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Overview of R&D Efforts Aimed at Improving Sustainability in Fisheries and Aquaculture

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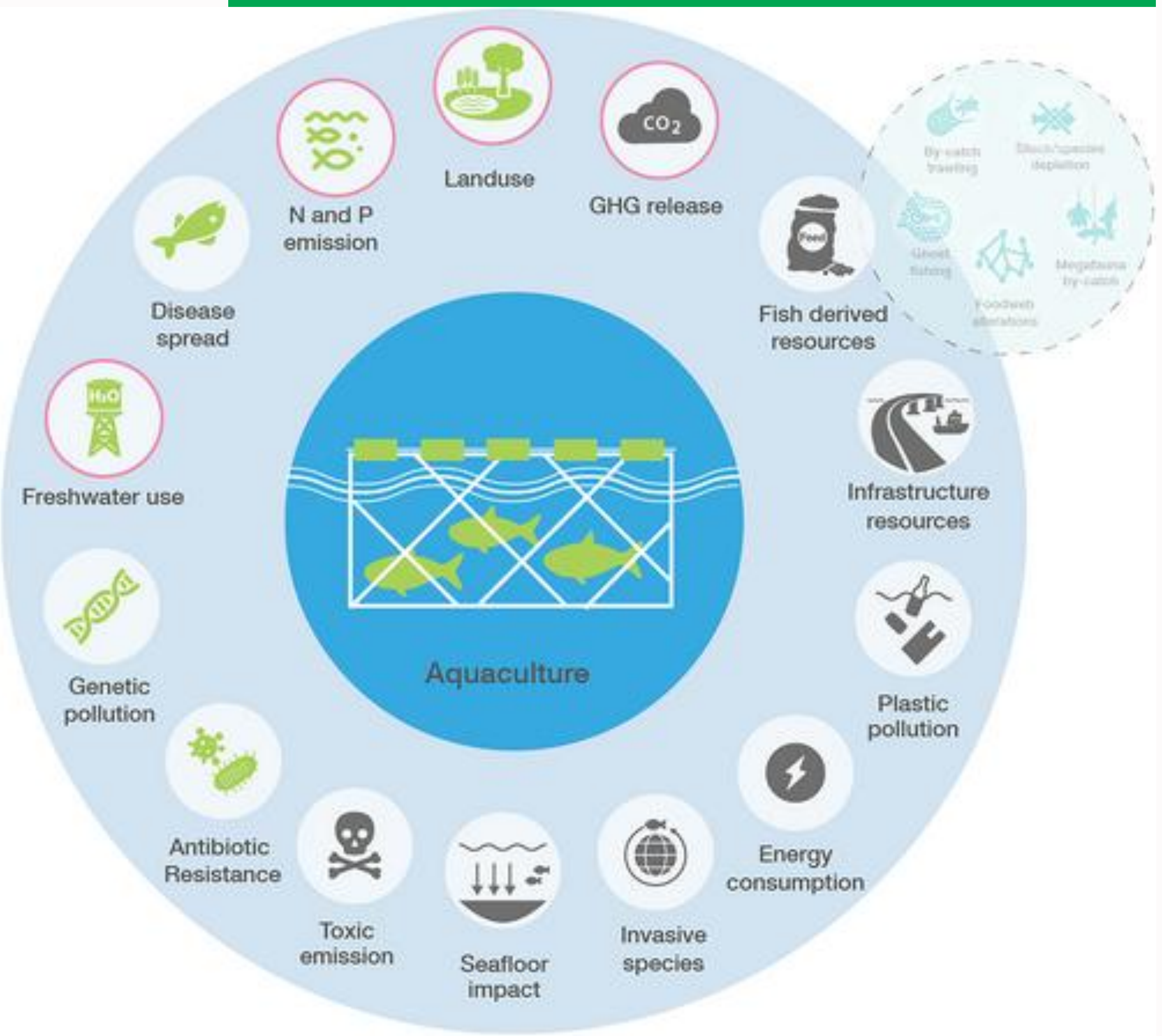
Outline



Troell et al. (2023)

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1. Selective Breeding and Genetic Innovations (1)

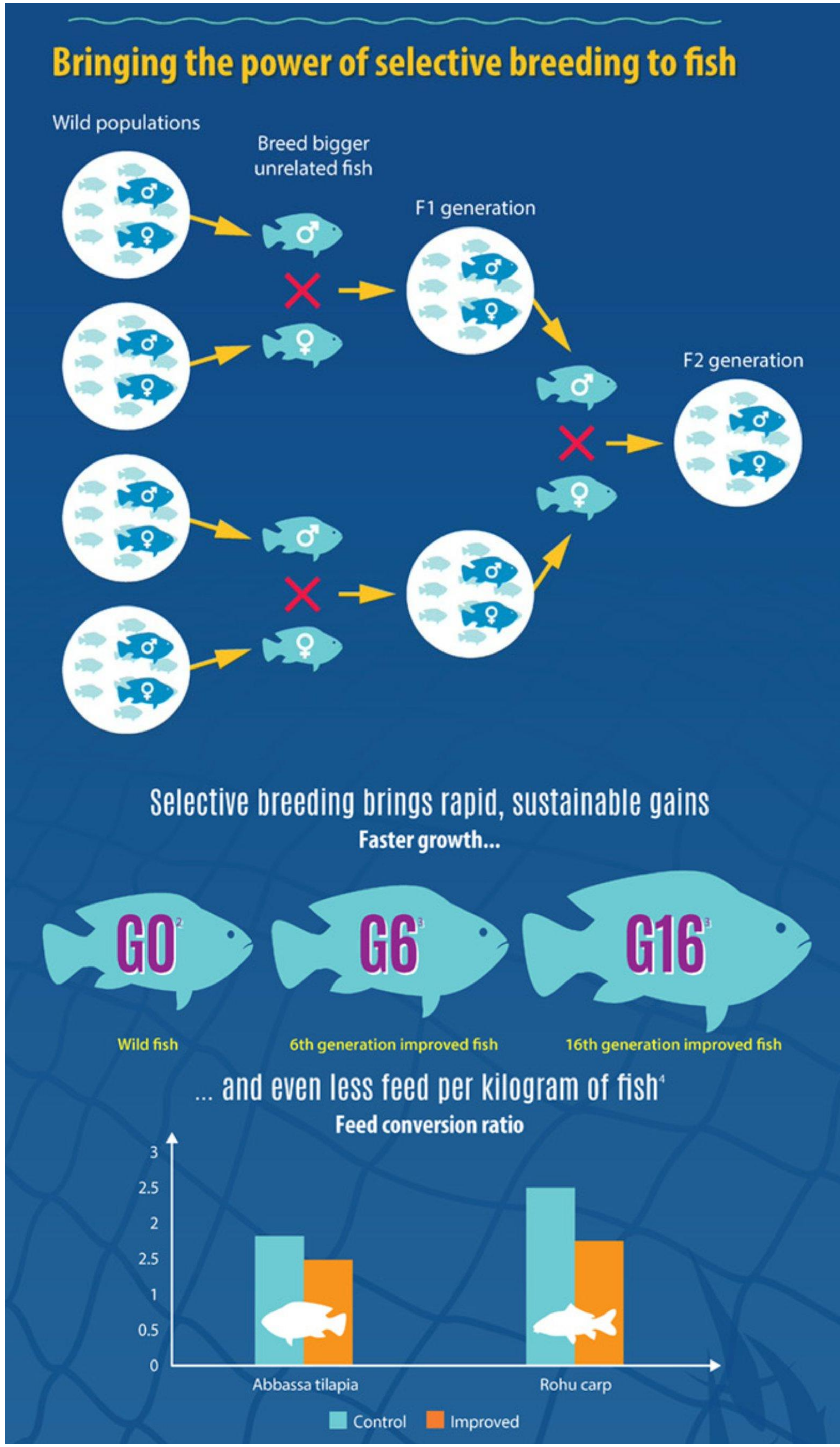
R&D is making strides in genetic improvements through selective breeding, enhancing fish growth rates, disease resistance, and overall productivity. This contributes to more resilient fish populations that can thrive in diverse environments, supporting global food security while minimizing ecological pressure.

Selective Breeding:

- In a selective breeding program, changes are random where the probability of desired changes to occur is low and a lengthy process for many generations to establish a breed.
- Enhances disease resistance and climate adaptability. Norway reduced antibiotic use in salmon by 99% through vaccinated, fast-growing strains [1].
- Develops salinity-tolerant tilapia (e.g., *Oreochromis mossambicus*) to be farmed in brackish water.
- Selective breeding of tilapia by ICLARAM (International Centre for Living Aquatic Research Management) → product: Gift strain → 100% faster compared to their base population and is able to thrive in a wide range of environment.

Visit:

- https://www.youtube.com/watch?v=rf4SEy7eFmw
- https://www.youtube.com/watch?v=ErHlNYZzAus



worldfishcenter.org

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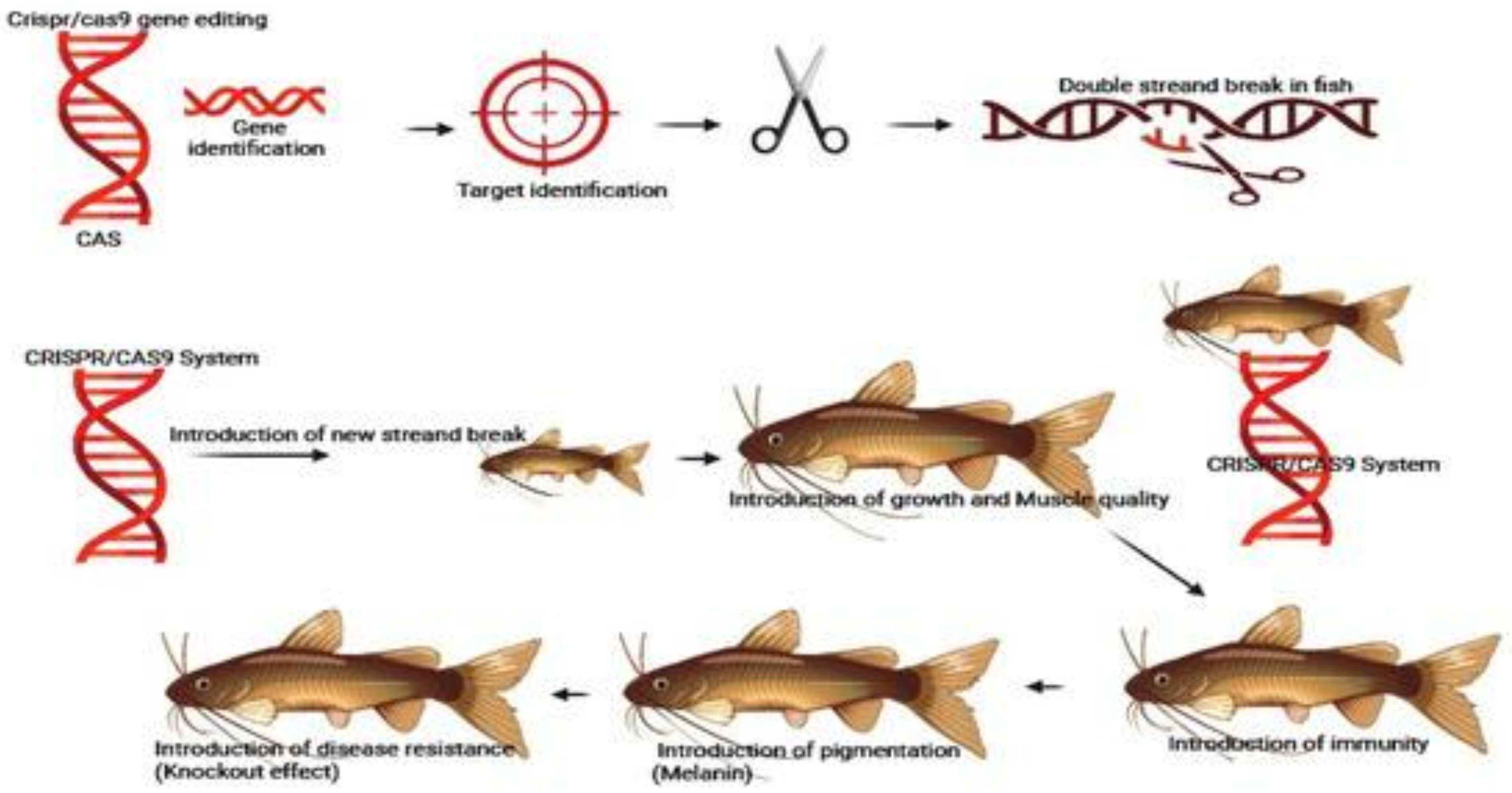
1. Selective Breeding and Genetic Innovations (2)

CRISPR and Gene Editing:

- Genome editing can fast-forward the breeding process with precision where changes occur in the targeted genes and there is a probability for the desired changes to occur.
- CRISPR/Cas9 has recently been applied to the traits valued in some aquaculture species (almost >20 species), targeting the main traits of traditional genetic improvement initiatives like growth, disease resistance, reproduction, sterility, and pigmentation [2].
- Has been applied to: Atlantic salmon; Nile tilapia; red sea bream; channel and southern catfish; rainbow trout; blunt snout bream; and farmed carps like Rohu, grass, and common carp, as well as Pacific oyster, Atlantic killifish, fighting fish, Chinese tongue sole, olive flounder, oriental and white prawn, and other species.



The application of CRISPR/Cas9 in aquaculture involves several steps. First, a specific gRNA is designed to match the target gene sequence. Then, the Cas9 protein binds to the target DNA, causing a double-strand break. Finally, the break is repaired (Roy et al., 2022)

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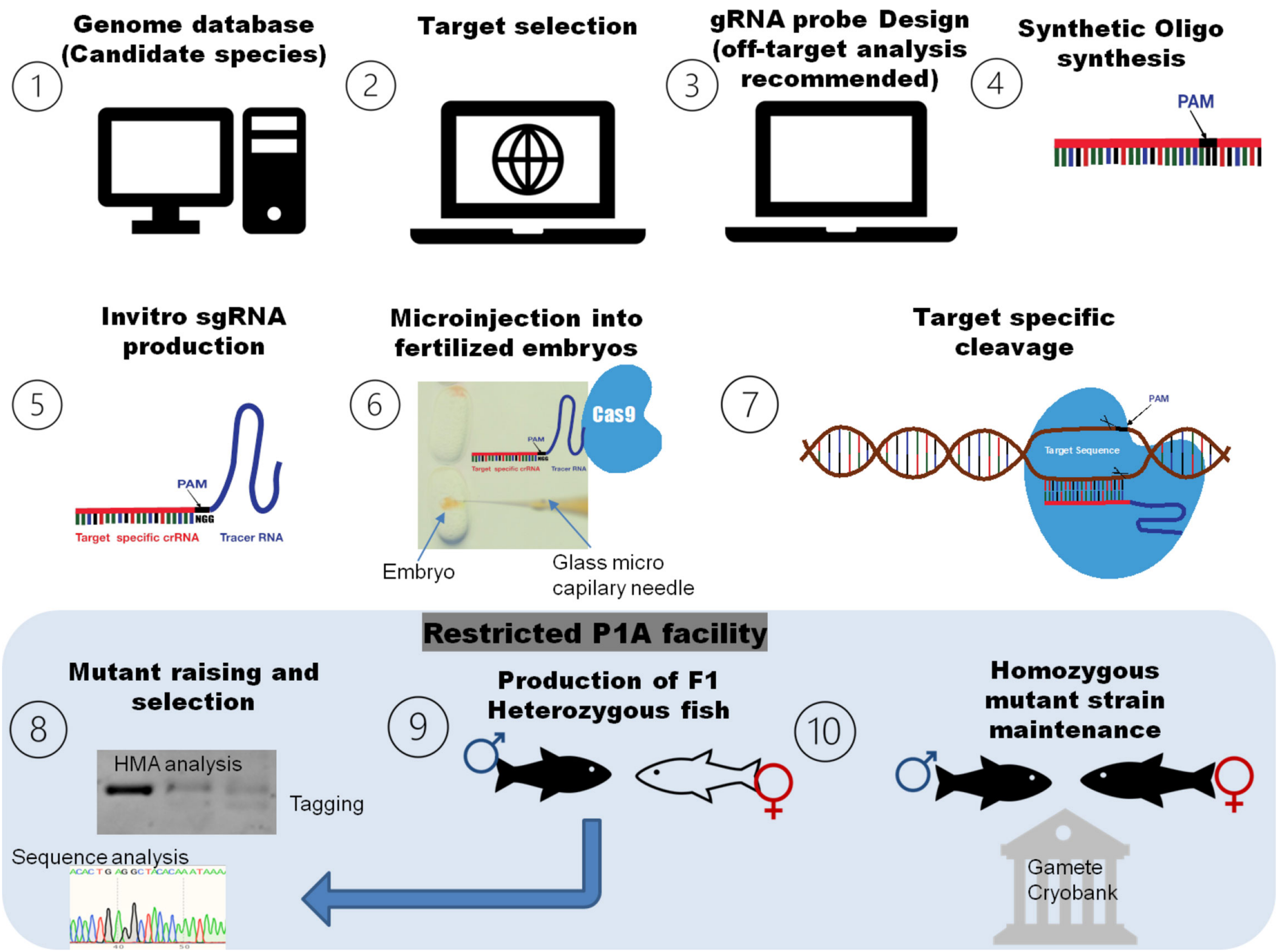
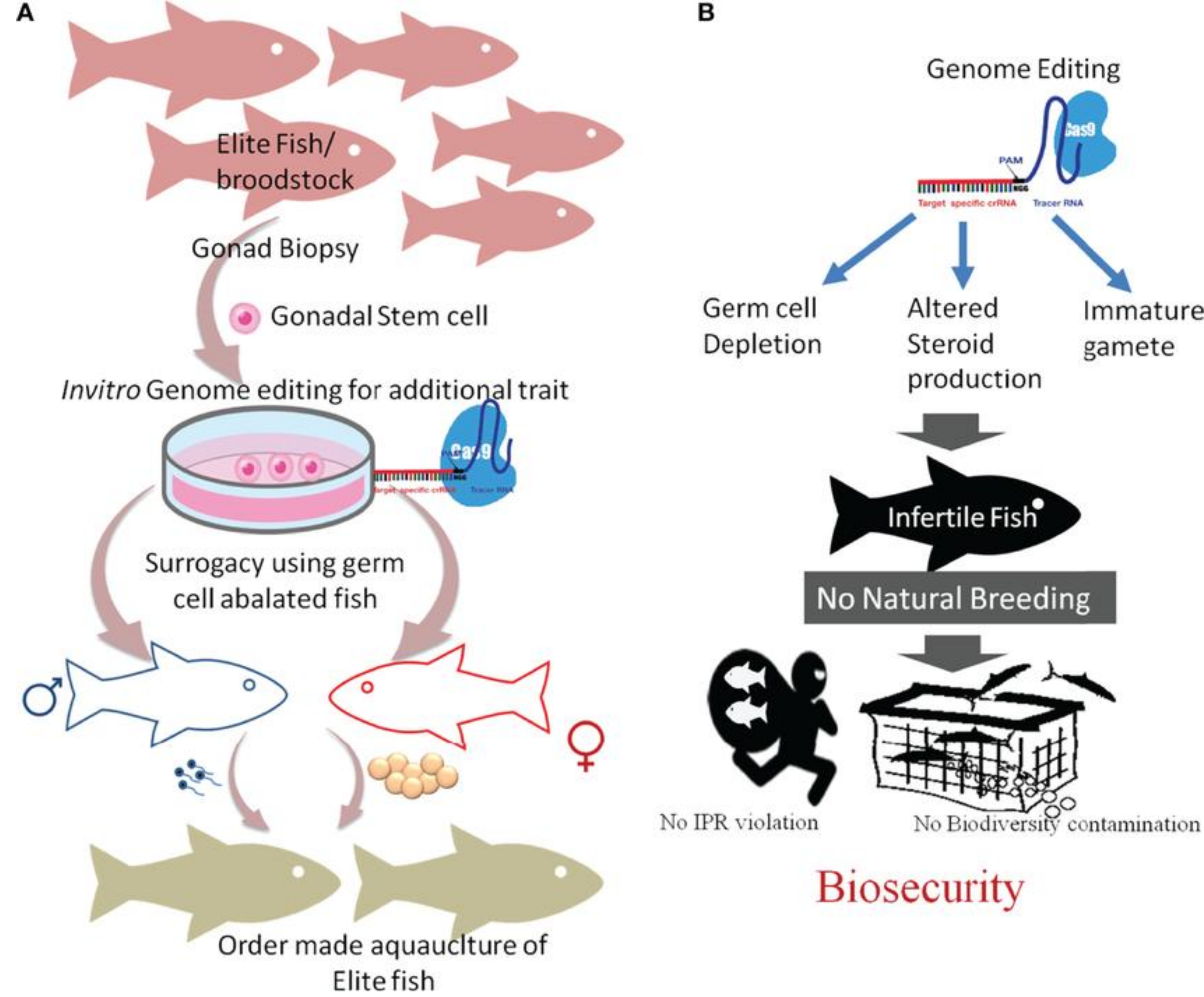


A simple roadmap of general methodology for CRIPSR/Cas genome editing in aquaculture and fisheries. The target gene has to be selected after searching the genome database of candidate species. The sgRNA has to be designed with the help of sgRNA-designing tools, and then, the sgRNA oligo has to be synthesized. For target-specific cleavage, the sgRNA and cas9 mixture needs to be delivered to the newly fertilized embryo at a one-cell stage by microinjection or similar methods. The final step is the assessing the genome-editing results and application stage that includes mutagenesis analysis, the selection of mutants, crossing with wild population and production of a specific mutant line, the evaluation of CRISPR-induced mutation associated phenotyp (s), and the establishment of new varieties with improved values in aquaculture.

(Roy et al., 2022)



Future of genome editing in aquaculture and fisheries. It is assumed that genome editing will be largely adopted in aquaculture to improve its sustainability. To produce a genome-edited stock, germline mutation is pivotal. (A) The right panel showed a gonadal stem cell [germ cell precursor cells or gamete-producing cells (GSC)] from various high-performing (elite) fish will be collected, cultured, and modified using genome editing. The in vitro genome- edited GSC, which carries the mutation, when transplanted into sterilized (germ cell-less or abalated) host will produce male and female gametes, depending on the sex of the host. The mixing of these gametes will produce a specific superior strain. (B) Illustration showing the application of GSC-based order made strain production in infertile fish production, controlled aquaculture, and biosecurity.

(Roy et al., 2022)

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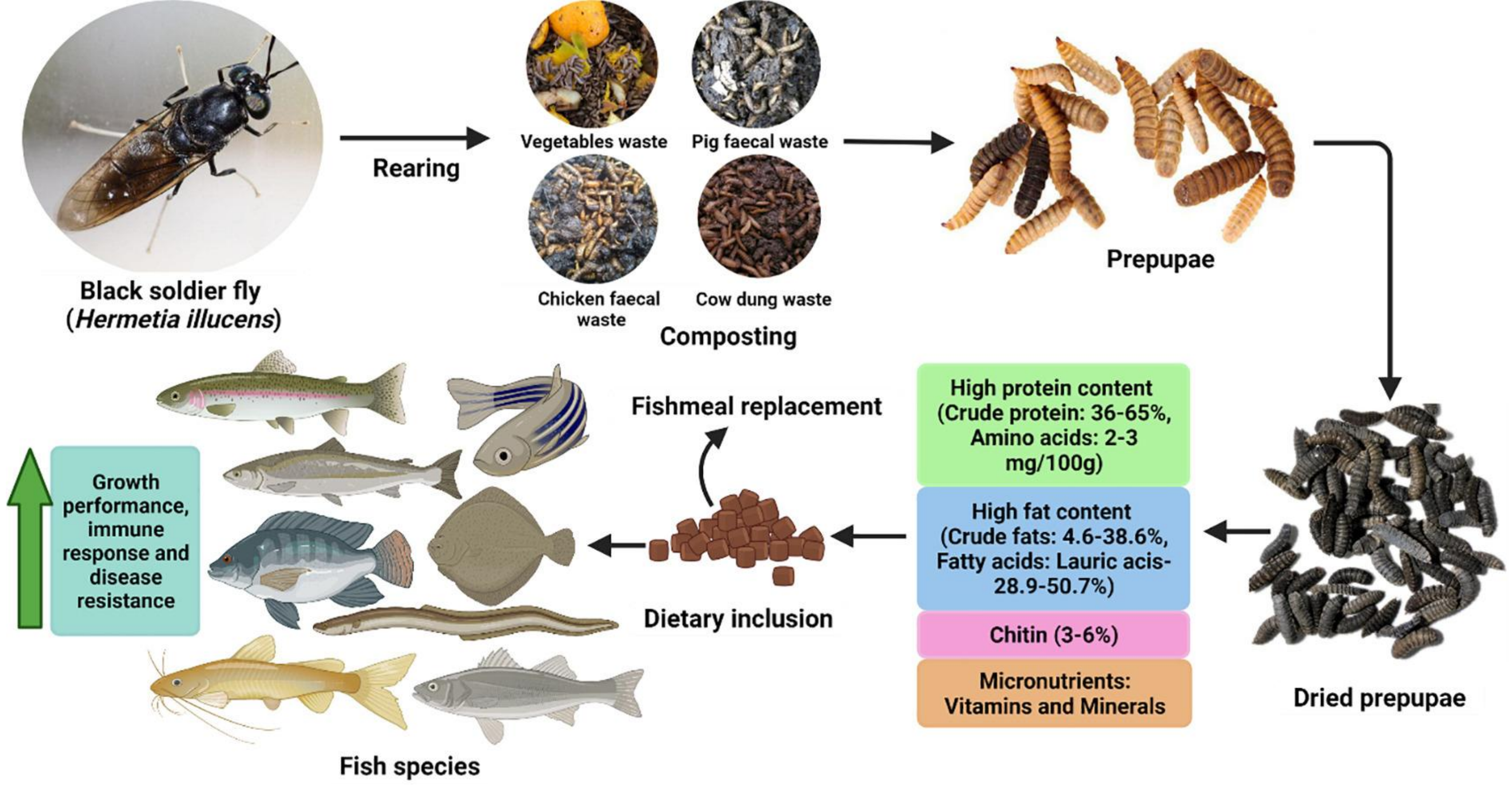
2. Alternative Feeds & Resource Efficiency (1)



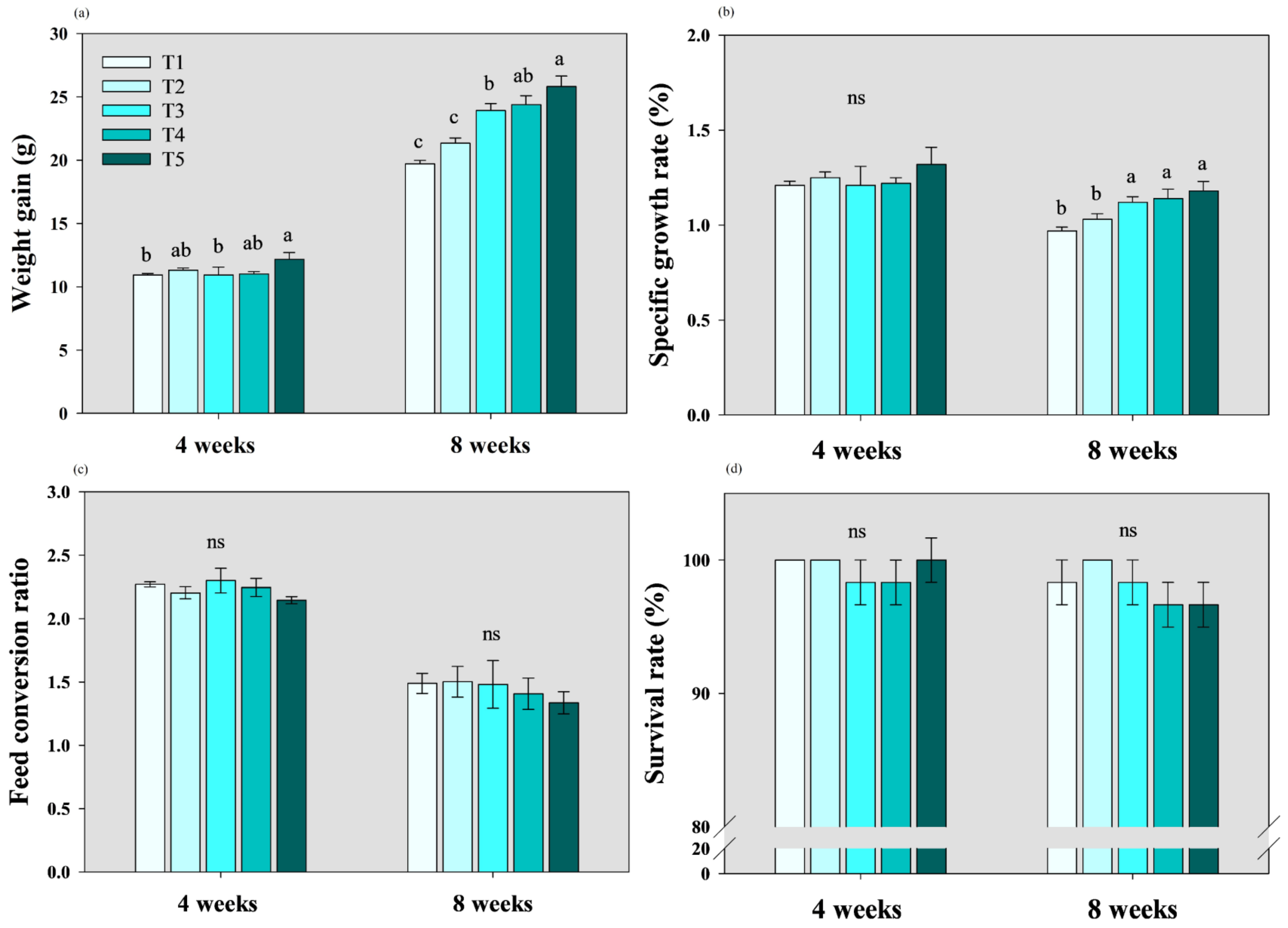
Mohan et al., 2022

Alternative Protein Sources:

- Insect meal (e.g., black soldier fly larvae), algae, and microbial proteins replace fishmeal, reducing reliance on wild-caught forage fish. Ecuador's shrimp farms achieved 25% higher yields post-transition [3].

Visit:

- https://www.youtube.com/watch?v=6WqgmMiYPak
- https://www.youtube.com/watch?v=3gAdT5YigGo



Measurement of WG or weight gain (**a**), SGR or specific growth rate (**b**), FCR or feed conversion ratio (**c**), and SR or survival rate (**d**) of Koi carp fed the following diets: 0 g kg^{-1} BSFLM (T1) control, 50 g kg^{-1} BSFLM (T2), 100 g kg^{-1} BSFLM (T3), 150 g kg^{-1} BSFLM (T4), and 200 g kg^{-1} BSFLM (T5). The data are presented as mean ± SEM, and the use of different letters signifies statistically significant differences between groups ($p < 0.05$). The symbol "ns" is used to indicate the absence of significant differences ($p > 0.05$). (Linh et al., 2024)

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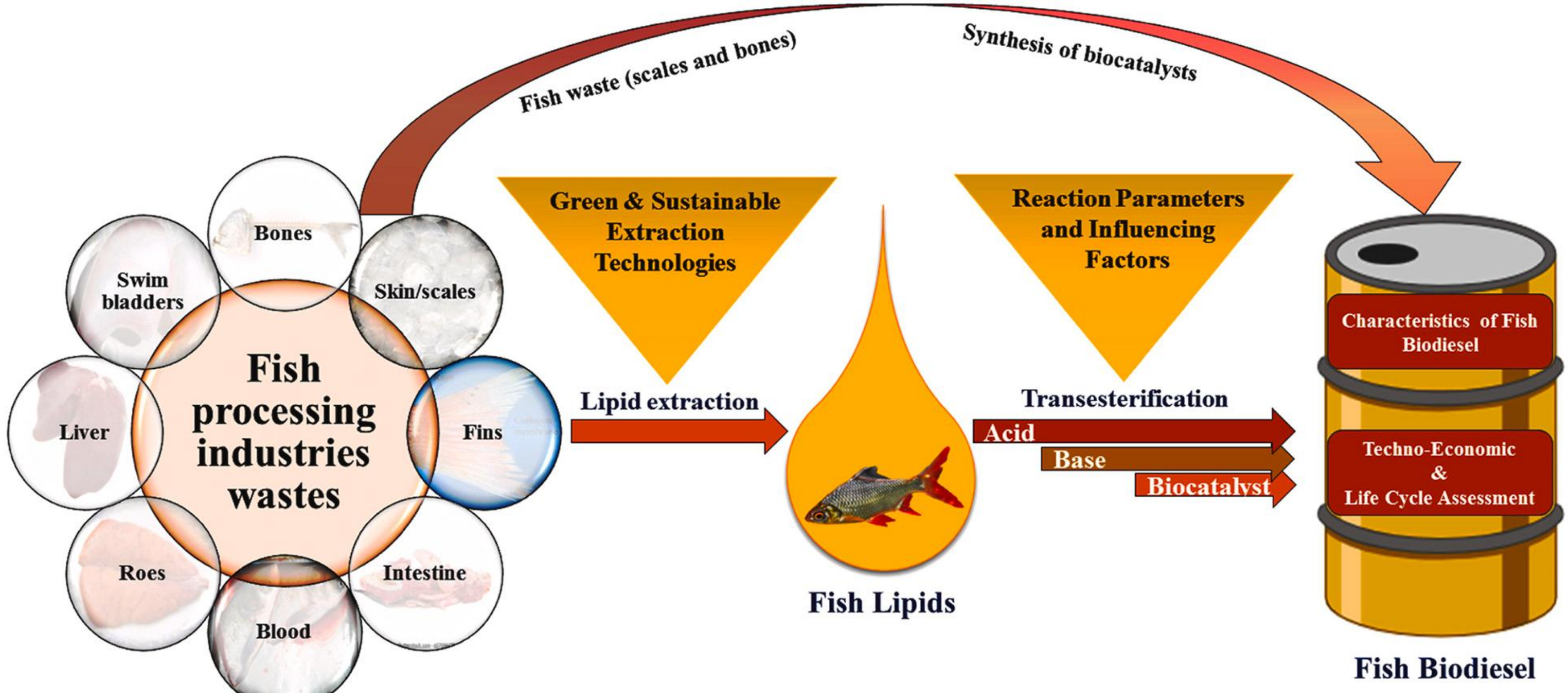
2. Alternative Feeds & Resource Efficiency (2)

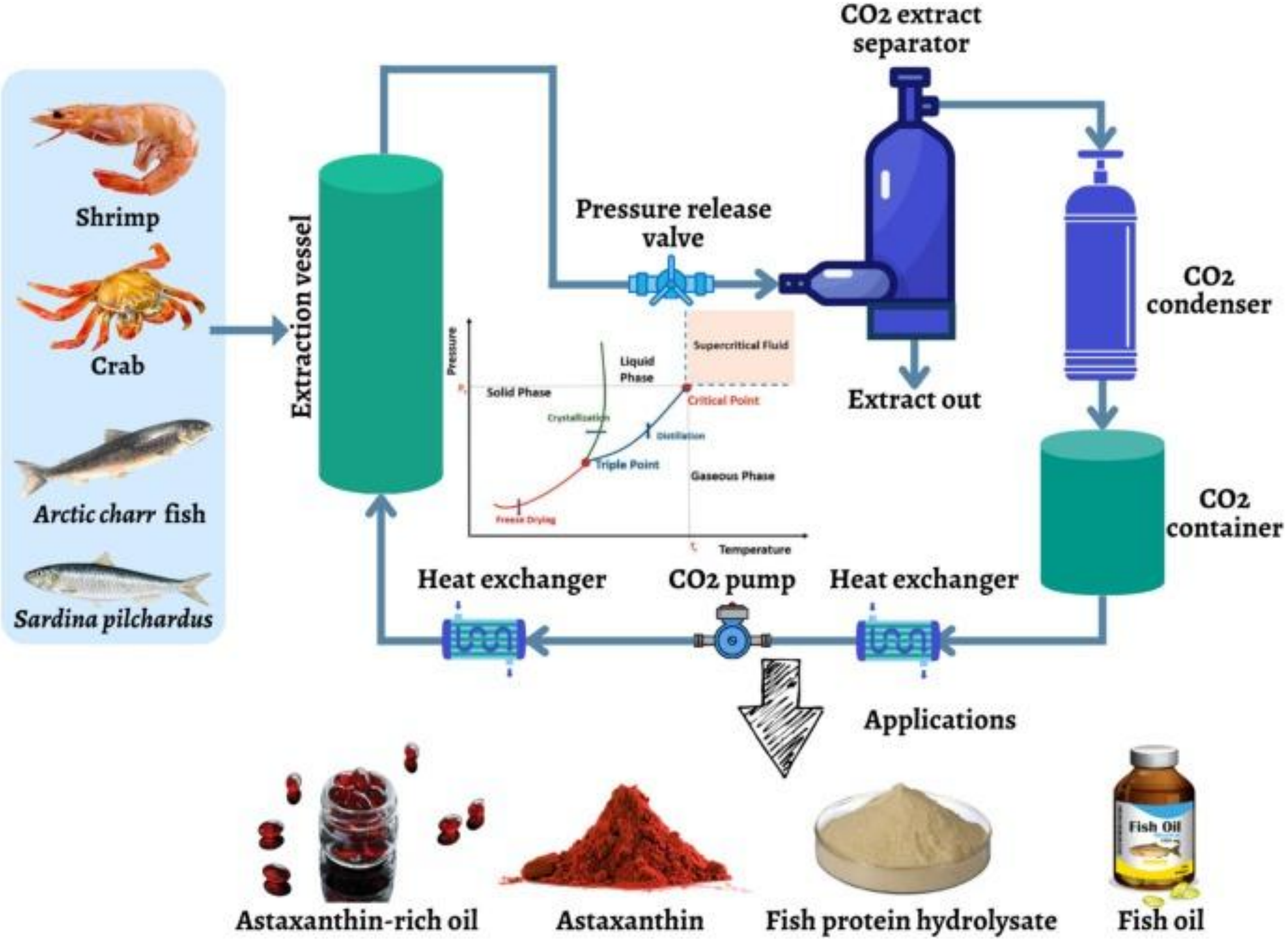


Jaiswal et al., 2024

Feed Conversion Ratio (FCR) Optimization:
- Genetic breeding and AI-driven feeding systems lower FCR from >1.5 to 0.9–1.1, slashing feed waste by 20% [4].

Waste Valorization:
- Fish processing byproducts converted into collagen, chitosan, or biofuels (e.g., TômTex's shrimp-shell leather), enabling circular economies [5].

Visit:
- https://www.youtube.com/watch?v=iCTAoOaBKw8
- https://www.youtube.com/watch?v=4XFEwVSG_rc



Schematic of working principle and application of microwave-assisted extraction (MAE) techniques (Xia et al., 2024)

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2. Transformative Production Technologies (1)

Recirculating Aquaculture Systems (RAS):

- Closed-loop systems that recycle >95% of water, reduce land use, and prevent pollution. Projects like Atlantic Sapphire (USA) demonstrate scalability, producing 10,000 tons of salmon annually with minimal environmental impact [4].

Aquaponics and Reservoir Integration:

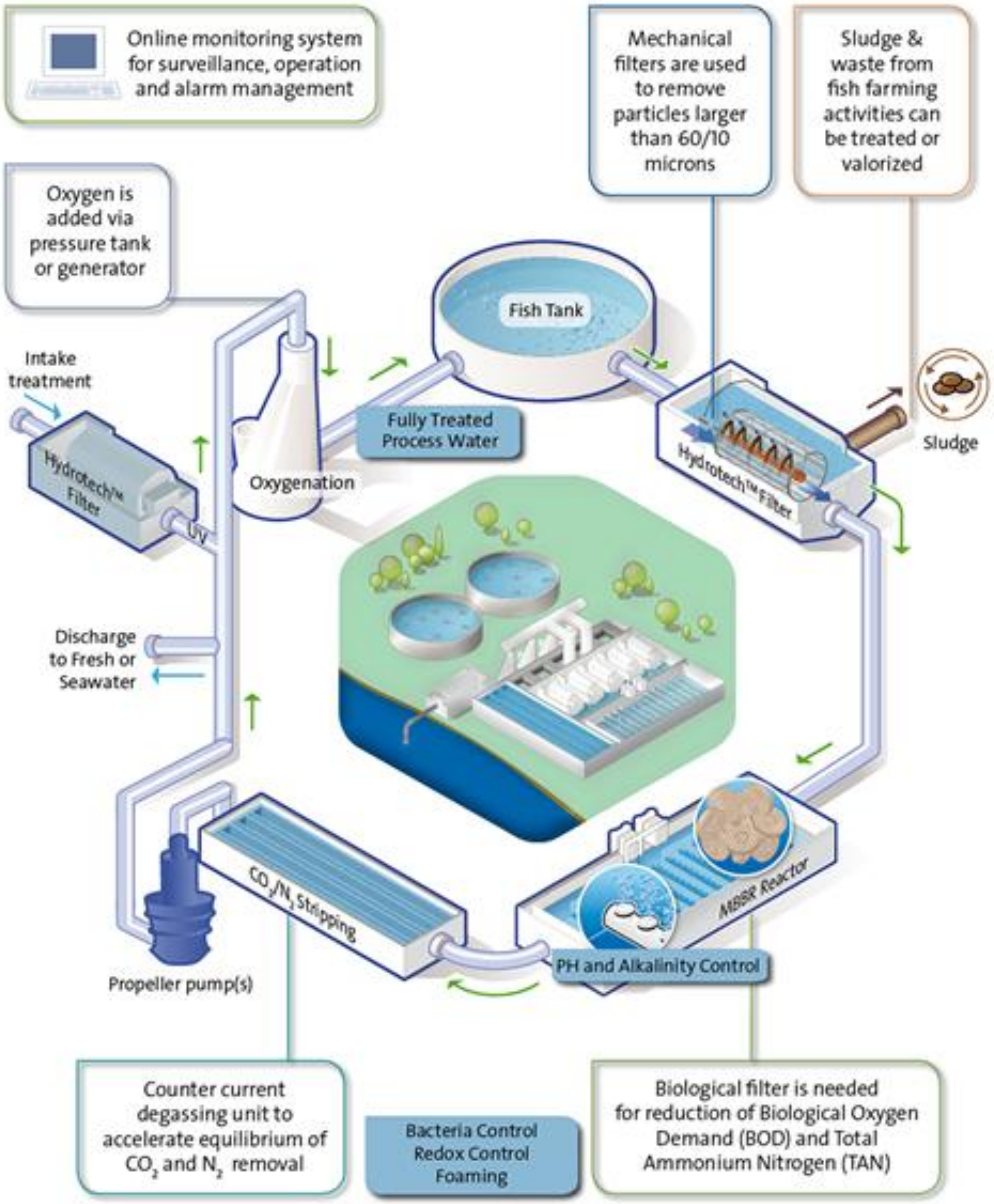
- Leverages existing water bodies (e.g., dams) for fish farming, optimizing resource efficiency without new habitat destruction [6].

Integrated Multi-Trophic Aquaculture (IMTA):

- Combines fish with seaweed/mollusks to recycle nutrients. Canadian salmon-mussel systems cut waste by 50% and boosted profits by 15–20% through byproduct valorization [5].

Visit:

- https://www.youtube.com/watch?v=Oo1V62fIGlM



RAS system (reddit.com)

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Integrated Multi-Trophic Aquaculture (IMTA) is a sustainable aquaculture practice that involves farming multiple aquatic species from different trophic levels together. This approach aims to improve efficiency, reduce waste, and provide ecosystem services like bioremediation. In essence, IMTA utilizes the byproducts of one species as nutrients for another, creating a more circular and environmentally friendly system.

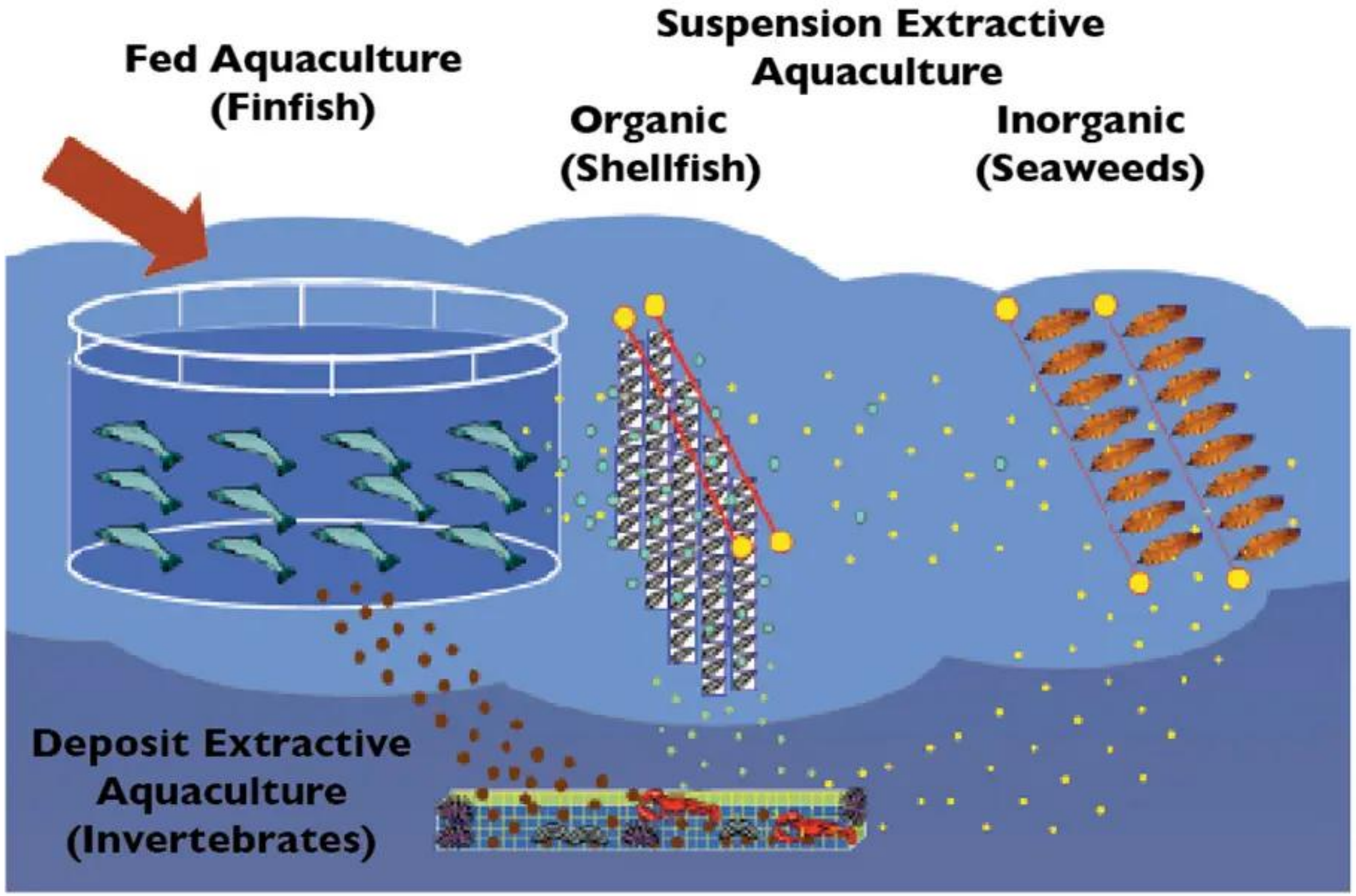
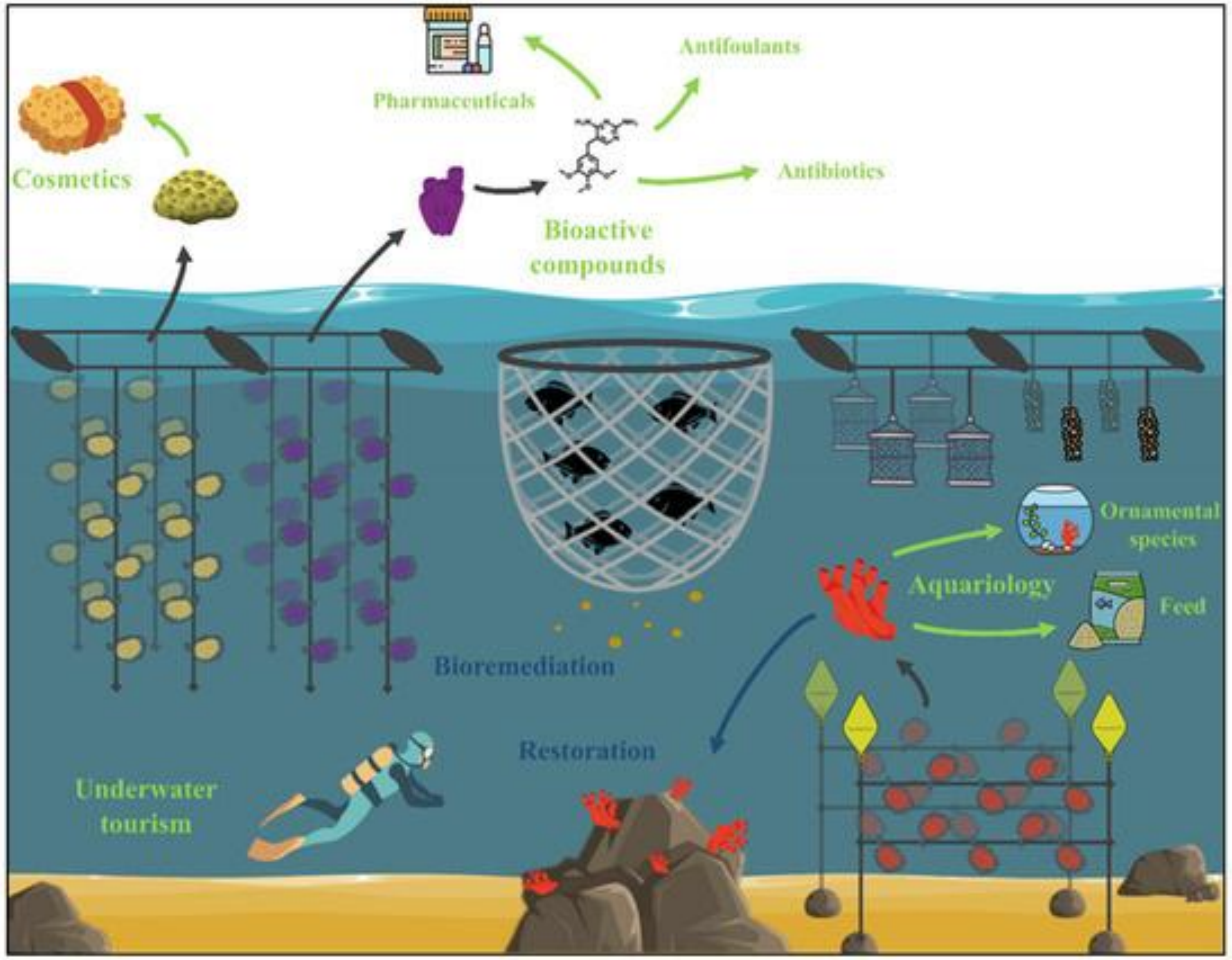


Diagram of an integrated multi-trophic aquaculture operation illustrates a combination of trophic levels that share the environment and take advantage of organic and inorganic nutrients made available by the various organisms (globalseafood.org)



Sponges as a by-product of an IMTA system. Environmental and economic benefits are represented in blue and green, respectively.
(Aguilo-Arce et al., 2023)

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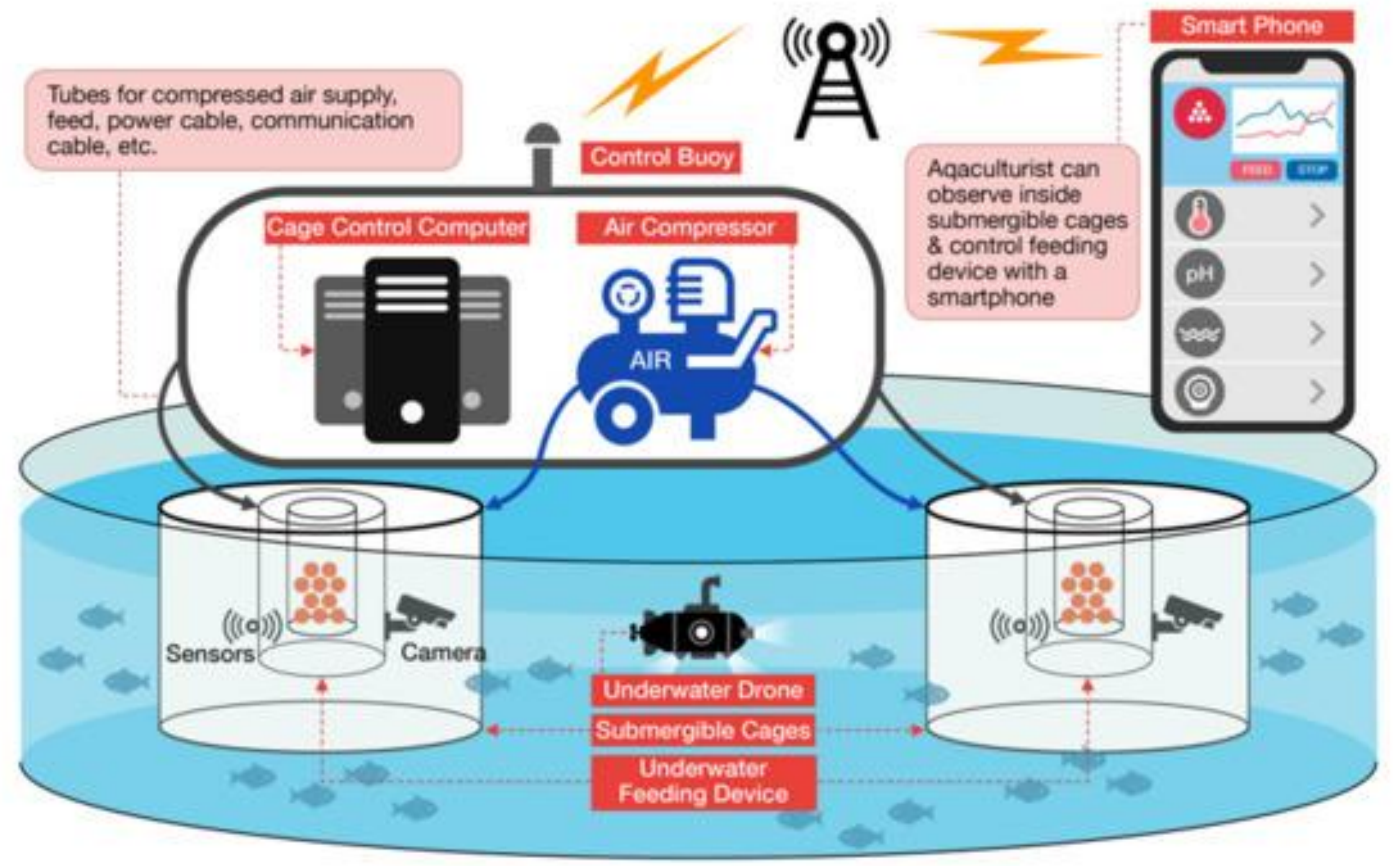
4. Precision Monitoring and AI(1)

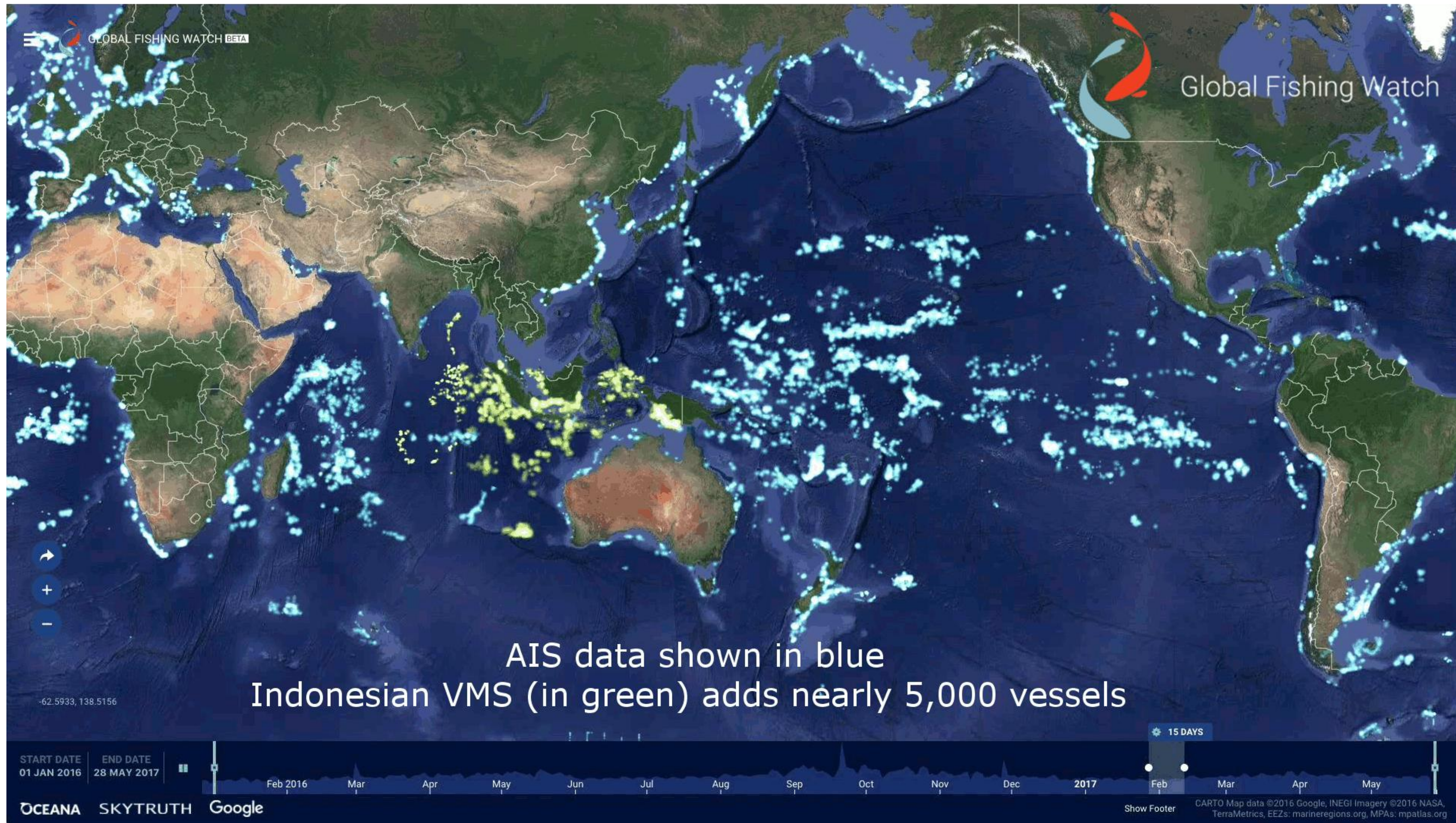
IoT Sensors and Real-Time Analytics:
- Monitor water quality, fish behavior, and disease outbreaks. Aquabyte's AI optimizes feeding, cutting costs by 15–20% [5].

Blockchain Traceability:
- Platforms like IBM Food Trust combat illegal fishing by tracking tuna from catch to consumer, ensuring ethical sourcing [7].

Satellite Surveillance:
- Global Fishing Watch detects IUU fishing in hotspots like Indonesia's Arafura Sea, aiding enforcement [1].



Concept diagram of smart aquaculture system (Vo et al., 2021)



https://globalfishingwatch.org/news-views/indonesia-must-continue-marine-transparency-leadership/

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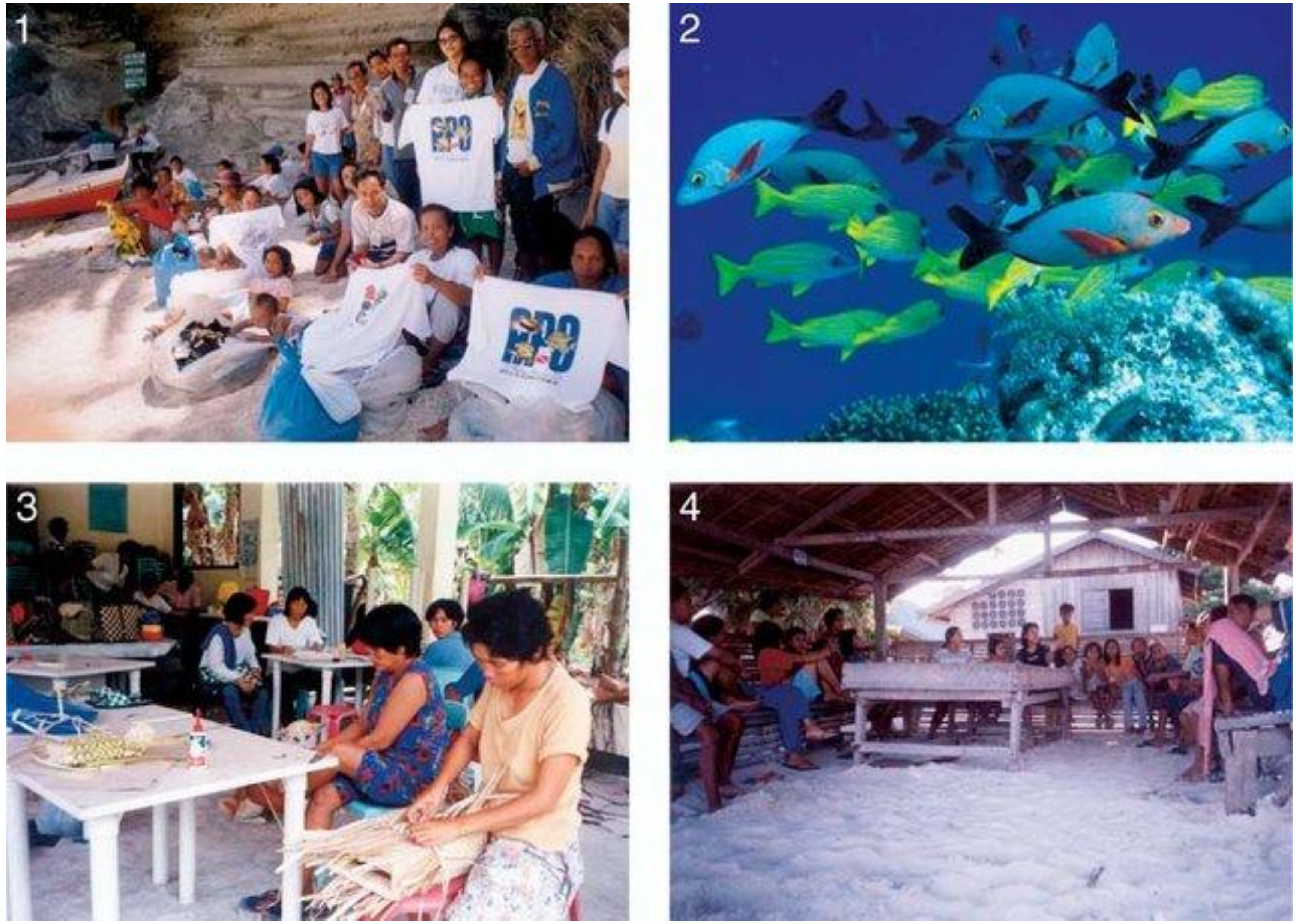
5. Policy, Equity, and Ecosystem Management(1)

Community-Led Co-Management:
- Marine Protected Areas (MPAs) and no-take zones (e.g., Philippines' Apo Island) increased fish biomass by 200% through local stewardship [8].

Key Aspects of Community-Led Co-Management on Apo Island:
- Collaborative Management: collaboration between the local community and the government
- Community Participation: Community members are actively involved in decision-making processes
- Empowerment: Local people are empowered to play a significant role in managing their marine resources.
- Success in Restoring Ecosystems
- Economic Benefits: Restoration of marine resources has led to increased fish catches for local fishermen and has also boosted tourism.
- Shift from Centralized Management: The importance of community participation in ensuring the long-term sustainability of marine resources.



Selling T-shirts at Apo Island. The Apo no-take reserve has generated considerable in-come from tourism for the local community. Photo: J. Maypa. Pho-to 2. A large group of tropical snappers (family Lutjanidae) in a Philippines no-take marine reserve. Photo: B. Stockwell. Photo3. Weaving baskets for sale at Selinog Island. Many of the marine-conservation and fisheries-management programs at the community and local government level now include generation of alternative livelihoods. Photo: J. Maypa. Photo 4. A meeting of the local community with a social worker at Mantigue Island (off Camiguin Island), southern Philippines. Photo: J. Maypa.
(Alcala & Russ, 2006)

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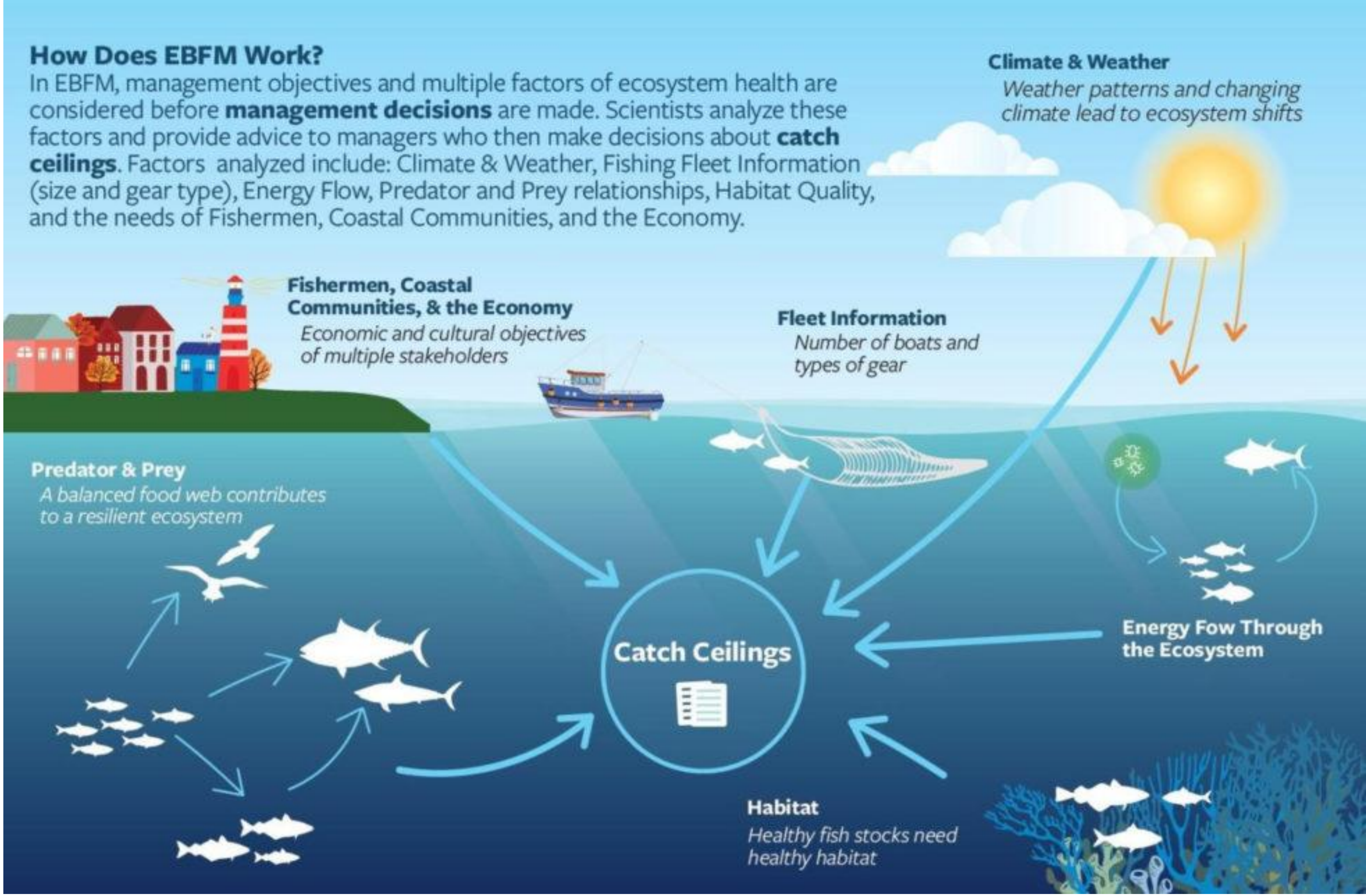

Ecosystem Based Fisheries Management takes a holistic approach

(capecodfishermen.org)

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5. Policy, Equity, and Ecosystem Management(2)

Gender-Inclusive Programs:

Women-led seaweed cooperatives in North Sulawesi raised incomes by 40% while restoring ecosystems [8]:

- Indonesia is a major player in the global seaweed industry, producing and exporting both raw and processed seaweed products
- In Indonesia, seaweed is the largest seafood commodity by volume—11.3 million tons in 2019—but economic returns are low
- Seaweed farming can, but does not always, lift rural households above the Indonesian poverty line
- In addition to direct financial benefits, seaweed farming also contributes to human and social capital within seaweed farming households and communities.

A group of women tying seaweed seedlings onto the nylon line in Ujung Baji Village, Takalar South (unido.org)

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6. Future R&D Directions

'R&D is not just about profit; it's about stewardship. The next breakthrough must serve both people and the planet" — **FAO Blue Growth Initiative**

Circular Economy Integration

Scale aquaponics and "waste-to-protein" systems for zero-discharge aquaculture

AI-Driven Forecasting

Predictive analytics for disease outbreaks and stock assessments (e.g., Malaysia's climate-resilient species breeding)

Democratizing Technology

Low-cost RAS and solar-powered tools for small-scale producers, supported by initiatives like FAO's Blue Growth

Transboundary Collaboration

Regional agreements (e.g., Mediterranean MPAs) to harmonize policies against IUU fishing

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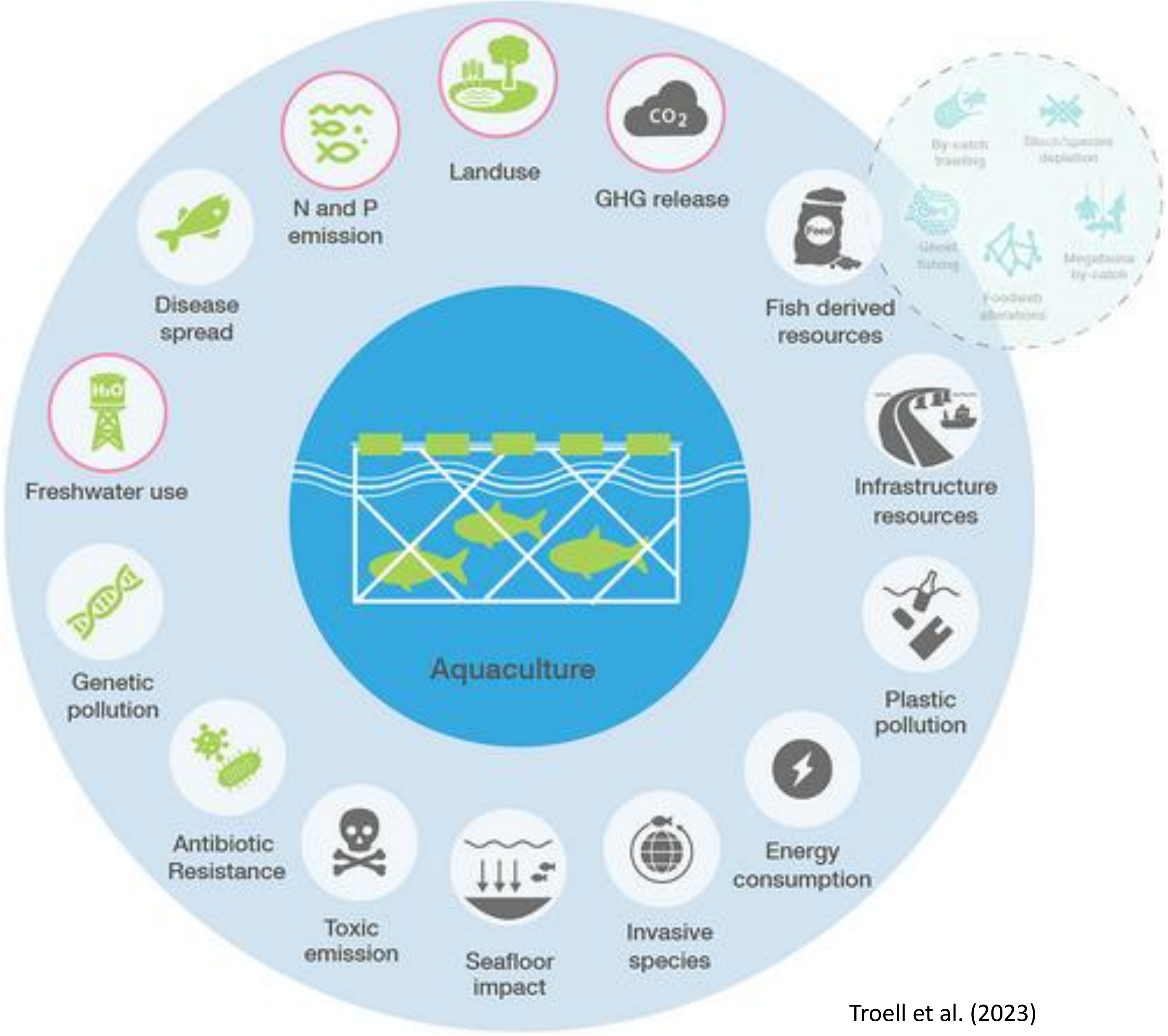
CONCLUSION

This R&D landscape prioritizes holistic innovation—merging technology, policy, and equity to overcome ecological and socioeconomic constraints. Key imperatives include democratizing access to affordable tools, strengthening traceability, and embedding circular principles. By addressing these, aquaculture can sustainably meet 2050’s projected 140M-ton seafood demand while safeguarding marine ecosystems.



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Xia, FLW, et al., 2022. Turning waste into value: Extraction and effective valorization strategies of seafood by-products. *Waste Management Bulletin* 2: 84-100.

Vo, TTE, et al., 2021. Overview of Smart Aquaculture System: Focusing on Applications of Machine Learning and Computer Vision. *Electronics* 10(22): 2882.

Further Reading

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Further Reading

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