

Cyanobacteria, and specialized denitrifying genera are dominant in engineering ponds, IMTA systems, and recirculating ponds. As system operation time increases, improvements in microbial diversity and functional gene abundance are usually associated with water quality improvement. Meanwhile, seagrass or macrophyte reservoirs and constructed wetlands can filter suspended solids, store nutrients in plant biomass, regulate dissolved oxygen through photosynthesis, and reduce pathogen loads, thereby pretreating and purifying pond inflow or tailwater (Liu et al., 2014; Biswas et al., 2020). While feeding on deposited organic detritus, benthic animals can disturb sediment through their activities, improving bottom-water exchange and sediment permeability. Engineering units such as aeration facilities, ecological ditches, and constructed wetlands further strengthen water circulation, sedimentation filtration, and plant uptake functions. As a result, pond systems no longer rely solely on frequent water exchange and chemical regulation, but instead maintain water quality stability and ecological balance through the integration of biological purification, microbial transformation, and engineering regulation.

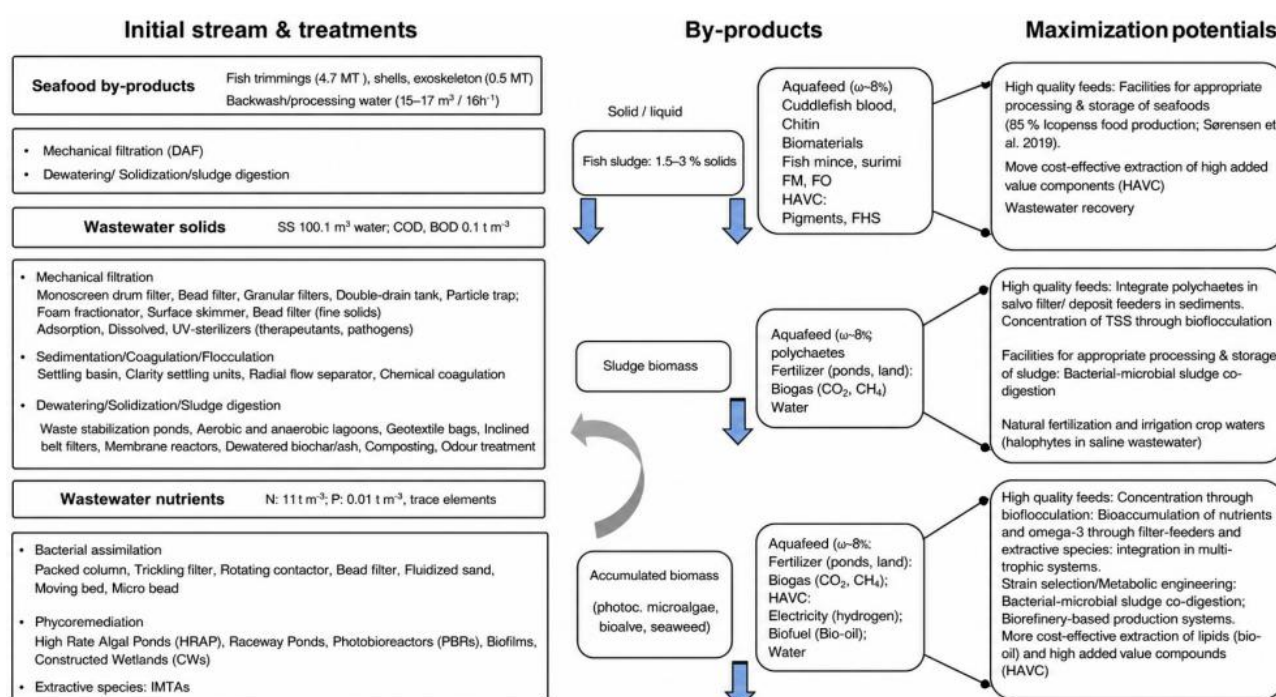


Figure 2 Potential co-products derived from the processing of seafood and wastewater treatments (Adopted from Campanati et al., 2021)

Image caption: Solid material from wastewaters is retained through mechanical filtration and/or sedimentation. Dissolved nutrients are retrievable from wastewater through bacterial assimilation and phycoremediation and can be upcycled (i.e. through increased yield in biomass) throughout the food web (e.g. IMTAs). Following removal of large solids and accumulated suspended material (i.e. TSS, biofloc, microalgae) in concentrated sludge form, dewatering and thickening then permit by-products to be obtained through different recovery paths and allow subsequent applications. Through this process of solid-liquid separation, the water discarded or generated from the processing (light-blue arrows) can be reused. Improvements that can maximize production (e.g. cost-effective methods for higher biomass yield) from recycled materials are highlighted on the right side of the diagram. DAF: Dissolved air floatation; FM: Fish meal; FO: Fish oil; HAVC: High added value components; PHs: Protein hydrolysate (Adopted from Campanati et al., 2021)

3.3 Multi-trophic synergistic enhancement mechanism

Multi-trophic synergy is an important basis for the comprehensive benefits of ecological food chain closure and is also the key mechanism distinguishing it from traditional monoculture or simple polyculture. Traditional single-species aquaculture often focuses on the utilization of a particular type of feed resource or water-layer space, which easily leads to insufficient resource use, unused ecological niches, and pollutant accumulation. In contrast, ecological food chain closure combines organisms according to their feeding habits, activity layers, and ecological functions, enabling effective use of different spaces, including the upper, middle, and bottom water