demonstrating awareness of policies, certifi cations, and best practices promoting climate-smart aquaculture (FAO, GAA, ASC standards)

Climate-smart aquaculture is supported by international policies, certification schemes, and best practices aimed at making aquaculture more sustainable, resilient, and environmentally responsible.

Key organisations such as the **FAO**, **Global Aquaculture Alliance**, and **Aquaculture Stewardship Council** play an important role in promoting sustainable aquaculture.

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- The **FAO** provides **global guidance through policies and recommendations focused on reducing environmental impacts, improving resource efficiency, and increasing climate resilience.**
  ➔FAO strategies include better site selection, ecosystem-based management, and responsible use of water and feed, helping farms adapt to climate-related risks.

- Certification schemes such as **BAP** and **ASC** **establish sustainability standards for aquaculture farms**.
  These certifications focus on key areas including water quality, biodiversity protection, animal health, and social responsibility.
  In the context of climate change, they promote reduced pollution, efficient energy use, and continuous environmental monitoring.
  For shellfish farming, these standards also emphasize maintaining good water quality and protecting surrounding ecosystems.

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Best practices promoted under these frameworks include:

- **regular water quality monitoring**
- **responsible stocking densities**
- **use of resilient species**
- **waste reduction**

They also encourage innovations such as **integrated multi-trophic aquaculture**, for example combining shellfish with seaweed to improve sustainability.

→ **These policies and certifications help aquaculture become more resilient to climate change while reducing environmental impacts.**

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