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Editorial: Towards an expansion of sustainable global marine aquaculture

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Editorial on the Research Topic
Towards an expansion of sustainable global marine aquaculture

Aquaculture is the fastest-growing food-producing sector, currently supplying 52 % of the aquatic animals consumed globally by humans (Misund et al., 2024). Yet, it is facing multiple challenges such as environmental impact, disease management, and economic sustainability. Innovative methods, technologies and new production systems are needed to reduce environmental footprints, increase climate resilience, and ensure the long-term viability of aquaculture while providing ecosystem services.

Engineering advances for offshore aquaculture

Nearshore aquaculture areas are facing multiple challenges such as limited water exchange, high parasite risk (e.g., sea lice), and competition with other coastal users. Moving aquaculture to more exposed sites or offshore can mitigate these pressures. However, offshore aquaculture also brings significant challenges and requires carefully designed technological, biological, and regulatory solutions. Niu et al. studies the dynamic motion response of large-scale steel aquaculture cages during towing, an important but underexplored aspect of offshore logistics. The study shows that towing speed, towline length, and towing configuration can significantly affect cage stability and towline tension. Such engineering insights are crucial for ensuring the safe and efficient transport of large aquaculture infrastructure in challenging conditions.

Similarly, Overrein et al. highlights the role of automation and computer vision in kelp aquaculture. By using underwater imaging and computer vision algorithms, the study provides robust, real-time biomass estimation of cultivated kelp. This enables cost-effective monitoring and yield prediction for large scale production. Such automation monitoring tools have the potential to promote the seaweed industry and will be useful for future offshore operations.

Health, welfare, and monitoring

Fish health and welfare remain major challenges to sustainable aquaculture expansion. (Merca et al., a; b) develop dynamic linear models (DLM) for monitoring monthly mortality of Atlantic salmon at multiple levels in Scotland, using open-source salmon production data. This is useful for various stakeholders as part of a monitoring system, offering insights into mortality trends at national, regional, and sites levels that may benefit from strategic resource management.

At the molecular level, Sandbakken et al. investigates the effect of partially replacing fishmeal with salmon protein hydrolysates on the intestinal gene expression and microbiota. Gene expressions of pyloric caeca (PC), midgut (MG) and hindgut (HG) revealed a downregulation of immunological genes involved in inflammation in the intestine of salmon fed with 18% salmon hydrolysate compared to those fed the control diet. Such dietary strategies improve welfare while reducing the reliance on fishmeal. Similarly, (Yang et al.) studies the regulation of melanogenesis in *Plectropomus leopardus*, indicating that ERK1/2 was involved in the regulation of melanogenesis through the regulation of MITF in *P. leopardus*. This provides a new perspective for exploring the variable skin colouration of coral reef fish.

Sustainable feeds

A majority of greenhouse gas emissions from aquaculture is accounted for by feed (Skavang and Strand). Innovation in feed is crucial for sustainable development of aquaculture. Buttle et al. explored the potential of using single-cell proteins (SCP) as feed ingredient, demonstrating high protein digestibility, balanced amino acid profiles, and fish health benefits in rainbow trout. Although cost and scalability remain challenges, SCP shows a promising avenue for sustainable aquafeeds.

Carr et al. explored the optimal levels of eicosapentaenoic acid + docosahexaenoic acid for farmed Atlantic salmon. Through large-scale trials in Chile and big-data analysis in Norway, the study shows that using algal oil-supplemented feed resulted in improved health responses and better fillet quality. The EPA + DHA levels > 8% reduce mortality variability by 21%, improve economic feed conversion ratio by 11%, and increase the likelihood of superior harvests by 27%, demonstrating productivity benefits.

Diversification of aquaculture species and systems

Diversification of aquaculture species and systems is important to meet growing consumer demand while ensuring environmental sustainability, economic viability, and food security.

Portuguese oyster (*Crassostrea angulata*), are highly valued for their nutritional and flavor qualities, making them important in global aquaculture. Chen et al. studies the flavor differences between triploid and diploid oysters, using metabolomics approach. Their findings show significant upregulation of inosine, guanosine, L-aspartic acid, and taurine in triploids which enhanced their flavor. This highlights the advantages of triploid oysters in aquaculture for improved flavor and nutrition, supporting their potential for year-round production.

Ghosh et al. evaluated the potential of the high-value marine fish (*Protonibea diacanthus*) in polyculture with Indian pompano, revealing superior growth of *P. diacanthus* and is a viable candidate species with significant potential for polyculture systems. Li et al. analyzed the nutritional composition of artificially fertilized eggs from Japanese eel (*Anguilla japonica*) and transcriptome of samples from fry to better understand nutrients requirements. Their findings will facilitate future studies on the nutrition of *A. japonica* larvae and other biological traits for reproductive research.

Seaweed aquaculture has gained increasing interest in recent years, especially in Europe. Vieira et al. examined the functional traits of *Gracilaria dura* from two intertidal populations in Gujarat, India, to understand their adaptations and potential for cultivation. The findings suggest that submerged cultivation maximizes biomass yield whereas exposure reduces yield but increases valuable bioactive compounds. Guo et al. developed an asexual tissue culture method for *Sargassum fusiforme* to maintain superior traits. The optimal condition was using holdfasts or stem tips on solid medium with 3 μM uniconazole for 17 days, followed by transfer to liquid medium. This resulted in 100% regeneration with high growth rates and enhanced photosynthesis. The technique enables continuous juvenile production, offering a reliable approach for preserving and expanding algal stocks.

Conclusion

This Research Topic demonstrates the breadth and dynamism of research in shaping the future sustainable marine aquaculture. From offshore aquaculture systems to seaweed genetics, from fish mortality models to alternative feed ingredients, demonstrating that sustainable expansion is possible through innovation, diversification, and systemic integration. Marine aquaculture has the potential to feed the increasing population and support climate-resilient food systems. Achieving this requires innovation, cross-sector collaboration, and global engagement in sustainability.

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