European Aquaculture

The European Union (EU) has identified aquaculture as a strategic sector for delivering sustainable food systems, in alignment with the European Green Deal, the Farm to Fork Strategy, the Biodiversity Strategy, and the recently adopted Nature Restoration Law. The Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture provide a shared framework for Member States and stakeholders to increase competitiveness and resilience while improving environmental and climate performance.

Sustainable Aquaculture

The most often quoted definition comes from the UN World Commission on Environment and Development: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Sustainability - Sustainable Aquaculture
Sustainable aquaculture must include:

- Environmental sustainability — Aquaculture should not create significant disruption to the ecosystem, or cause the loss of biodiversity or substantial pollution impact.
- Economic sustainability — Aquaculture must be a viable business with good long-term prospects.
- Social and community sustainability — Aquaculture must be socially responsible and contribute to community well-being
- Energy sustainability - originally not included

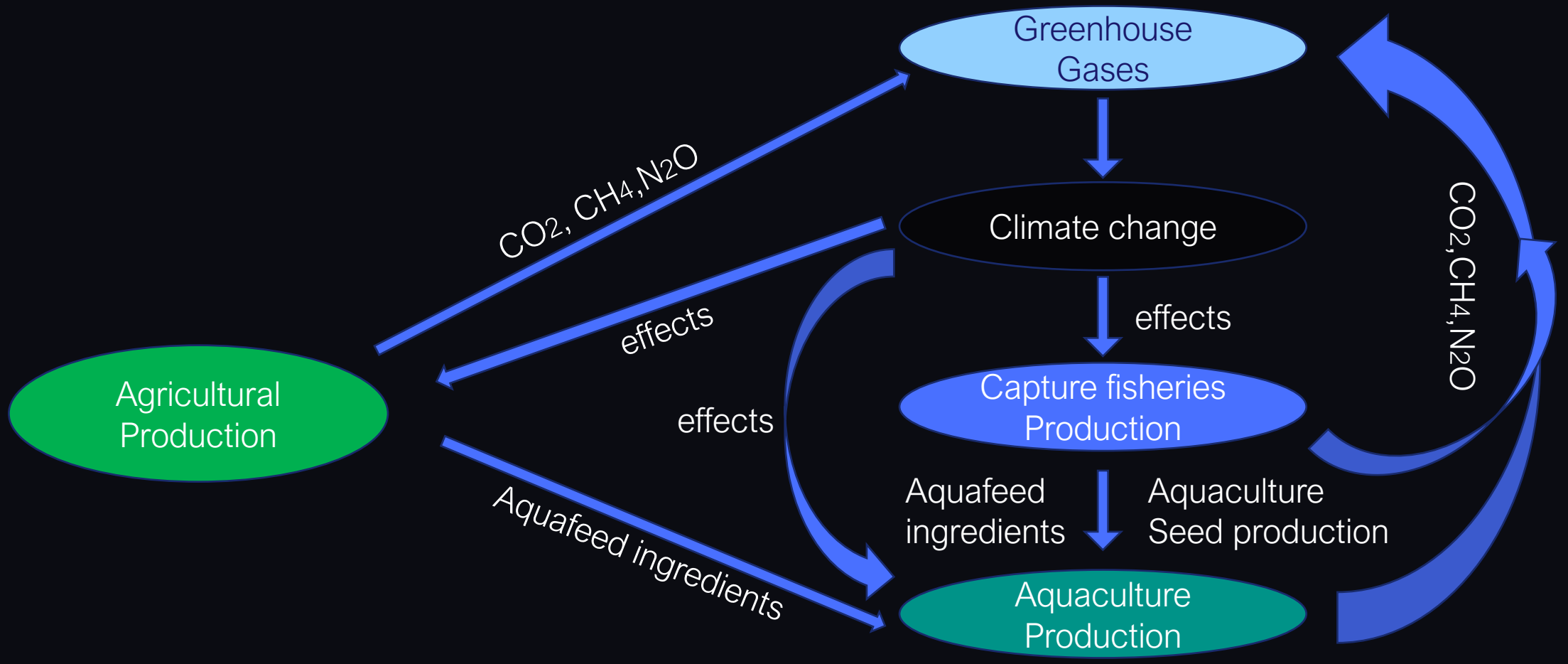
Recent recommendation to move towards sustainability

- Move aquaculture inland – recirculating aquaculture systems
- Move aquaculture offshore - enables more efficient dilution of the waste produced from the farm (high capital cost and just a partial solution for the pollution)
- Utilize multi-trophic aquaculture -reducing nutrient build-up simply using filter feeders (system is usually not very profitable, and difficult to balance and control) or plants
- The ultimate solution to the sustainability relies in the mass production of algae and filter-feeding and herbivore organisms (Duarte et al.2009)
- Invest in new renewable energy sources - reduce long-term operating costs and increase competitiveness and profitability
- Include aquaculture in Circular economy

Climate change effects on aquaculture production are both direct and indirect

- The direct effects include influencing the physical condition and physiology of finfish and shellfish stocks in production systems
- Indirect effects may occur through altering the primary and secondary productivity, and structure of the ecosystems, input supplies, or by affecting product prices, fishmeal and fish oil costs, as well as other goods and services needed by fishers and aquaculture producers.
- These elements will not affect aquaculture production equally, since, like any other farming practice, the sector is defined in time, space and size, and therefore the elements have a fair degree of maneuverability while affecting fish populations at different life cycles as well.

Direct and indirect pathways through which climate change will affect aquaculture production



Predicted multi-dimensional impacts of climate change

- Shifts in water temperature (Warming)
- Changes in ocean currents
- Changes in rainfall/precipitation patterns
- Sea level rise
- Extreme weather (Droughts and Floods)
- Acidification
- Deoxygenation
- Harmful algal blooms
- Alterations in ecological dynamics

Alterations in ecological dynamics

- Change of species distribution
- Decrease in abundance
- Habitat degradation
- Erosion of Biodiversity
- Alteration of trophic networks

Mitigation and adaptation options

- To reduce the effects of climate change, many studies present different ways of mitigation and adaptation. Selective breeding, species diversification, and aquaculture systems like integrated multi-trophic aquaculture, aquaponics, and recirculating aquaculture system are some of the most widely accepted and adapted solutions.
- Further research on intervention in seed and feed in terms of quality improvement, bioresource utilization, and technological and genetic improvement is required.
- Climate change policies from the government are also essential.
- Farming communities, ecosystems, and populations, in general, may benefit from climate change mitigation and adaptation strategies that are also effective and efficient in building resilience and in responding to changing climatic conditions.

Resilience from climate change impacts

Mitigation

- Mitigation focuses on reducing or reversing the rate of climate change. This involves mainly reducing GHGs emissions with a special focus on carbon dioxide emissions which account for more than 60 percent of human enhanced increases.
- Aquaculture systems account for <2% of the global lentic habitat area, they contribute 8.8% of the total CH_4 emissions from these ecosystems.
- Relative to other major animal products, aquaculture has a lower CO_2-eq per unit of protein produced, but its total emissions could still offset 4.0% of the terrestrial carbon sink.
- Given the fact that emissions stemming from the production of feed are allocated to the aquaculture sector, achieving carbon neutrality in aquaculture requires achieving carbon neutrality as well in agriculture, unless compensatory measures are taken.

GHG Reduction Costs and Pathways to Net Zero by 2050

Eight scenarios were then designed considered technically and economically feasible:

- emerging feed materials and breeding,
- AI-based tools,
- renewable energy,
- integrated multi trophic aquaculture,
- improved energy efficiency,
- increasing the share of non-fed aquaculture,
- and offsetting tools such as buying carbon credits on the voluntary market and paying for ecosystem restoration.

Resilience from climate change impacts

Adaptation

- Integrated multi-trophic aquaculture (IMTA) systems are more environmentally friendly, sustainable and economically rewarding as well as more resilient to changing climate compared to monoculture
- The utilization and incorporation of local and indigenous knowledge in adaptation strategies have also been shown to offer effective adaptation to climate change
- The use of closed system technology that does not depend on external climatic factors (RAS)
- Shifting to aquaculture species, techniques or areas that are less vulnerable or are more resilient to a changing environment and resources
- Combining aquaculture production systems with other sectors, such as agricultural systems, either integrated or as separate systems – Circular Economy

IMTA - Polycultures

- Some examples of sustainable systems are integrated multitrophic aquaculture (IMTA)
- Different species are cultured jointly composing a small food web rather than in isolation, can increase the yield of aquaculture by 30 %, for a give use of feed, while reducing environmental impacts
- Polycultures can combine fish cultures with a belt of filter-feeders, such as mussels or oysters, that filter out the excess particles in the water

Integrated multi-trophic aquaculture (IMTA)

Integrated multi-trophic aquaculture (IMTA) is the co-cultivation of fed species (such as finfish or shrimp) together with extractive species, such as suspension-feeding (e.g., mussels and oysters) and deposit-feeding (e.g., sea-cucumbers and sea-urchins) invertebrates and macroalgae (e.g., kelps), which may feed on the organic and inorganic effluents generated by the fed species.

By establishing such integrated cultivation systems, the sustainability of aquaculture may be increased. However, in order for IMTA to be economically viable, each of the individual components must be marketable or adding value through accounting for the ecosystem services that extractive species provide

Environmental contributions of pond/ wetland, and bivalve aquaculture under three main categories

- Provisioning services: Supply of highly nutritious, low-carbon aquatic foods that diversify protein sources and strengthen food security and support health.
- Regulation and maintenance services: Improvements to water quality through nutrient cycling and sequestration of nitrogen, phosphorus (and in some cases, carbon dioxide); sediment stabilization; hydrological buffering against droughts and floods; and enhancement of biodiversity through habitat creation around aquaculture infrastructures. These services contribute to climate mitigation and resilience.
- Cultural services: Contributions to cultural heritage, local traditions, eco-tourism, and environmental education, which in turn improve social acceptance and create added economic value. Case studies in Ireland, Greece, and the Baltic Sea (for marine bivalves), and Poland, Hungary and Greece (for pond/wetland farming) highlighted the importance of site-specific conditions in the balance between environmental benefits and risks.

Sustainability of Bivalve Aquaculture

- Besides the spatial distribution of bivalves, several aspects of their biology, such as growth, reproduction, feeding, behavior, and respiration (among others), are also affected by changes in climate. During emersion periods, bivalves also have to deal with hypoxia and the interruption of feeding, since they are filter feeders.
- When exposed to stressful conditions, such as severe variations in temperature and salinity, bivalves usually close the valves—as a mechanism of protection against osmotic stress reduce feeding activity, and show slower growth and respiration rates and, consequently, alterations in oxygen consumption.
- Bivalve aquaculture is an important source of high-quality animal protein,-with the annual production surpassed 20 million tonnes in 2022, accounting for over 20% of total aquaculture production. On a bivalve individual carbon budget level, bivalves released CO_2 during respiration and calcification, while they store carbon in their flesh and shells, and promote deposition of carbon in the sediment through the fecal and excretion.
- With targeted support bivalve aquaculture can evolve from niche sectors into central components of Europe's green transition, delivering not only sustainable food but also measurable contributions to biodiversity, climate resilience, and rural development.

Extensive and semi-intensive Pond and wetland aquaculture

- Extensive and semi-intensive Pond and wetland aquaculture in the EU involves the farming of fish in culture systems that attempt to replicate natural characteristics. The culture systems typically involve some degree of hydrotechnical modification of natural pond and wetland structures for control over water flow and production.
- Pond aquaculture face a common set of systemic barriers in environmental, regulatory, socio-economic, and management areas, as highlighted in EU strategic guidelines and recent analyses of climate change adaptation.
- Production of fish in ponds and wetlands in the EU is dominated by cyprinid carp production in ponds, mainly common carp (*Cyprinus carpio*), for food and recreational fishing restocking markets.
- Income diversification via eco-tourism, cultural events, education, and recreation enhances farm viability and builds public awareness and acceptance

Despite several opportunities, the sector faces serious and urgent obstacles

- Environmental challenges, including droughts, water quality degradation, predation pressures, invasive species, and disease transmission, can undermine sustainability.
- Climate change poses overarching risks that could exacerbate abandonment, habitat degradation, and biodiversity loss without robust mitigation strategies.
- Social acceptance remains limited, with some public perceptions framing aquaculture as environmentally harmful despite evidence of ecosystem service benefits.
- Low economic feasibility of extensive systems, which often produce lower-value species with long production cycles, and low market demand, limiting profitability.
- Market volatility increases risk to farmers and disincentives investment. This in turn limits expenditure on alternative sustainable production methods.

Mortality in the carp pond due to lack of water and oxygen



Lack of water and shallow ponds not only cause mortality due to low oxygen, but shallow water also makes fish easier prey for fish-eating birds – the farmed fish population decreases, while the bird population increases multiple times





Resilience and Adaptation

Apart from these general and theoretically justified methods and strategies that require a broader approach and joint efforts from the aquaculture industry, science, and financial institutions, and which can be slow and already lag behind the actual situation on the ground, it's important to highlight methods based on the experience and creativity of experts in the field, combining existing methods and technologies, which are already showing positive effects and potential adaptability to current pond farming. Existing carp ponds are adapting to current climate changes, including introducing recirculation technology into part of the production process, designing smaller ponds where it's easier to control water quality and fish behavior, and using some devices and methods known from other systems to improve water quality.

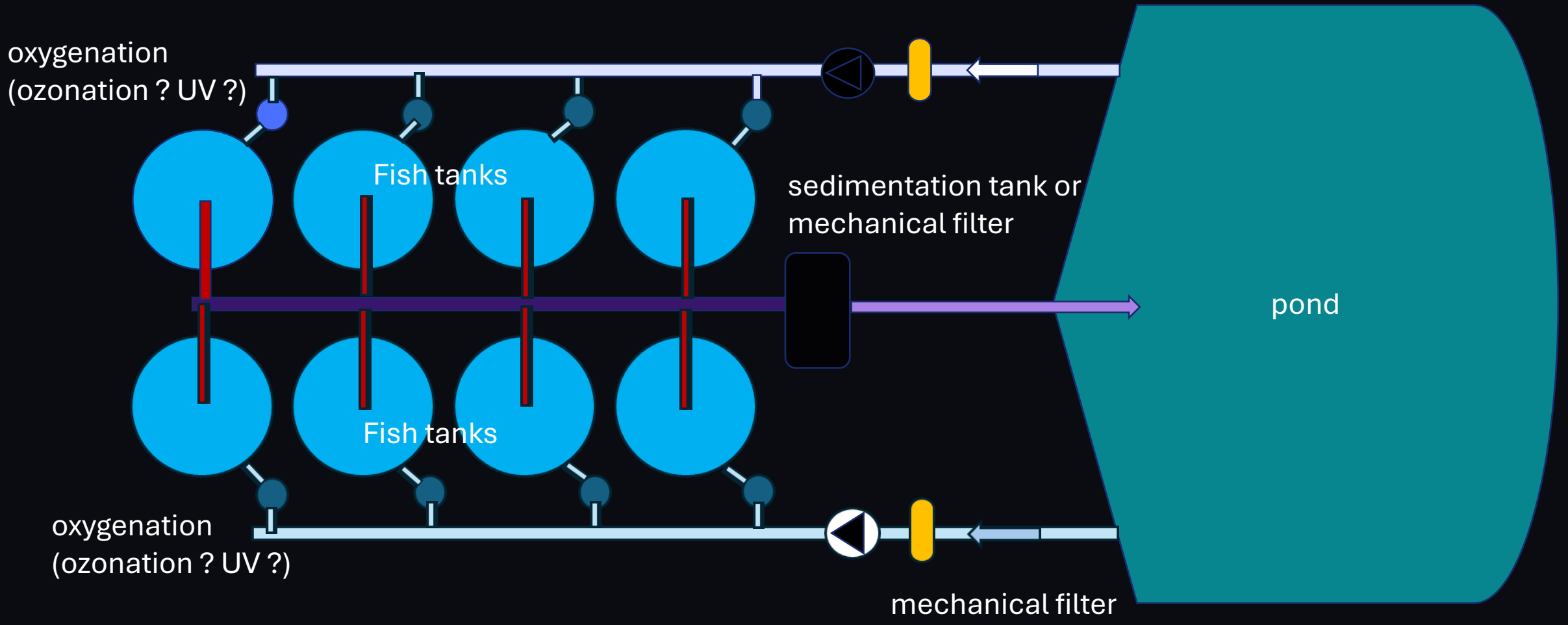
Water management possibilities

Higher densities of fish may require mechanical aeration, supplemental feeding, and a supplemental flow through water source




Construction of carp tanks with natural pond-biofilter
Partial recirculation

Natural (Pond) biofilter



A large pond divided into two separate units for easier water quality maintenance, easier handling and more efficient harvest

The newly built embankment that separates them will also include electricity supply for establishing oxygenation. A lack of water requires better excavation, electricity supply for aeration, and water quality control



Incorporation of Recirculating an indoor nursery system into carp pond cultivation

- System acclimates fry to artificial food
- Selections take place before stocking juveniles in outdoor nursery ponds
- Juveniles fully independent from natural food (pond fertilization and sensitive timing), that only enhances the diet
- Avoids impact from extreme temperature changes and reduces damages from predators
- Production cycle 1.5 – 2 months in the nursery
- Extended 1st growth season (starting indoors)

The flow-through system

The flow-through system maintains optimal water quality exclusively through speed and flow, that is, the volume of fresh water passing through the system per unit of time.

It uses and discharge large amounts of water. that contain a low concentration of dissolved substances and mechanical particles.





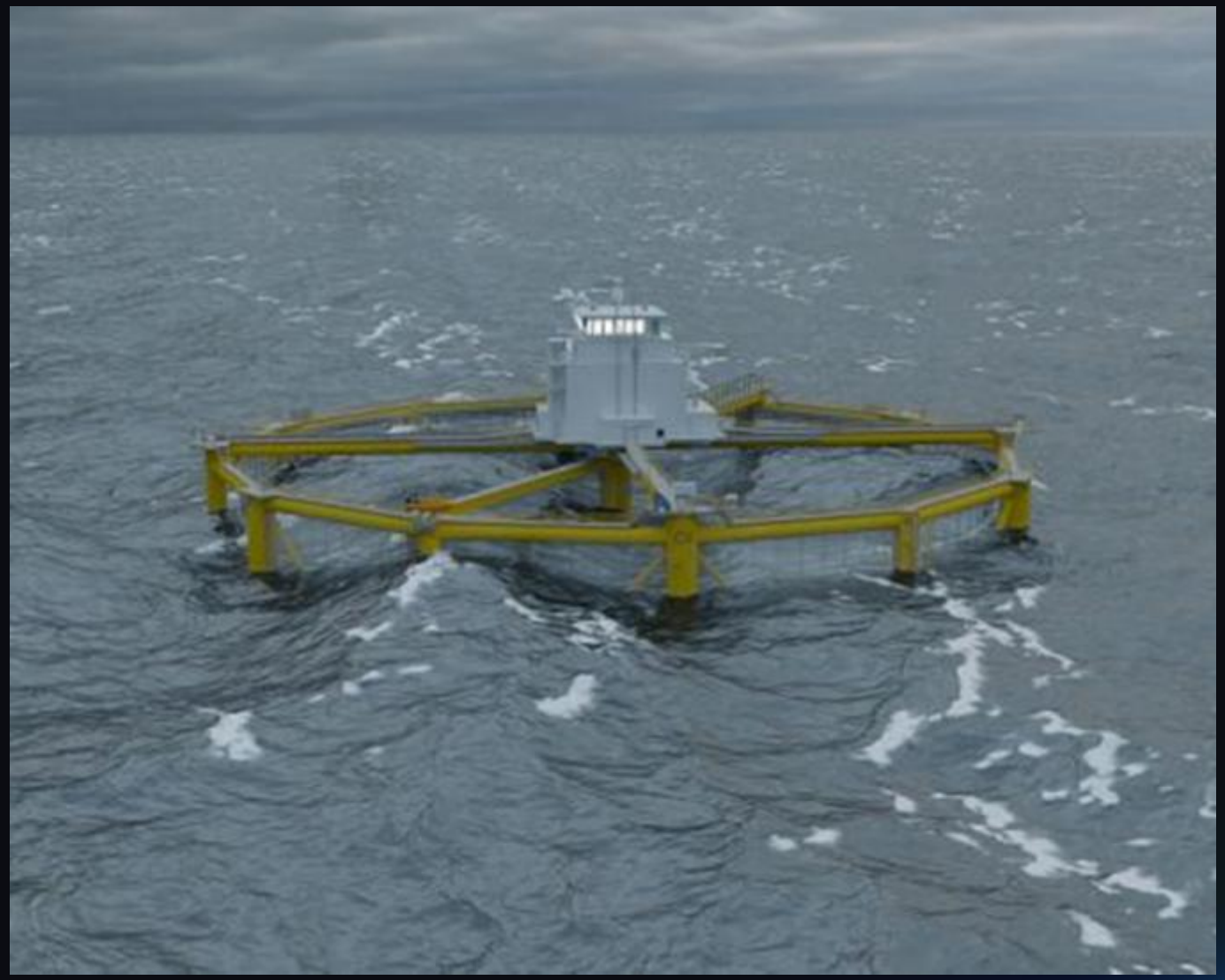
Systems suffer from chronic water shortages and are not resistant to droughts caused by climate change. In the image, the water deficiency is being attempted to be compensated with aerators. Despite this, the planting density, that is, the food intake, had to be reduced.

Concrete reservoir with an integrated mechanical and biological filter in a trout flow-through system to compensate for water deficiency and establish a partial flow-through system



Cage Farming Systems and their Resilience





Cage Culture

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According to the FAO (Halwart et al., 2017), 62 countries reported cage culture production in 2015. Almost all marine finfish aquaculture is in cages.

Freshwater cage farming in rivers and lakes is dominated by small-scale farmers and employs traditional wooden frames for net cages and plastic drums for floatation. In contrast, marine cages involve more advanced technologies for cage installations and stock management.

Only a few studies have focused explicitly on the impact of climate change on cage farming and the required mitigation and adaptation measures. Cage aquaculture adaptation must be flexible enough to allow methods to be discontinued, switched, merged, or new ones incorporated when conditions and knowledge shift. Furthermore, adaptive strategies must meet a number of criteria, including being effective enough to significantly reduce risk, robust enough to effectively function under a variety of conditions, flexible enough to accommodate future modifications, free of unwanted side effects, cost-effective, and supportive of all stakeholders, particularly small farmers and vulnerable households (Lebel and Chitmanat, 2015),

Climatic changes on cage farming

Several studies have investigated the effects of climate change on aquaculture over the last decade, classifying them as direct (e.g., cage destruction due to high water levels) or indirect (e.g., increased disease risk as water temperature rises) and/or positive and negative consequences. Most of these studies have discussed future strategies for adapting aquaculture and fisheries to climate change, focusing on uncertainty or variability of yield, lower profitability, and economic concerns. At the same time, many other studies have focused on the overall influence of climatic changes on aquaculture and fisheries (i.e., marine, coastal, and inland aquaculture) productivity.

Only a few studies have focused on the influence of climatic changes on cage farming and the mitigation and adaptation techniques required For fish cultured in cages or pens, either in ponds, rivers, lakes or in open seawater, periodic assessments of the cage design and its capacity to maintain its position and integrity in preventing escape or loss may be necessary. All mitigation and countermeasures, however, are not without the need for capital investment; however, such investments may be beyond the means of many small to medium-sized producers at the local scale and for low to low-middle income category countries on a national scale where coordinated strategic plans of area management would be required.

Research gaps

- Urgency for ongoing studies to fill current knowledge gaps necessary to formulate robust biosecurity measures for cage culture and strategies to mitigate the impacts of climate change on production.
- Better understanding the tolerance of intensively-farmed species to environmental stressors such as extremes of temperature, salinity, dissolved oxygen, etc.,
- The tolerance of new genetic lines and the evaluation of new species or strains for aquaculture with better resilience to these changes.
- Studies on the effects of climate change on molecular level alterations in fish are scarce, and such research might promote the genetic selection
- Study of resistant strains suitable for cage culture and more easily adapted to climate change impacts.
- Additionally, research on the impact of ocean acidification on marine cage cultured species is limited, and data on other climatic impacts such as temperature fluctuations, storms, and rainfall fluctuations must be expanded across multiple regions and ecosystems to develop mitigation and adaptive strategies that can be implemented with minor modifications in any region.

Recirculating Aquaculture Systems - RAS

RAS has been under development and refinement for the past 30 years. After the initial research phase the primary focus has been to create, develop, and refine recirculating technologies that can produce food fish on an economically competitive basis.



Recirculating Aquaculture Systems

The advantages attributed to properly designed recirculating aquaculture systems include:

- complete environmental control
- optimal bio-security for control of disease
- elimination of escape of domestic stocks
- minimal use of land and water resources
- complete control of effluents and waste products
- limited volume of waste can be effectively transported for treatment as a concentrated sludge.

Development of RAS design

The high market price, inadequate design and the fact that it is a closed system often involving a solid building required capital costs that made most recirculating aquaculture projects unprofitable.

In the last ten years, the components of recirculation systems have become cheaper thanks to mass production and simplified constructions, and a significant part of the complete systems has been adapted to the cultivation of various types of aquatic organisms, with the involvement of competent experts.

At the same time, the accumulated experiences enabled the development of new creative, simplified and financially justified designs.

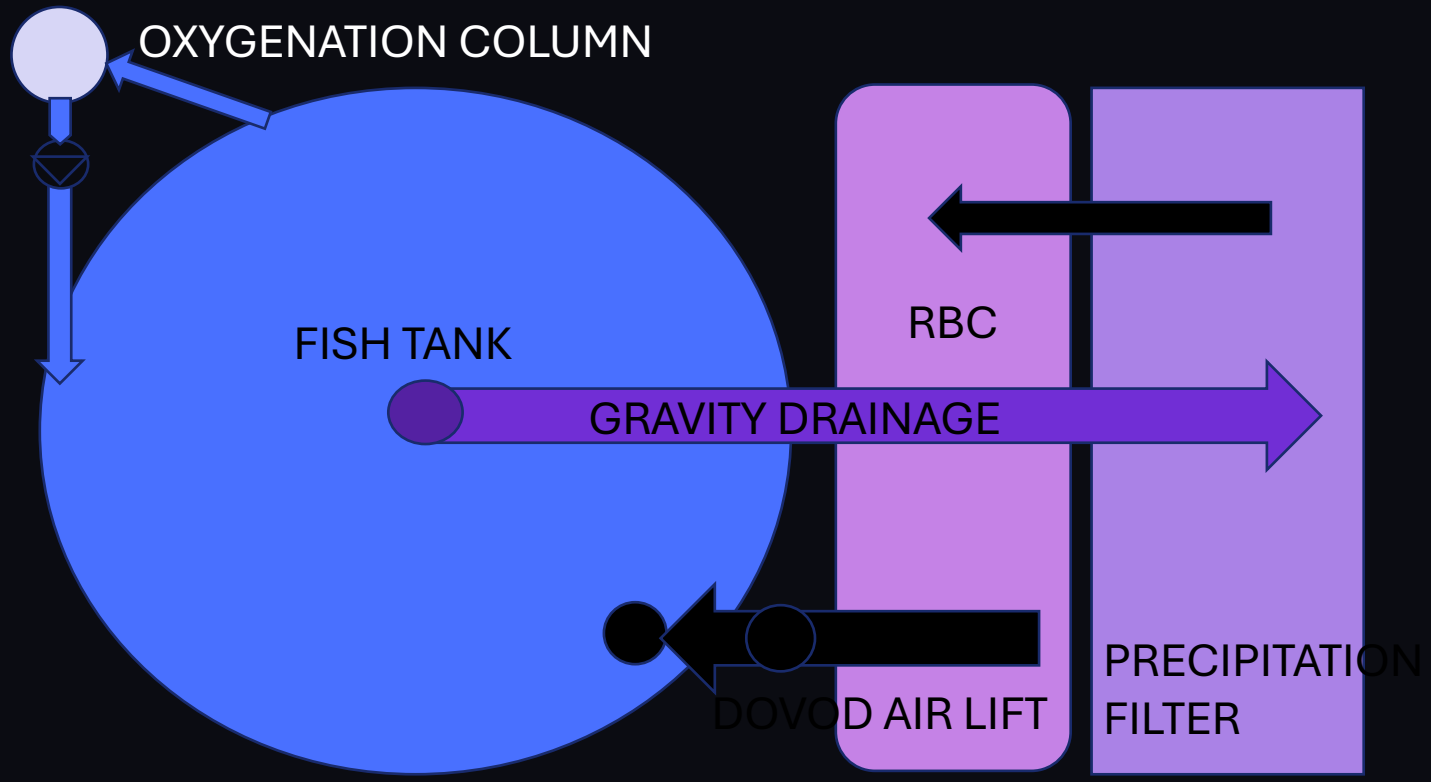
In the last few years, interest in including RAS in fish farming projects has increased significantly in Europe.

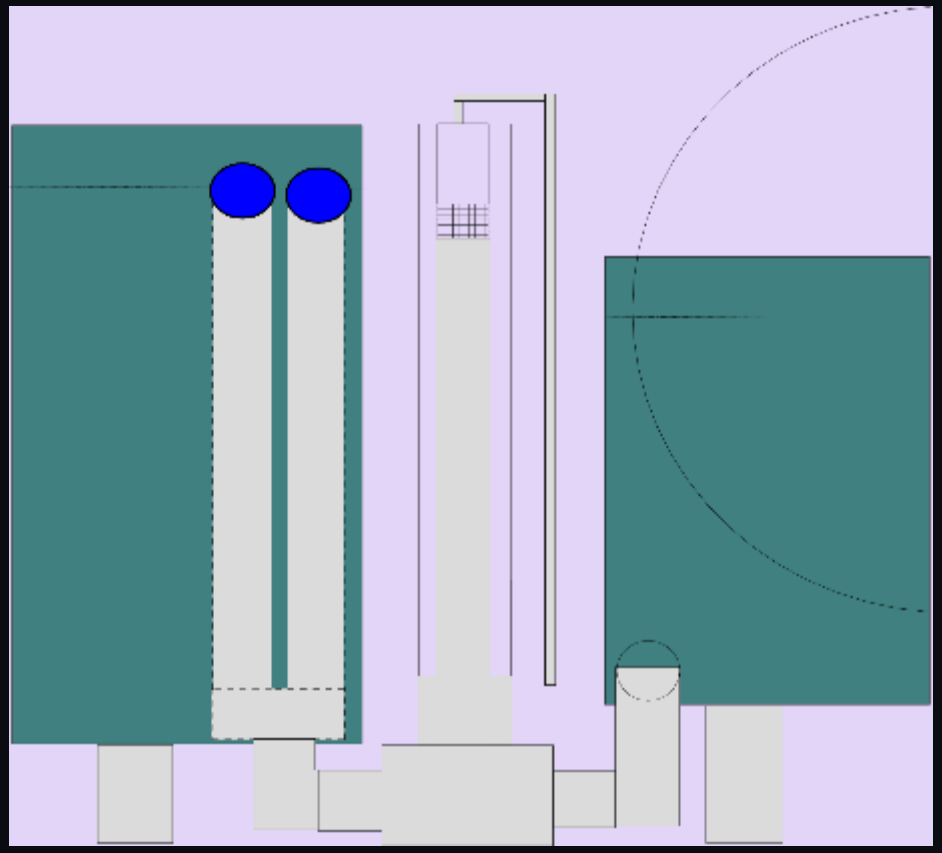
Low pressure system diagram

Cheap unsophisticated equipment

Requires a lot of relatively cheap human labor

Very low energy costs





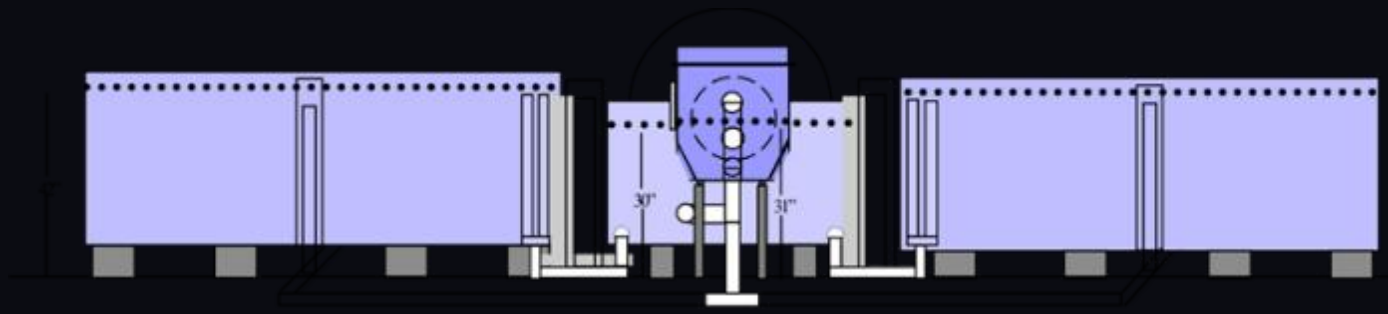
More sophisticated low-pressure system

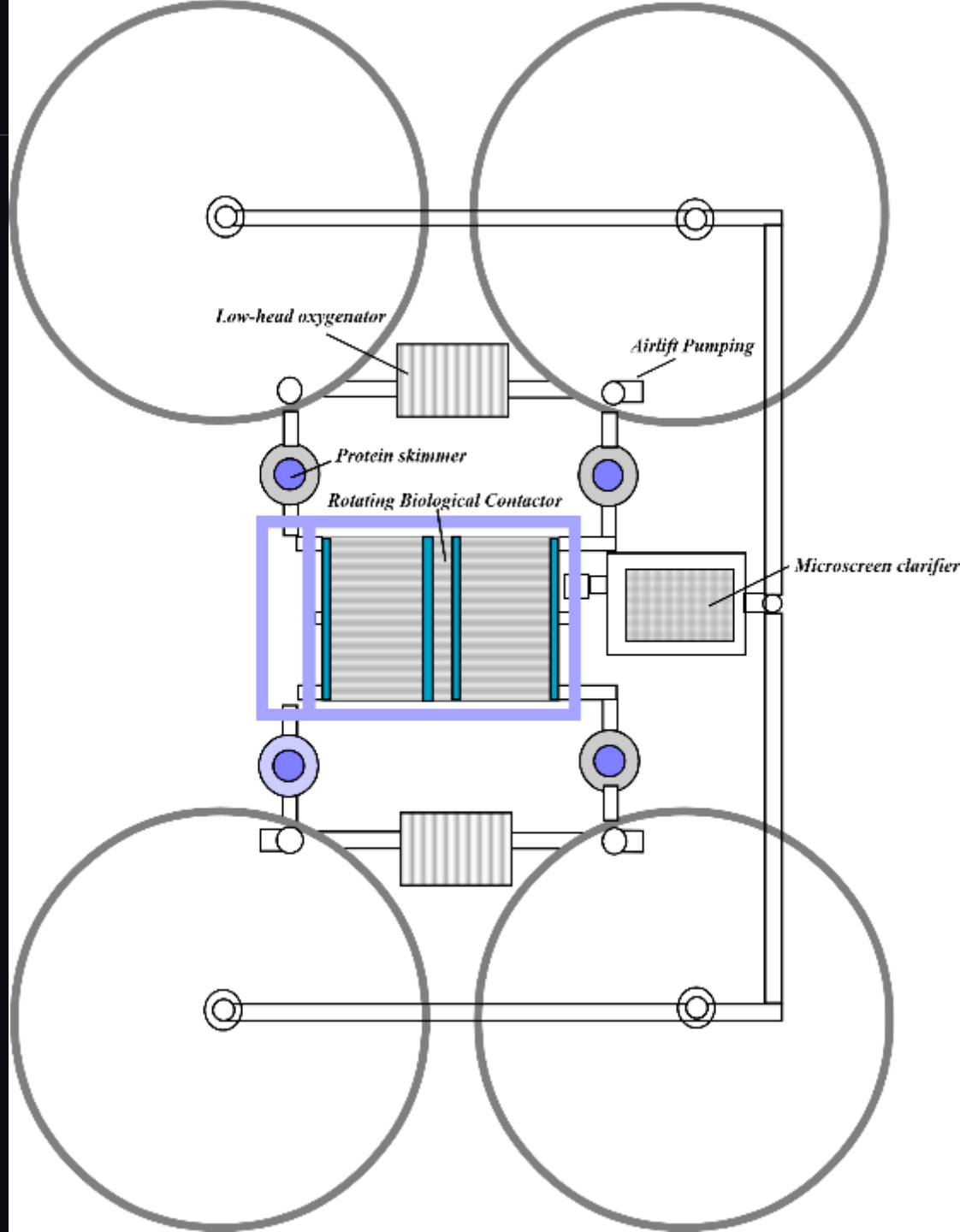
More sophisticated and efficient equipment

Relatively high capital costs

Low energy requirements

Quite complicated management requires educated staff or sophisticated computer control





RAS Fish Production in Europe

More than 27.000 tons were produced in recirculation systems in 2018 in the EU.

RAS systems are mostly used for freshwater species, with more than 95% of the production occurring in freshwater environment (the remaining 5% occurring in sea and brackish water).

Denmark, Netherlands, Germany, France and Poland are the leading MS, with more than 90% of the RAS production in the EU.

In terms of species, rainbow trout, North African catfish and European eel accounted for 93% of the RAS production in the EU in 2018. Rainbow trout alone represented circa 62% of the EU production

The Norwegian DNB Bank and the Rabobank from The Netherlands have both agreed that land-based indoor fish farming will become one of the major growth industries in food production. DNB ASA is Norway's largest financial services group with total combined assets of more than NOK 1.9 trillion and a market capitalisation NOK 164 billion. The emphasis is on volume of production, to achieve the economies of scale necessary to make operations profitable.

Superior Fresh LLC is a fish farm and processing operation located in Hixton, Wisconsin. Focusing on commercial coldwater aquaponics, Superior Fresh LLC raises rainbow trout and Atlantic salmon in RAS in conjunction with a hydroponic greenhouse. The facility started with operation in 2018.

Blue Ridge (Henry County, Virginia), said to be the world’s largest producer of indoor-raised tilapia, produces 2 million kg of the fish a year using RAS and ships between 5,000 and 10,000 kg of live tilapia each day.

Resilient and Adaptive Finfish Species

Traditional finfish farming will face increasing challenges as sea temperatures rise. Northern Europe finfish aquaculture sector currently relies on salmon, which are known to be sensitive to temperature change. By finding new species to grow in aquaculture settings, the seafood sector can not only expand its offering to consumers but also develop resilience to changes in the climate.

The recent New Zealand aquaculture project is showing that sea-pen farming is a highly feasible production system for snapper. As a warm-water species, snapper grow well under local conditions and display strong survival and performance traits—even in regions increasingly affected by marine heatwaves.

Results demonstrate that selective breeding can produce snapper that are not only faster-growing but also more resilient to environmental stressors, offering a climate-adapted solution for aquaculture.

The study underscores the importance of further research into warm-water species like snapper, which could safeguard seafood production in a changing climate. With continued selective breeding and refinement of farming techniques, snapper farming has the potential to become a cornerstone of sustainable aquaculture. These findings also offer valuable insights for aquaculture sectors worldwide seeking species that are robust to warming and variable marine conditions.

Back in 1986, Cenmar from Zadar, Croatia, was the first in Europe to start farming Pacific sea bream (*Pagrus major)*in floating cages. Over time, it got the popular name Japanese sea bream. Since 2012, they haven't been farmed in the Adriatic anymore.

Red seabream is a marine subtropical oceanodromous demersal fish, found in the Northwest Pacific from the northeastern part of the South China Sea (Philippines excluded) northward to Japan. commonly known as red seabream or madai, is a marine fish in the Sparidae family, highly valued for its culinary, cultural, and economic importance in the Western Pacific.

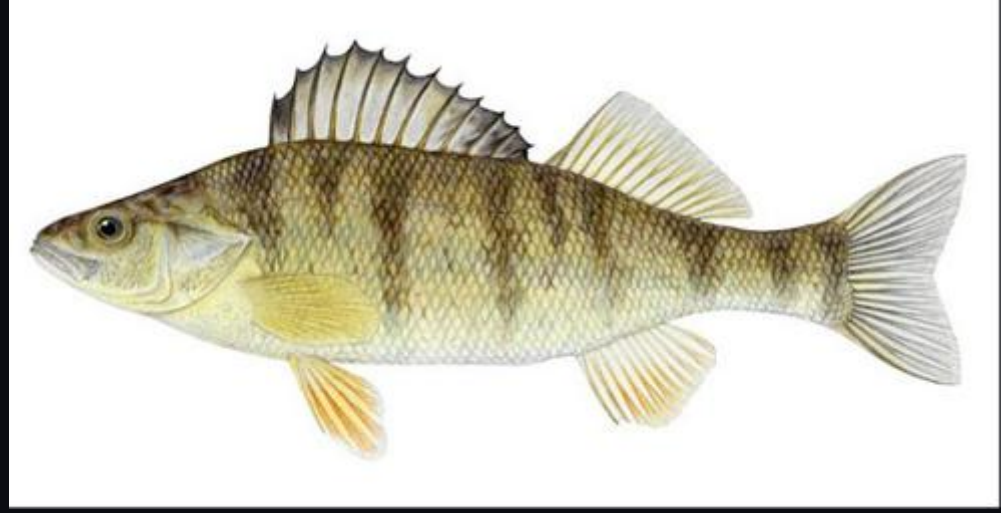
Despite the fact that it handled breeding conditions in Adriatic cages very well, escapees never established an Adriatic population.



Pacific sea bream *(Pagrus major)*

a foreign subtropical species that was cultivated in the Adriatic

Perch cultivation



Optimal temperature for Perch cultivation

was reported to be:

18°C, 20-22°C, 21-24°C, 24-25°C, 25°C.

It was reported that above 26°C under conventional aquaculture conditions (ponds) and above 21°C under high density conditions (in net-pens and tanks), perch show signs of stress, disease and reduced growth (Malison, 1996).

Successfully raising the newly hatched fry to fingerlings in intensive aquaculture was identified by several authors and potential producers as another major constraint to successful yellow perch aquaculture.

It is found in lakes, ponds and rivers, in a temperature range of 0 - 30 ° C. Inhabits also brackish waters and salt lakes (Frimodt, 1995).

EU produces approximately 250,000 tonnes of gilthead sea bream.

The temperature tolerance of early juvenile stages is very well documented, but long-term exposure in adult fish is not. There's a lot of experience, but it's not properly documented.

There are signs that ELS may approach physiological limits near or above 28 °C, where aerobic performance plateaus and oxidative stress begin to emerge. Indeed, our integrative approach confirms that it is likely that the species would inhabit habitats with temperatures between 23.8 °C and 28 °C only occasionally, while hotspot habitats are those with temperatures ranging between 19 °C and 23.7 °C. Future increases beyond this threshold may compromise performance and survival (Almeida et al. 2025).



Sparus aurata

Tilapia *Oreochromis niloticus* in floating sea cages



Tilapia are mainly freshwater fish native to Africa and the Middle East, inhabiting shallow streams, ponds, rivers, and lakes, but easily found in brackish water. Historically, they have been of major importance in artisanal fishing in Africa, and they are of increasing importance in aquaponics. Tilapia can become a problematic invasive species in new warm-water habitats such as Australia, whether deliberately or accidentally introduced, but generally not in temperate climates due to their inability to survive in cold water.

Malta has established itself as a European hub for tilapia, *Oreochromis niloticus,* cage farming in early nineties, with several companies and initiatives contributing to the industry.

Differently declared status of circular and sustainable food systems

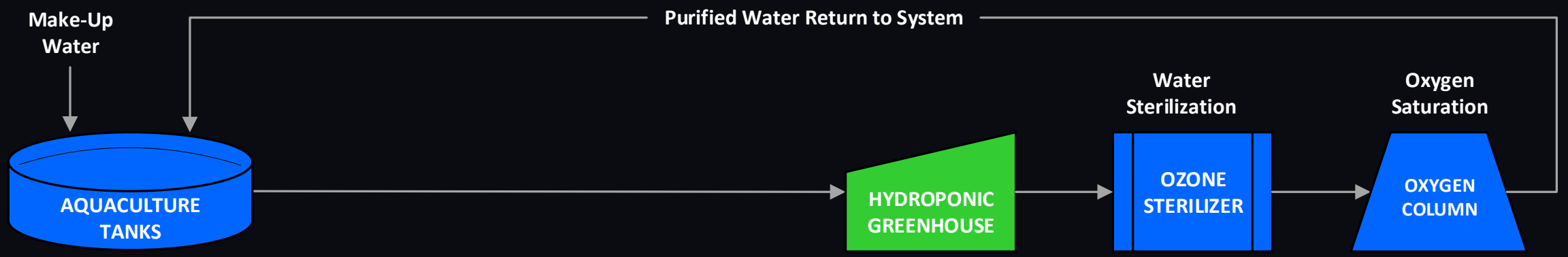
- “This gap is significant: as established earlier, blue-green integration innovations such as aquaponics and rice-fish systems function as niche-level developments capable of challenging the dominant, separately managed regimes of industrial agriculture and conventional aquaculture” (Geels 2006; van Zanten et al. 2019).
- While aquaculture has become well-integrated into the global food system since 2000, its integration into local nutrition-sensitive, circular, and sustainable food systems remains a stated future priority rather than an achieved outcome (Verdegem et al. 2023).
- There are a couple successful examples of aquaponic systems and circular bioecomony projects, experimental and commercial, and they give valuable insights into this kind of circular and sustainable food system (Rakocy et al. 2006; Gavrilović et al. 2017). Examples from both aquaculture and terrestrial agriculture provide insights into how sustainability can be incentivised and scaled

Inclusion of RAS in Circular Economy

- A circular economy is an economic system aimed at eliminating waste and the continuous use of resources.
- It should minimize the use of resource inputs and the generation of waste and pollution and minimize carbon emissions. Circular economy would appear to be more sustainable than the current linear economic system.
- “Waste" should become "food" for another process: either a by-product or recovered resource for another industrial process or as regenerative resources for nature
- Circular systems employ reuse, sharing, repair, refurbishment, remanufacturing and recycling to create a closed-loop model

Aquaponics System – Basic Principle

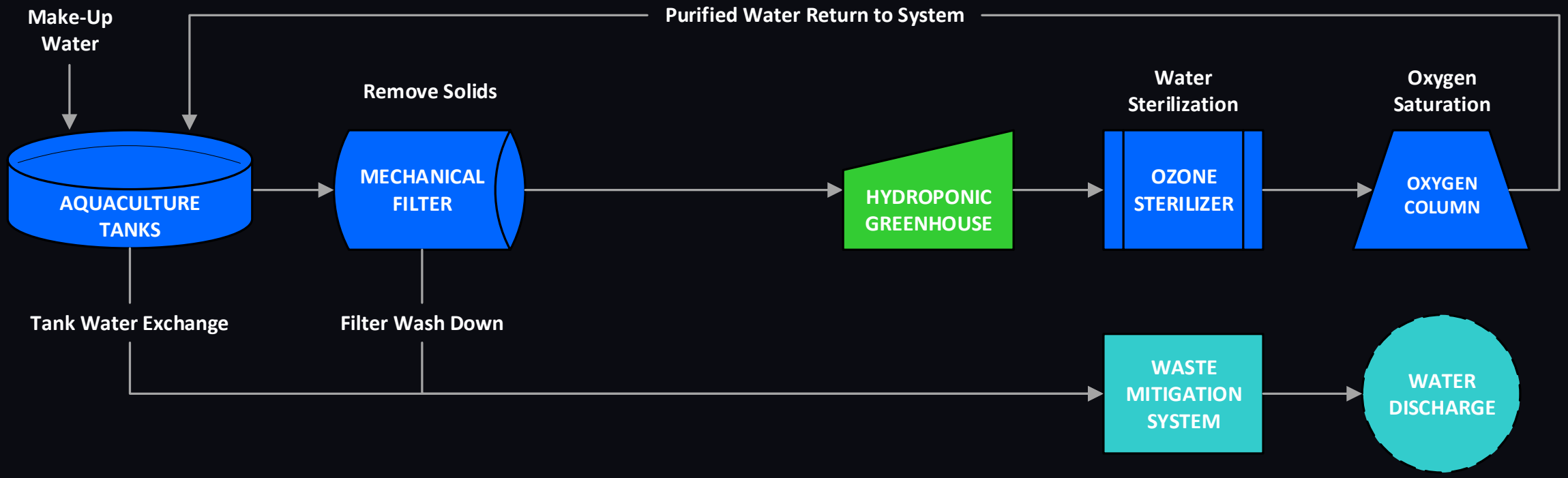
Water Management Process



- No mechanical or biological filtration components. Filtration is achieved through hydroponic plant cultivation
- Approximately 25% of the feed given to fish is excreted as solid waste. If solids are not removed they will adhere to plant roots, decrease oxygen levels as they decompose and have an adverse effect on nitrogen bacteria. As solids decompose oxygen is consumed and ammonia is produced.

Coupled Aquaponics System

Water Management Process with Waste Mitigation



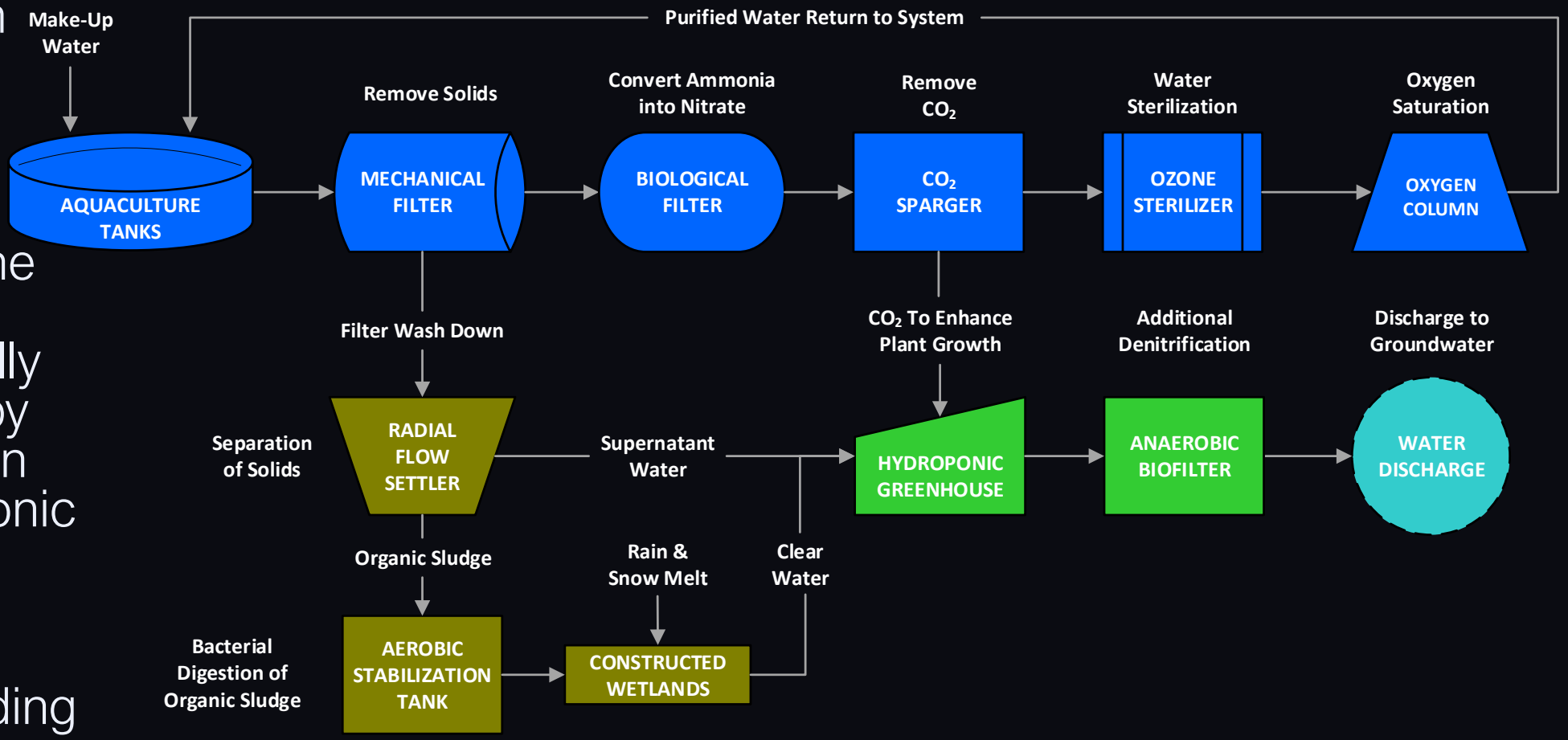
- To be effective at nutrient removal, coupled aquaponics systems should be sized correctly to balance nutrient production from fish culture and nutrient uptake by plants. This balance can be tricky to achieve and maintain.
- Nitrification efficient at pH 7.5 or higher and practically ceases at less than 6.0. The optimum for nutrient solubility is 6.5. If pH is too high, nutrients precipitate out of solution and plants display nutrient deficiencies.

Coupled Aquaponics System



Uncoupled Aquaponics System – Three different technologies included

The fish production process and hydroponics production are separated. Wash down water from the mechanical filter is removed, aerobically stabilized, filtered by reed beds, and then sent to the hydroponic greenhouse. That water, after further treatment, can go back into the breeding tanks or be used for other purposes.



Aerobic Stabilization Tanks & Wetlands



Basin construction
Phragmites plantings



Aerobic stabilization tanks
and Constructed Wetlands

Raft system in a Hydroponic Greenhouse

Greenhouse area is scaled to efficiently extract nutrients from water discharged from the recirculating aquaculture system.



THE USE AEROBIC STABILIZATIO, REED BED AND HYDROPONIC TECHNOLOGY



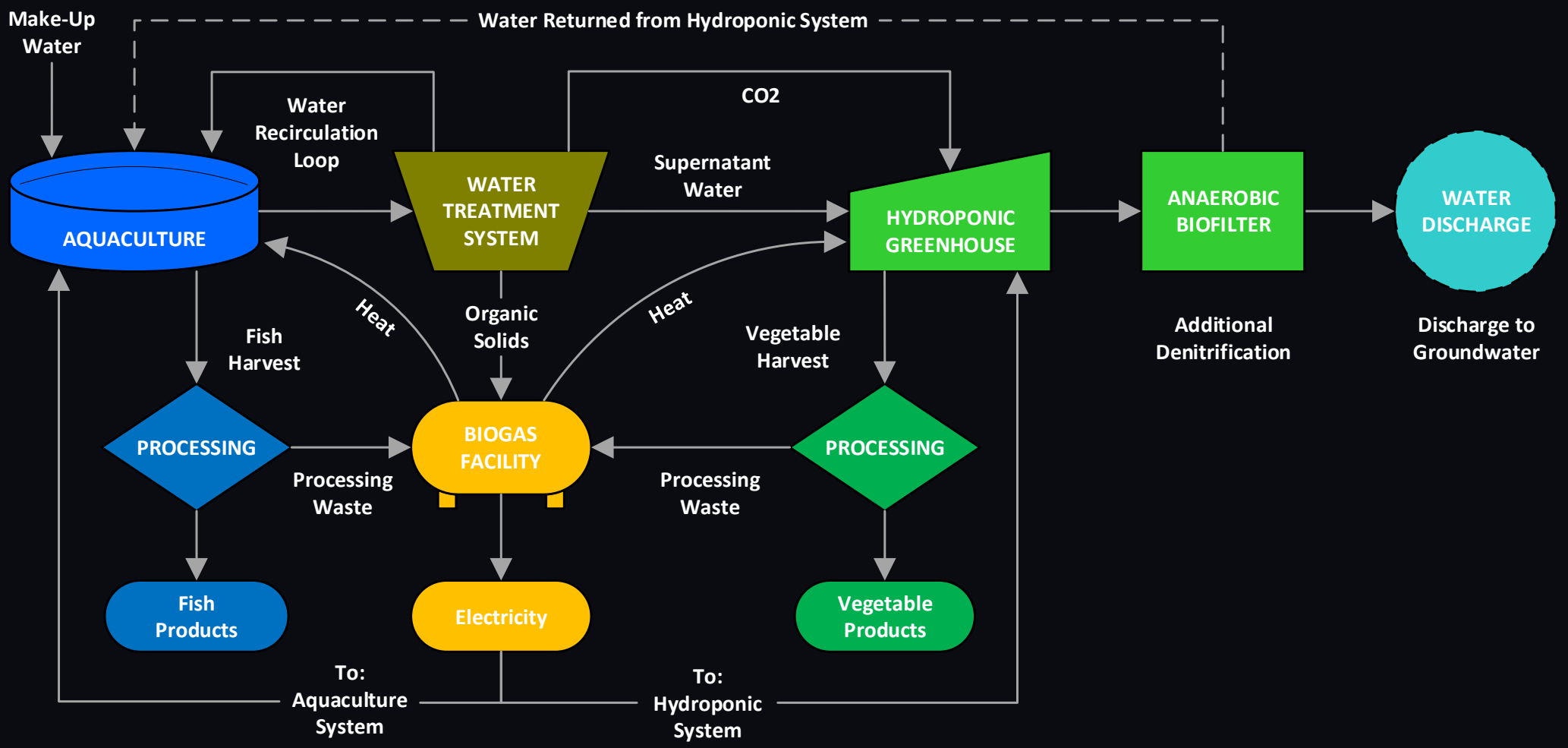
Introduction of a Biogas Facility in the Aquaculture System

- Biogas Facility digests organic waste to create methane gas, which generates electricity
- Heat is a byproduct of that process, which is considered thermal pollution if improperly discharged
- Heat can be mitigated by the Recirculating Aquaculture System and Hydroponic System
- Closed Recirculation Aquaculture System and a Biogas Facility are a perfect synergy



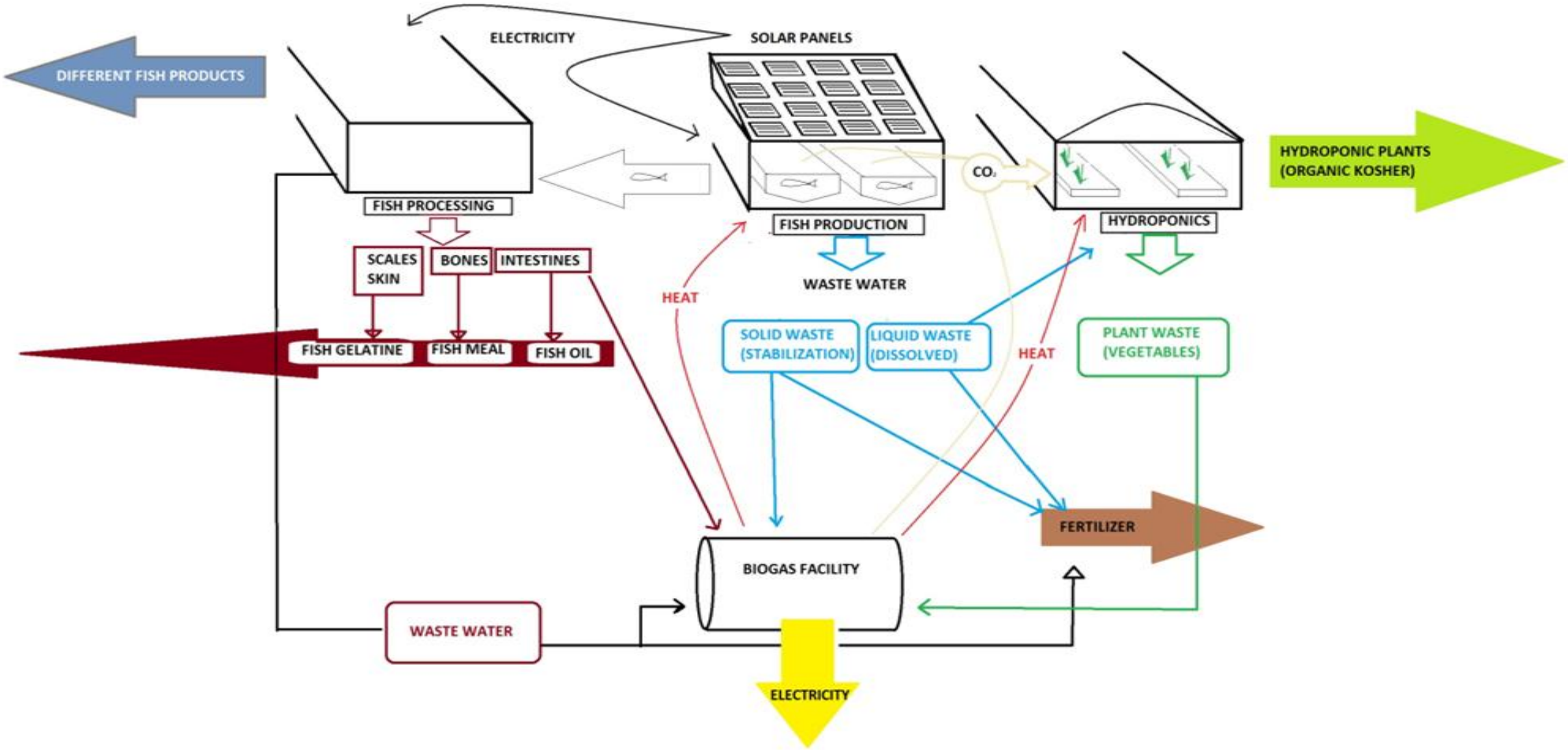
Biogas Facility

Aquaponics Production System with Biogas Facility



Circular economy system

which integrates production in a recirculating aquaculture system with a hydroponic operation to treat and purify wastewater, while also creating a secondary source of income through growing vegetables. A more advanced circular economy system adds a processing unit for fish and vegetables and biogas production to turn vegetables and fish by-products, as well as solids from wastewater, into reusable fuel, providing electricity and heat for the aquaculture operation and making the whole operation more sustainable and more resilient.



EXAMPLE OF CIRCULAR BIOECONOMY

The introduction of new technologies in aquaculture production and the use of methods applied in other industries led to the development of more sustainable, more efficient and more environmentally friendly production systems and processes.

Such a trend allows the integration of aquaculture with other branches of agriculture, and the use of by-products that have so far been proclaimed as wastes, in the creation of commercially interesting products and the production of energy from renewable sources.











Conclusion

While technical solutions exist, they alone cannot resolve current issues. To ensure a sustainable transition, the sectors must engage profound societal and institutional transformations, backed by science, competitiveness, local and indigenous knowledge, and based on inclusive governance, and strengthened cooperation. Adapting fishing and aquaculture is not just a necessity; it presents an opportunity to collectively build a more sustainable and desirable future for climate, biodiversity, and human societies.