Despite its economic promise, traditional nori farming models face growing resource and environmental constraints that challenge long-term sustainability. Production systems are highly sensitive to environmental variability, particularly temperature, irradiance, and the availability of nitrate and dissolved inorganic carbon, all of which directly affect photosynthesis, reserve accumulation, and yield stability (Tac et al., 2025). Resource-use assessments also show that although seaweed farming is less input-intensive than many fed aquaculture systems, most impacts in *Porphyra* production are still linked to fuel use during operation and maintenance, indicating that farm design and logistics remain central sustainability concerns. In practice, traditional expansion is also limited by finite suitable farming areas, labor demands, and management constraints, factors that have contributed to stagnation in some established producing regions even as market demand continues to rise (Da Silva et al., 2025).

These pressures make the development and evaluation of green farming models an urgent research priority. Seaweed aquaculture is increasingly viewed as a nature-based production system that can contribute to food supply, climate mitigation, and eutrophication control, while avoiding some of the land and freshwater constraints that limit terrestrial agriculture (Duarte et al., 2021). For *Porphyra* specifically, cultivation can remove substantial amounts of dissolved inorganic nitrogen and phosphorus from coastal waters, showing that appropriately designed systems can generate both marketable biomass and measurable environmental services. At the same time, not all "green" models will perform equally well across ecological and economic contexts, so evaluation frameworks are needed to compare options such as low-input farming, integrated multi-trophic aquaculture, and site-optimized cultivation in terms of productivity, resilience, resource efficiency, and environmental benefit. Such evaluation is essential if nori cultivation is to move from a traditionally successful industry toward a genuinely sustainable and scalable blue-food system (Zhu et al., 2025).

2 Theoretical Basis of Green *Porphyra* Farming Models

2.1 Concepts of green aquaculture and ecological fisheries

Green *Porphyra* farming can be understood as an aquaculture model that prioritizes low external inputs, efficient nutrient use, and positive ecological functions while maintaining commercial productivity. In the broader seaweed sector, cultivation is increasingly framed as a nature-based production system because it can provide food and industrial raw materials while also contributing to carbon uptake, eutrophication mitigation, and circular bioeconomy development (Duarte et al., 2021). Ecological aquaculture extends this logic by arguing that seaweed farms should be designed to mimic the form and function of natural ecosystems and be managed as knowledge-based production systems embedded in social as well as environmental contexts (Augyte et al., 2021).

Within this framework, ecological fisheries and green aquaculture converge around the principle that farming systems should not merely reduce damage, but should actively recycle materials and generate ecosystem services. Integrated multi-trophic aquaculture is especially relevant because seaweed functions as an extractive component that assimilates dissolved nutrients released by fed species, thereby improving nutrient recycling and potentially increasing both environmental and economic performance (Lead et al., 2021; Zhu et al., 2025). For *Porphyra* cultivation specifically, this principle supports a transition from single-output farming toward ecosystem-based and restorative production models in which biomass harvest is linked to water-quality regulation and coastal ecological management.

2.2 Structure and function of the *Porphyra* farming ecosystem

The *Porphyra* farming ecosystem is structured by interactions among cultured blades, their life-history stages, surrounding water conditions, and associated microbial communities. *Porphyra* cultivation depends on a complex life cycle in which the conchocelis phase is maintained under controlled laboratory conditions before transition to blade production, making hatchery management and environmental regulation central parts of the farming system rather than auxiliary steps (García-Poza et al., 2020). Early nursery production also involves tightly managed developmental stages with controlled temperature, light, aeration, and stocking density, indicating that the farming ecosystem begins in enclosed technical environments and later expands into open-water ecological interactions (Cortez et al., 2026).