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Sustainable Development and Ecosystem Health at Oyster Farming



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Abstract

Oyster culture at Rushan coastal water is one of China's most important shellfish aquacultures. To address space limitations in aquaculture, the government promoted raft cage technology and "autumn oyster fattening", which has significantly improved oyster quality and yield. However, environmental overcapacity and disease risks now pose critical challenges to the industry's sustainable development. Carrying capacity evaluations (e.g. water quality, nutrient cycling, and ecosystem impacts) are essential for sustainable management. Global warming, sea level rise, and ocean acidification threaten oyster reproduction, growth, and diseases. A few developments in oyster hatcheries were planned or in operation on how to achieve key benefits, such as strengthening ecosystem adaptation by mangroves to sea level rise and erosion, addressing the climate crisis through carbon storage and reduced acidification, and enhancing the safety and prosperity of coastal communities.

Keywords: Oyster; Global changes; Carrying capacity evaluation; Blue carbon; Integrated multi-trophic aquaculture

The importance of oyster culture

Shellfish aquaculture accounts for 80% of global shellfish production, with oysters playing a pivotal role in aquaculture within estuarine and coastal environments. These oysters are essential for their ecological contributions as filter feeders and habitat engineers. Rushan, located near the Yellow Sea of China, provides an ideal physical and biological environment for oyster cultivation, extending from the shallow inner bay to the coastal areas. Although oysters have long been part of the local food supply, their exploitation was minimal until the early 1950s when industrial fishing vessels were introduced. Public fisheries, where fishers harvest oysters from state-owned waters, saw rapid growth with China's economic reforms, reaching a peak in the early 1990s. To meet the demand for high-quality oysters, an extensive industry chain was established, integrating factory nurseries, coastal seawater farming, and global live shipping. Today, oyster farms span approximately 13,000 hectares, yielding over 300,000 tons annually and generating revenue exceeding 2.4 billion yuan (\$347 million), making it the leading oyster producer in China (Weihai Marine Development Bureau, Government report 2022).

Problem from the operation and global changes

With the increased breeding time and the expansion of the aquaculture area, the available space has become limited, especially in beach and shallow seawater. To solve this problem, the government promotes raft cage technology for oysters (*Crassostrea gigas*). The new cultivation way, annual breeding with temporary fertilization takes place the traditional way. The technology of "autumn oyster fattening" refers to the thin and weak oysters in commercial farms being moved to seawater for fattening and strengthening. Generally, it takes 60 to 90 days for oysters to meet quality standards and are sold more expensive in the market. The fertilization of autumn oysters could last until mid-April next year. This policy change has increased the oyster culture benefit from improving the quality of oysters and prolonging their duration. Meanwhile, the empty raft and cage can be deployed for the next generation to grow, thus the turnover time was shortened greatly. To meet the rapid growth in the oyster market and industry needs, oysters were transported from local farms and other provinces from autumn to early spring.

The yield of oysters increased by more than 50% in recent years (Weihai Marine Development Bureau, Government report 2022). Environmental overcapacity has caused serious damage to the aquatic environment and aggravated the dangers of disease, which has hurt the sustainable development of this industry in the future.

Globally, oysters are currently experiencing an unprecedented rate of climatic warming and ocean acidification. Thomas et al. (2020) [1] found that warming and acidifying oceans negatively affected benthic organisms by reducing the average biomass and changing their recruitment phenology. Oysters are sensitive to acidification due to their reliance on calcium carbonate for shell formation, a process that is disrupted in more acidic conditions. Ocean acidification, driven by the increased absorption of carbon dioxide (CO₂) from the atmosphere, lowers the pH of seawater and reduces the availability of carbonate ions, which are essential for forming calcium carbonate. In particular, oyster larvae (e.g. the Olympia oyster and the Pacific oyster *C. gigas*) are sensitive to acidifying oceans (Venkataraman et al., 2019) [2]. Adult oysters are often cultured at intertidal regions of estuaries where they endure constantly fluctuating water conditions with nutrient richness (Spencer et al., 2020) [3]. Due to the expansion in aquaculture, excessive stocking density results in competition among oysters for limited nutrients and oxygen, and causes sickness due to disease transmission. These inhibit growth and reduce yield. Moreover, the raft cages for adult oysters expanded from shallow, intertidal water to far offshore. This might exert potential risks for oysters due to limited food supplies in the future.

Strategy

There is an urgent need to study the carrying capacity and to set up scientific and adaptive management strategies. The local government aims to implement environmental carrying capacity evaluation for more sustainable spatial management. Several evaluations were considered. Firstly, plankton and seaweed uptake carbon via photosynthesis and convert inorganic carbon to organic matter, the major food supply. The water quality, hydrology, phytoplankton community, nutrient loading, and bioavailability were monitored to evaluate eutrophication and the possibility of food supply for oyster growth. Moreover, the residual bait, oyster excretion, metabolized particles, and dissolved substances produced by cage culture impact the water quality and bottom habitats around the aquafarm. To evaluate cage culture capacity, the estimates include field investigation of nutrients and benthic feedback (such as sulfur and nutrient internal cycles), particulate organic carbon, and deposition flux estimation (Porter et al., 2004; Thomsen and McGlathery, 2006) [4,5]. The individual-based modeling was applied for the growth of a single bivalve by predicting time-series changes based on changing environmental conditions. As more data were collected, the coupled biogeochemical-hydrodynamic models, such as the new

Dynamic Energy Budget (DEB) model for oysters and co-culture commercial species (e.g. Kelps, fishes), would be considered as a powerful tool for understanding ecosystem functioning and predicting the implications of shellfish aquaculture on the environment.

Furthermore, the ocean serves as the largest carbon sink, absorbing greenhouse gases and helping reduce the effects of climate change. The alternative way is creating “blue carbon” ecosystems—such as mangroves, kelp, tidal marshes, and seagrass meadows- that store more carbon per unit area than land forests and protect coastal communities from floods and storms (Li et al., 2023) [6]. Oysters absorb carbon to build their calcium carbonate shells, which can store carbon over time. While individual oysters don’t sequester large amounts of carbon compared to other blue carbon ecosystems like mangroves and seaweed, the Integrated Multi-Trophic Aquaculture (IMTA) of Shellfish and Seaweed would lead to cumulative impacts across large populations and farms (Chen et al., 2022; Park et al., 2018) [7,8]. Therefore, sustainable development in oyster hatcheries was planned or in operation on how to achieve key benefits, such as strengthening ecosystem adaptation by mangroves to sea level rise and erosion, addressing the climate crisis through carbon storage and reduced acidification, and enhancing the safety and prosperity of coastal communities.

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