Zero-Waste Approaches in Modern Seafood Processing Facilities Farming

Tanuja Kulshrestha[1]*, Pritha Kumar[1], Niharika Mohapatra[1], Aditya Singh[2] and Mutum Sardalini[3]

[1]*Department of Fish Processing Technology, Faculty of Fishery Science, West Bengal University of Animal and Fishery Sciences, Kolkata (700 037), West Bengal, India*
[2]*College of Fisheries, Central Agricultural University (Imphal), Lembucherra, Agartala, Tripura-799210, India*
[3]*Department of Fish Nutrition and Biochemistry, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Srinagar, 190025, India*

Corresponding Author
Tanuja Kulshrestha
Email: tannukulshrestha96@gmail.com

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ABSTRACT

The zero-waste movement in seafood processing emphasizes sustainable practices that reduce environmental burdens and enhance economic value. By shifting from traditional linear models to circular systems, modern facilities integrate innovative technologies, resource recovery, and eco-friendly packaging. Collaborative efforts across industries promote energy efficiency, water recycling, and the development of high-value markets for previously underutilized materials. This approach aligns with global sustainability goals, supporting responsible seafood consumption and improved waste management. With growing consumer demand for eco-conscious products, zero-waste strategies are reshaping the seafood sector into a model of environmental stewardship and economic resilience.

INTRODUCTION

Modern seafood processing facilities are increasingly embracing zero-waste strategies to tackle the environmental, economic, and resource-related challenges of the seafood industry. These approaches emphasize reducing raw material consumption, reusing by-products, and recycling or recovering all waste streams generated during processing (Osei *et al*., 2025; Yadav *et al*., 2025). By implementing such measures, facilities not only minimize production waste but also improve resource efficiency, lower energy consumption, and enhance environmental sustainability throughout the supply chain. In the face of global concerns like overfishing, the depletion of wild fish stocks, and marine ecosystem degradation, zero-waste practices promote a circular economy model. This ensures the valorization of seafood by-products into high-value compounds while significantly reducing environmental pollution. Additionally, advancements in digitalization and Industry 4.0 technologies such as artificial intelligence (AI), the Internet of Things (IoT), and blockchain enable precise monitoring, optimized utilization, and innovative valorization of seafood waste. These technologies play a crucial role in fostering sustainable operations and aligning the seafood sector with broader global objectives, including the United Nations Sustainable Development Goals (SDGs) by 2030 (Areche *et al*., 2024).

Rethinking Waste: The Zero-Waste Revolution in Seafood

The traditional “take-make-dispose” model of seafood processing is no longer viable in a world where sustainability is a priority. With the fishing industry contributing significantly to global protein demand, up to 50–70% of fish weight can become by-products during filleting and processing. Zero-waste seafood facilities focus on valorization, converting these by-products into high-value products rather than discarding them. Fish heads and bones are rich in proteins, minerals, and omega-3 fatty acids, while crustacean shells contain chitin, a biopolymer with immense industrial potential (Xia *et al*., 2024). This “nose-to-tail” or “fish-to-fin” approach ensures that every part of the catch fillets, heads, guts, scales, and skin is repurposed into valuable resources such as food ingredients, animal feed, cosmetics, pharmaceuticals, fertilizers, and biofuels. Below is a suitable table 1 summarizing the key strategies of the zero-waste revolution in seafood.

Table 1. Summarizing the key strategies of the zero-waste revolution in seafood

Key Strategy	Description / Example	Impact
Full Utilization of Seafood	Norway's Seafood Council promotes using all edible parts of fish, encouraging chefs and markets to include underutilized parts in products.	Enhances sustainability and increases consumer awareness.
Valorization of By-products	Scientific methods transform by-products (heads, bones, shells) into resources like collagen, fish oil, and nutraceuticals.	Creates economic value and reduces waste.
Aquaculture Zero-Waste Practices	Companies like Regal Springs Indonesia use 65% of non-filleted fish for other industries heads for food, guts for feed and fuel, scales for cosmetics and clothing.	Promotes resource efficiency and industry diversification.
Innovative Waste Processing	Fish waste is converted into fertilizers, fish feed, and renewable biogas via composting, pelletization, anaerobic digestion, or biodiesel production.	Supports circular economy models and renewable energy.
Circular Economy & Collaboration	Industry-wide initiatives encourage recycling, reducing raw material consumption, and innovation in waste management.	Lowers environmental impact and improves economic viability.

Turning Fish Scraps into Valuable Products

Turning fish scraps into valuable products involves various innovative approaches that maximize the use of fish processing by-products, reducing waste and generating economic value. These scraps consisting of heads, bones, skins, viscera, scales, and other non-fillet parts can be converted into a wide range of high-value products across food, agriculture, pharmaceutical, cosmetic, and industrial sectors (Soladoye *et al.*, 2025; Vaishnav *et al.*, 2025) (Table 2).

Green Technologies for Cleaner Processing

Green technologies for cleaner fish processing aim to reduce environmental impact while improving efficiency and product quality across the seafood value chain. As part of the broader sustainable fish processing movement, these innovations integrate resource conservation, waste reduction, and pollution control. Recirculating Aquaculture Systems (RAS) recycle up to 99% of water through mechanical, biological, and chemical filters, significantly lowering water consumption and pollutant discharge (Pawar *et al.*, 2023). Energy-efficient equipment combined with renewable energy sources like solar panels and heat recovery systems helps reduce carbon footprints and operational costs. Advanced wastewater treatment methods, including pre-treatment, membrane filtration, and biological or chemical processes, allow efficient water recycling and pollution minimization. By-product valorization turns fish scraps into valuable products such as fishmeal, oils, fertilizers, biogas, and bioactive compounds, supporting circular economy principles (Arena, 2024). Automation and smart monitoring systems streamline feeding, sorting, grading, and environmental control, improving resource efficiency and reducing errors. Technologies like solar-powered drying, super chilling, and cryogenic freezing preserve product quality while minimizing energy use and post-harvest losses. Additionally, enzymatic extraction recovers bioactive compounds without harsh chemicals, while membrane filtration systems extract proteins and oils from wastewater. Collectively, these advancements foster a sustainable, eco-friendly seafood processing industry that balances productivity with environmental responsibility.

Table 2. Valorization of Fish Waste: Products, Processes, and Applications

Valorized Product	Source/ Processing	Applications
Pet Food	Fish waste processed into kibble/powder with gamma irradiation	Nutritionally adequate, microbiologically safe, extended shelf life for pets
Encapsulated Fish Oil	Oils (EPA, DHA) from heads, bones, viscera, encapsulated	Nutritional supplements for humans and animals, improved shelf life and storage quality
Biodegradable Films	Proteins from fish scraps treated (e.g., gamma irradiation)	Food packaging and industrial uses, eco-friendly alternative to plastic
Fish Meal and Fish Oil	Traditional valorization of fish waste	Animal feed, aquaculture, and industrial applications
Bioactive Compounds	Collagen, gelatin, chitin, chitosan, carotenoids, enzymes	Pharmaceuticals, cosmetics, nutraceuticals (skin health, anti-inflammatory, antioxidants)
Organic Fertilizers & Silage	Viscera and other residues	Sustainable agriculture, circular economy
Renewable Energy	Anaerobic digestion or chemical conversion of fish waste	Production of biogas and biodiesel, renewable energy sources
Chitin & Chitosan	Extracted from shrimp and crab exoskeletons	Food Industry (natural preservatives, edible coatings), Medical Applications (wound dressings, drug delivery, surgical threads), Water Treatment (natural flocculant for heavy metals and toxins).

Water Recycling and Energy Efficiency

Seafood processing is water-intensive, with large volumes used for cleaning, cooling, and product preparation. Modern zero-waste facilities incorporate closed-loop water recycling systems to reduce water consumption. Advanced treatment technologies, such as reverse osmosis and ultrafiltration, allow wastewater to be purified and reused for non-potable purposes within the plant. Energy efficiency is equally important. Facilities are adopting heat recovery systems to capture and reuse heat from boilers and refrigeration units. Some plants are integrating renewable energy sources, such as solar or wind power, to reduce dependence on fossil fuels. Waste biomass from fish by-products can even be used for biogas production, providing an additional renewable energy source on-site.

Packaging Innovations for a Sustainable Future

Plastic packaging has long posed significant environmental challenges for the seafood industry, prompting modern facilities to develop eco-friendly packaging solutions that align with zero-waste principles. Innovations include biodegradable films made from chitosan, seaweed extracts, or fish gelatin, which offer a sustainable alternative to conventional plastics. Recyclable and compostable containers further help reduce landfill waste, while edible coatings derived from seafood proteins or polysaccharides create thin, protective layers that preserve freshness without relying on plastic packaging. These advancements not only extend the shelf life of seafood products but also significantly lower their environmental footprint, supporting a more sustainable and circular seafood supply chain (Mehta *et al.*, 2025; Yadav *et al.*, 2025).

Global Examples of Zero-Waste Seafood Practices

Countries like Norway and Iceland are leading the way in zero-waste seafood initiatives. For example, Iceland's “100% Fish” project focuses on utilizing every component of fish, including producing fish leather for fashion accessories. Japan, known for its minimal waste culture, has seafood plants that convert fish waste into dashi (broth) and other culinary ingredients. In India, shrimp shell waste is being processed into chitosan, which is exported worldwide for medical and industrial applications. Similarly, U.S. seafood companies are creating fish jerky and protein powders from trimmings, reducing waste while meeting the growing demand for high-protein snacks.

The Future of Zero-Waste Seafood Processing

As the global seafood industry grows, the transition to zero-waste will play a critical role in ensuring environmental and economic sustainability. The future will see the integration of smart technologies, such as artificial intelligence and IoT (Internet of Things), to monitor processing efficiency and track resource utilization in real-time. Facilities will become more energy self-sufficient, powered by renewable sources and waste-to-energy solutions. Moreover, consumer trends are shifting toward eco-friendly products. Brands that showcase their commitment to sustainability through zero-waste processing and eco-packaging will gain a competitive edge in global markets.

CONCLUSION

Zero-waste seafood processing is no longer just a trend it is becoming an industry standard. By fully utilizing every component of seafood, modern facilities are reducing environmental impact, creating new revenue streams, and supporting the circular economy. From collagen supplements to biodegradable packaging, the possibilities are endless when innovation meets sustainability. As technology advances and consumer demand for sustainable products grows, zero-waste approaches will define the future of seafood processing. It's a win-win scenario protecting our oceans while creating valuable products that benefit people and the planet.

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