adaptation strategies are future-proof site selection, selective breeding or trait selection, ecosystem-based farm design, and stronger environmental monitoring. Reviews of North Atlantic seaweed aquaculture identify site selection, breeding and microbiome manipulation, and restorative aquaculture as the three main resilience pathways, while general climate-resilient aquaculture reviews similarly emphasize selective breeding, diversification, ecosystem-based management, and advanced systems as core adaptation tools.

These strategies appear effective when matched to the dominant local stressors, but evidence for each remains uneven. Site selection is strengthened by improved oceanographic and climate modelling, and biotechnology-oriented approaches such as tissue culture, selective breeding, and genetic engineering show promise for improving stress tolerance and yield; however, many of these interventions are still developing, and their commercial performance under open-water farming conditions is not yet fully resolved. Some adaptation benefits are already measurable at farm scale. Seaweed farms can buffer local acidification, with *Saccharina japonica* farms showing mean pH increases of about 0.10 and reduced pCO_2 relative to surrounding waters, which supports the view that farming can create localized refugia from acidification and deoxygenation.

Even so, adaptation effectiveness should not be judged only by whether kelp survives climate stress. Large-scale farming can introduce trade-offs such as habitat disruption, nutrient competition, or uncertain carbon benefits, so strategies are most credible when paired with habitat-friendly practices, IMTA, and rigorous monitoring and regulation rather than treated as universally beneficial solutions. Future development should prioritize breeding and seed systems, predictive farm planning, and cultivation technologies that are robust under a warmer and more variable ocean. The literature points to opportunities in omics-assisted breeding, targeted microbe treatments, and wider use of resilient species or strains, while also highlighting offshore farming and advanced monitoring as promising directions for sustaining production under climate stress. At the same time, the next phase of industry development will require stronger supporting systems beyond farm technology alone. Reviews from Norway and Tanzania both show that climate resilience depends on adapted regulatory frameworks, coordinated support, farmer training, and investment in improved varieties and knowledge transfer, especially where producers have limited capacity to absorb climate shocks on their own.

Another major priority is to build credible frameworks for environmental accounting and risk governance. Seaweed carbon accounting remains poorly developed, and robust monitoring, reporting, and verification systems are still needed to quantify sequestration pathways, evaluate trade-offs, and distinguish realistic climate services from claims that outpace the science. In the longer term, a climate-resilient seaweed industry will likely emerge from cross-sector integration rather than from farm expansion alone. Recent syntheses call for stronger global research collaboration, integration of new technologies, and development of robust value chains and circular bioeconomy pathways so that seaweed farming can support food security, low-carbon materials, and sustainable coastal livelihoods under climate change. Kelp farming under climate change is therefore best understood as a conditional opportunity: the sector shows real adaptive potential, but durable success depends on combining biological innovation, careful siting, ecological safeguards, and supportive institutions. Future progress will be strongest where resilience is pursued as a system-level strategy, not as a single technical fix.

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