For *Porphyra*, IMTA is attractive because the genus functions as an efficient inorganic nutrient extractor while retaining commercial value as a food crop. Modeling studies indicate that macroalgal bioremediation performance depends strongly on species choice, flow regime, optical conditions, and harvest frequency, and that management can increase nutrient removal capacity by up to 25-fold. Broader reviews also note that although IMTA improves ecological balance and co-cultured species performance, long-term adoption still depends on practical issues such as seaweed selection, cultivation-area allocation, infrastructure cost, and economic evaluation rather than environmental benefit alone (Zhu et al., 2025).

3.3 Digital and intelligent green farming models

Digital and intelligent green farming models apply sensors, remote sensing, and predictive analytics to improve environmental control, crop monitoring, and harvest decisions in seaweed aquaculture. In precision aquaculture, interconnected sensors are used to monitor farm conditions and support data-driven management, and this model is increasingly framed as part of an Internet of Things architecture for sustainable aquaculture intensification. For seaweed specifically, low-power underwater devices can now log temperature, light, depth, and motion directly on cultivation structures, giving farmers continuous environmental information relevant to biomass development and farm stress (Da Silva et al., 2021).

The technical characteristic that distinguishes intelligent *Porphyra* farming is the shift from periodic manual inspection to continuous prediction and automated decision support. Drone-based multispectral monitoring has already shown that seaweed biomass and product traits can be estimated at the level of individual cultivation lines, opening a pathway toward plot-scale precision management (Nurdin et al., 2023). Likewise, IoT-based monitoring combined with physics-constrained machine learning improved biomass forecasting accuracy and can identify growth plateaus or suboptimal conditions early enough to support better harvest timing and operational adjustment (Kunapinun et al., 2024).

4 Construction of an Evaluation Indicator System for Green *Porphyra* Farming Models

4.1 Indicators for ecological and environmental benefits

Ecological and environmental indicators should measure whether *Porphyra* farming improves coastal ecosystem quality while remaining within ecological carrying capacity. In seaweed aquaculture, carrying capacity is a core concept under the Ecosystem Approach to Aquaculture because it defines the upper production limit that does not compromise ecosystem functioning, and indicator systems therefore need to track water quality, benthic effects, cultured-organism health, food-web interactions, and resource use. For green *Porphyra* models, these dimensions can be operationalized through indicators such as dissolved inorganic nitrogen and phosphorus removal, dissolved oxygen change, water transparency, sediment condition, and stocking density relative to site capacity.

Nutrient removal and carbon-related services are especially important because they capture the distinctive ecological value of seaweed farming. Large-scale seaweed aquaculture in China removed about 75,563 t of nitrogen and 9,592 t of phosphate, while also sequestering 539,555 t of carbon and absorbing 1,980,167 t of CO2, showing that nutrient extraction and carbon regulation are quantifiable environmental outputs. For *Porphyra* specifically, cultivation significantly lowered coastal nutrient concentrations and also enhanced refractory dissolved organic matter production, supporting the inclusion of nitrogen and phosphorus uptake, carbon sequestration potential, and water-column organic carbon dynamics as key indicators (Wang et al., 2025).

4.2 Indicators for economic benefits

Economic indicators should assess whether green *Porphyra* farming models can convert environmental performance into stable commercial returns. At the production level, yield, biomass quality, product standardization, and output reliability are essential because seaweed productivity and quality vary strongly with site conditions, cultivation method, and stock characteristics (Rimmer et al., 2021). Controlled land-based cultivation also shows that high-quality and standardized biomass can be produced efficiently when systems allow traceability and optimal expression of genetic potential, so evaluation should include premium-quality rate, processing suitability, and price realization as well as simple biomass output.