



Integrative Systems: Multitrophic and Circular Culture Approaches

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DESCRIPTION

An increasing body of research is exploring integrated culture systems in aquaculture as a strategy to improve resource efficiency and environmental sustainability. These systems combine multiple species such as fish, shellfish, seaweeds or microbial communities within a shared environment where the by-products or waste generated by one group serve as inputs or resources for another. This approach mimics natural ecosystems where nutrients are recycled through various trophic levels, minimizing waste and optimizing the use of available space and water. The fundamental principle behind these integrated setups is the synergy created when species with complementary biological roles are cultivated together in a controlled environment. In many experiments, fish serve as the primary cultured organism, producing nutrient-rich waste through uneaten feed and excretions. Rather than disposing of this effluent or relying entirely on mechanical filtration, integrated systems direct it toward other organisms that can utilize the nutrients. For example, seaweeds are often introduced to absorb dissolved nitrogen and phosphorus compounds from fish wastewater. This not only helps maintain water quality but also produces an additional crop that holds commercial value. Similarly, filter-feeding shellfish such as mussels or oysters are added to remove suspended solids and organic particles from the water. These bivalves help polish the water by feeding on plankton and detritus, improving clarity and reducing the need for external filtration.

Microbial cultures are also employed in some systems to further process organic waste. Biofilters or microbial reactors house communities of nitrifying and denitrifying bacteria that break down ammonia and nitrate into less harmful compounds. These microbial components often work in tandem with physical filtration units and other species to create a balanced and self-regulating aquatic environment. By orchestrating these multiple biological processes, integrated systems reduce environmental discharge and promote circular nutrient use, making aquaculture more sustainable and less dependent on constant water exchange or chemical treatments. Research comparing integrated

culture systems with conventional monoculture setups has yielded promising results. Trials often assess variables such as water consumption, nutrient retention and biomass output across both systems. A key focus is the reduction of waste nutrients like nitrogen and phosphorus, which are typically lost in monoculture operations through water discharge or sediment accumulation. In integrated setups, these nutrients are converted into additional biomass by seaweeds or shellfish, effectively turning waste into value. This nutrient capture improves the ecological footprint of aquaculture and enhances its compatibility with surrounding ecosystems, particularly in coastal or freshwater settings vulnerable to eutrophication.

Yield per unit of water is another critical metric studied in these systems. Since integrated designs often allow for multi-species production in the same volume of water, they offer the potential to increase cumulative output without expanding the physical footprint of the farm. Researchers have documented cases where the combined yield of fish, shellfish and seaweed significantly exceeds what would be obtained from a fish-only system occupying the same area. This increased productivity supports the concept of sustainable intensification producing more with less by maximizing resource use and minimizing waste. Studies also examine feed conversion ratios and overall feeding efficiency, noting that integrated systems can sometimes reduce feed requirements for fish by supporting natural food sources or stabilizing water conditions that improve fish health. Several experiments incorporate sequential harvest strategies, where species are harvested at different intervals to maintain continuous productivity and system balance. For instance, seaweeds might be harvested more frequently to prevent overgrowth and ensure optimal nutrient uptake, while shellfish are left to grow over longer cycles. These staggered harvest plans allow farmers to optimize space and labor use while ensuring that each species contributes consistently to nutrient recycling and biomass production. The flexibility of integrated systems also enables them to adapt to seasonal changes or market demands by shifting emphasis between species as needed.

Monitoring water parameters remains a central aspect of research in integrated aquaculture. Studies often track dissolved

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oxygen, pH, ammonia and nitrate levels across system components to ensure environmental conditions remain within tolerable limits for all organisms involved. The interaction between different species can influence these parameters positively or negatively, so maintaining system balance is crucial. Integrated systems that function well tend to show more stable water quality over time compared to monocultures, which are often more sensitive to feed overloading or waste accumulation. The use of integrated systems is also being evaluated in terms of scalability and economic viability. Although they are more complex to design and manage than traditional setups, the

potential to produce multiple revenue streams from a single system is appealing. Seaweed can be sold for food, cosmetics or biofuel; shellfish have strong market demand; and fish remain a primary product. Some studies include basic economic modeling to estimate the cost-effectiveness of these systems compared to monocultures, considering inputs like infrastructure, maintenance and labor. While challenges remain in standardizing designs and ensuring consistent yields, integrated systems offer a model for more sustainable and profitable aquaculture in the long term.