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Perplexity and choice: challenges and future development of laver cultivation in Jiangsu Province, China

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1 Introduction

Seaweed cultivation holds significant importance in addressing global challenges. On the one hand, it aids in alleviating the food crisis. On the other hand, it offers substantial ecological benefits, such as enhancing carbon sequestration, facilitating nitrogen cycling, and mitigating eutrophication (He et al., 2008; Wu et al., 2015; Mantri et al., 2023). Globally, the dominant cultivated economic seaweeds include *Laminaria* spp., *Kappaphycus* spp., *Gracilaria* spp., *Neopyropia* spp., and *Undaria* spp (Park et al., 2021; Khan et al., 2024). In 2022, the annual global production of seaweed is estimated to be approximately 36.4 million metric tons (live weight), with red algae accounting for about 55.8% and brown algae for approximately 43.8% (FAO, 2024). Asia constitutes the principal region for seaweed cultivation, representing over 97% of global production, with China (about 60%), Indonesia (about 25%), South Korea (about 5%), and the Philippines (about 4%) being the largest contributors to this industry (Khan et al., 2024; Liu et al., 2024).

Among them, the *Neopyropia* species, a type of high-end red algae, is highly favored among consumers (Li et al., 2023) and possesses rich edible and medicinal values (Subramaniyan et al., 2021; Zhao et al., 2023; Wu et al., 2024). It is frequently utilized for the production of foods such as laver sushi and laver pancakes. Consequently, the significance of laver cultivation is self-evident. China boasts the world's largest laver cultivation area, with total production reaching 209,939 metric tons (dry weight) in 2023 (Fishery Administration Bureau of Ministry of Agriculture and Rural Affairs et al., 2024). The main cultivated laver species include *Neopyropia haitanensis*, *Neopyropia yezoensis*, *Neopyropia acanthophora*, and *Neopyropia dentata* (Wang et al., 2020; Wu et al., 2024). Notably, Jiangsu Province, China, serves as the leading production area for the highly sought-after *N. yezoensis* (Figure 1).

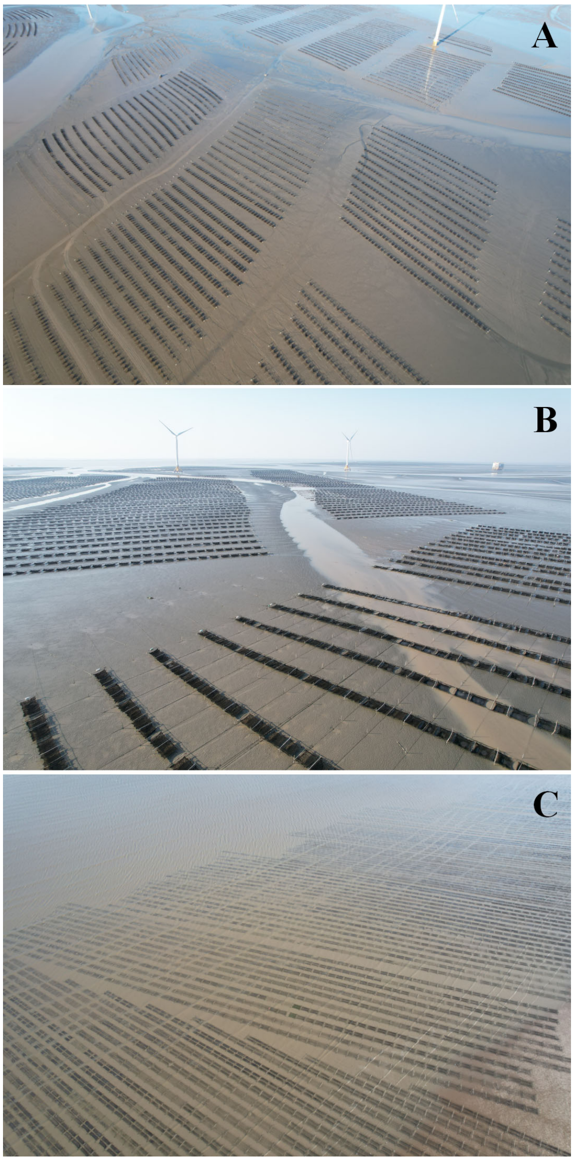

FIGURE 1
Laver cultivation areas in the coastal seawaters of Nantong **(A)**, Yancheng **(B)**, and Lianyungang **(C)** cities in Jiangsu Province.

The *N. yezoensis* aquaculture industry in the Subei intertidal zone of Jiangsu Province originated in the 1970s of the 20th century (Liu et al., 2021a). After more than 50 years of development, the intertidal zone in Jiangsu Province has become the largest global *N. yezoensis* aquaculture area, leading both nationally and globally. For instance, in 2023, the area of laver cultivation in Jiangsu Province reached 33,393 hectares, approximately 51.81% of the total national laver cultivation area. During the same year, the production of laver in Jiangsu Province reached 35,936 metric tons (dry weight), accounting for about 17.12% of the total national laver production (Fishery Administration Bureau of Ministry of Agriculture and Rural Affairs et al., 2024). The industry is of considerable scale and has comprehensively enhanced the coastal economic development and industrial reputation of Jiangsu Province. Furthermore, many impoverished individuals have achieved poverty alleviation and wealth accumulation through seaweed cultivation (Li et al., 2011).

Nevertheless, the laver cultivation industry in Jiangsu Province is progressively encountering certain challenges, such as extreme marine events and disasters. This opinion article aims to identify the key factors affecting laver cultivation in Jiangsu Province and proposes recommendations for its sustainable development.

2 The principal elements influencing the development of laver cultivation in Jiangsu Province

2.1 Climate change

For the growth stages of seaweed, extreme climate changes can lead to cellular and subcellular damage in the thalli, ultimately affecting its growth, quality, and yield (Khan et al., 2024). Currently, the negative impact of climate change on seaweed aquaculture is a long-term and widespread issue encountered in global aquaculture processes (Veenhof et al., 2024), which is difficult to resolve effectively in the short term. Over the past six decades, the sea surface temperature in the Southern Yellow Sea (SYS) has generally shown an increasing trend, with a warming amplitude of approximately 0.61°C. This indicates that under the backdrop of global warming, the SYS region has exhibited a warming trend (Guo et al., 2024). Concurrently, the interannual and multidecadal variability of sea surface temperature in the SYS is also associated with large-scale climatic factors such as El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) (Wang and Yu, 2014), leading to anomalous warming of regional seawater temperatures in certain years. Elevated seawater temperatures indirectly promote the frequent occurrence of diseases and other factors that hinder the growth of *N. yezoensis*. Currently, climate warming is leading to frequent occurrences of seedling rot, slow growth, and significant reductions in yield during the cultivation of *Neopyropia*, resulting in economic losses for the laver cultivation industry in the SYS region in recent years (Figure 2A). For instance, from late 2016 to mid-2017, influenced by factors such as abnormally high temperatures in the Haizhou Bay area, the production of *N. yezoensis* in Lianyun District, Lianyungang City, Jiangsu Province, was severely reduced, with a decrease of about 60% compared to the previous year (Lianyun District People's Government, 2017).

Extreme weather events triggered by climate change also warrant attention. At the end of April 2021, an infrequent event featuring extreme winds and thunderstorms occurred in the Subei intertidal zone of the SYS, with wind gusts reaching level 14. This event resulted in direct economic losses exceeding 140 million RMB Yuan in Nantong City, Jiangsu Province (Lu and Du, 2022), and the large-scale collapse of *Neopyropia* cultivation rafts (Lu and Du, 2022). Tens of thousands of raft components, including ropes and bamboo poles (Figure 2B), are being swept into the ocean (Sun et al., 2022a), causing economic losses to laver farmers. It affected the smooth progress of the *Neopyropia* raft recovery operations, and in addition, caused casualties, either directly or indirectly (CCTV, 2021). Similarly, in January 2016, Lianyungang City, Jiangsu Province experienced severe sea ice and strong winds caused by extremely cold weather. This affected over 7,000 hectares of *N. yezoensis* cultivation area, leading to incalculable economic losses for local farmers (Sohu, 2016).

In addition, rising global CO_2 concentrations contribute to ocean acidification, which can impact interspecific competition among seaweeds (Feng et al., 2024). Although the elevated CO_2 levels alleviate the competitive relationship between *N. yezoensis* and the harmful epiphyte *Ulva* species (e.g., *Ulva prolifera*), the long-term perspective indicates a growing competitive advantage for *Ulva* under this climate change scenario (Sun et al., 2021). Traditionally, *N. yezoensis* is considered a cold-tolerant seaweed, whereas *U. prolifera* exhibits a greater capacity to endure higher temperatures compared to *N. yezoensis*. Micropropagules of *U. prolifera* are persistently present in the SYS region (Cao et al., 2023; Xia et al., 2024a), and the areas on the raft components not colonized by laver are also conducive to the attachment of *U. prolifera*, leading to the subsequent occupation of ecological niches by *U. prolifera* on the raft structures (Zhang et al., 2019a). Concurrently, as *U. prolifera* matures, it demonstrates a stronger ability to absorb nutrients than *N. yezoensis*, thereby allowing the epiphytically growing *U. prolifera* to gradually establish a growth advantage (Shan, 2022). This results in *Ulva* species with an enhanced capability to occupy ecological niches, which subsequently impacts the normal growth of laver and affects the future development of *Neopyropia* aquaculture in the SYS region.

2.2 Diseases

Neopyropia yezoensis is susceptible to various diseases during cultivation and growth due to the impact of global climate change, harmful microbial infection, and overcrowding during cultivation (Kim et al., 2014). Common diseases include seedling rot, chytrid blight, green spot disease, and white rot (Qiu et al., 2019; Yang et al., 2020; Bae et al., 2024), which frequently lead to the genetic characterization decline of laver populations. In addition, the coastal waters of Jiangsu Province are severely eutrophic (Liu et al., 2013), and heavily polluted sea areas are particularly prone to harmful pathogens proliferation. These pathogens negatively impact seaweed growth, ultimately reducing laver yield and causing significant economic losses for local farmers. For instance, in 2004, approximately 5,000 hectares of *N. yezoensis* in the Nantong City maritime area suffered from severe rot, resulting in an estimated loss of 60 million RMB Yuan (Yangtze Evening Post, 2004). Similarly, in 2016, over 1,300 hectares of *N. yezoensis* in the Rudong County maritime area of Nantong City experienced rot, with cost losses alone amounting to around 40 million RMB Yuan, causing economic losses to more than 3,000 laver farmers (Wang, 2016). In January 2019, 134 hectares of *N. yezoensis* in the Yancheng City maritime area exhibited rot, which was caused by the pathogenic bacterium *Opliidopsis* sp (He et al., 2021).

It should be clarified that seaweed cultivation inevitably faces diseases to varying degrees (Khan et al., 2024). These diseases encountered during laver cultivation are not unique to China but represent a global issue (Yang et al., 2020). For example, between 2013 and 2014, an outbreak of green spot disease in the laver farms in Sunchon, South Korea, could cause complete rot of laver thalli within 1-2 days, resulting in a loss of 1.1 million USD, equivalent to 10.7% of total farm sales (Kim et al., 2014). The sudden onset of such diseases during *N. yezoensis* cultivation often prevents timely and effective mitigation measures to reduce disease damage, ultimately leading to substantial losses for laver farmers.

2.3 High-density cultivation

Neopyropia yezoensis cultivation demands high-quality seawater and thrives best in waters with moderate flow velocity and strong water exchange capacity (He et al., 2018). In Jiangsu Province, suitable cultivation areas have been largely exploited, limiting the potential for further expansion of the cultivation scale.

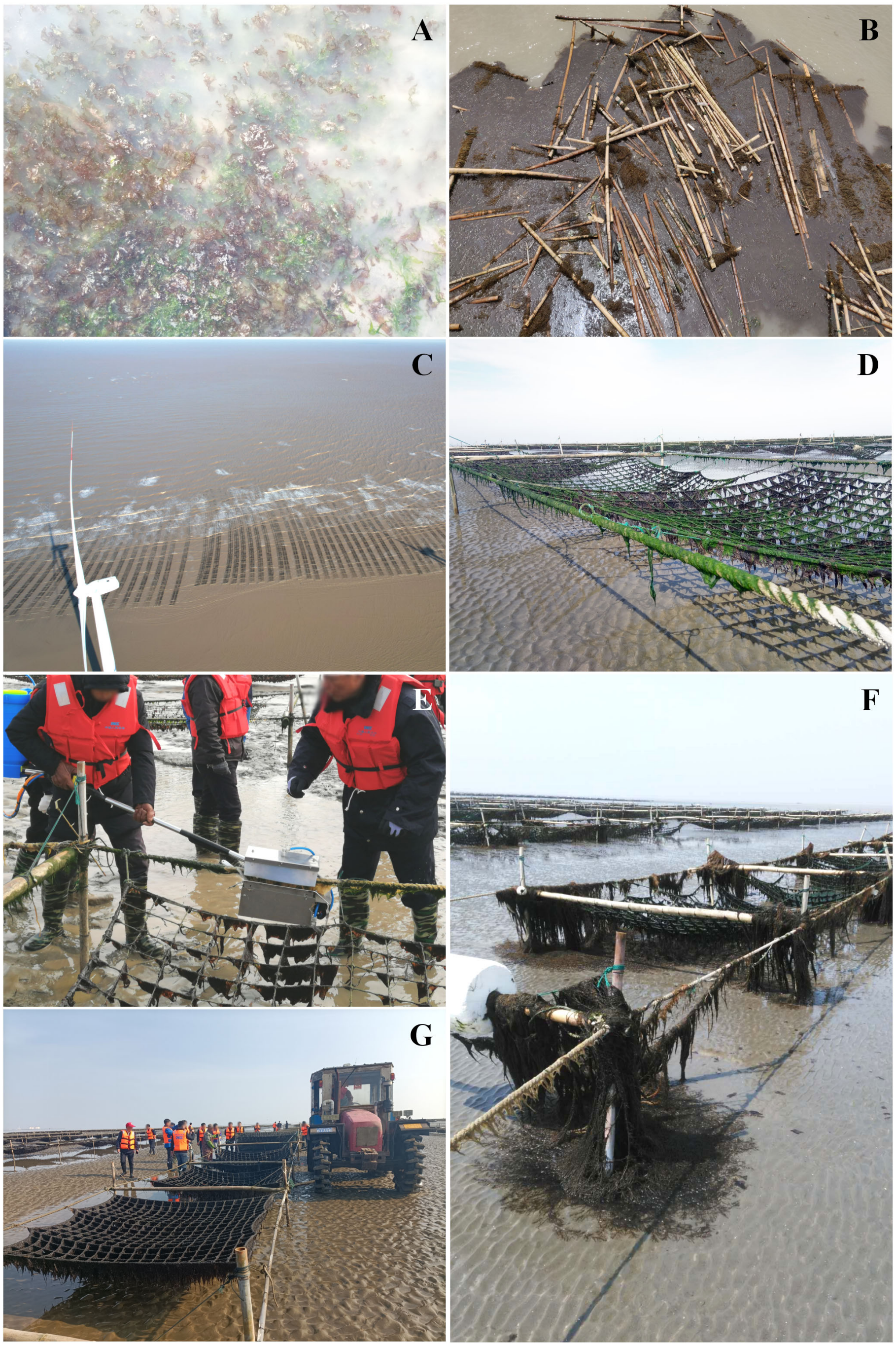

FIGURE 2
Death and detachment of *Neopyropia yezoensis* (indicated by brownish-red areas) on laver cultivation nets due to unusually high temperatures, along with *Ulva* species (green areas) remaining on the tidal flats after manual cleanup **(A)**; Damage to laver cultivation facilities caused by extreme wind events, leading to the drift of some raft components into open waters **(B)**; A laver cultivation area in Binhai County, Yancheng City, Jiangsu Province, which did not comply with the maritime usage standards, has subsequently been banned by the government **(C)**; *Ulva* species, which appear as green areas, are epiphytic on laver cultivation rafts **(D)**; Laver farmers are removing the green seaweed tide that is attached to the ropes **(E)**; The accumulation of invasive golden seaweed tide on laver cultivation rafts is damaging the raft facilities and affecting the normal growth of *N. yezoensis* **(F)**; Laver farmers in the coastal waters of Nantong City, Jiangsu Province, are beginning to experiment with the cultivation of *Neopyropia haitanensis* **(G)**.

Similarly, *N. yezoensis* struggles to grow in low-nutrient sea areas (Huang et al., 2023). Although the high levels of nitrogen and phosphorus in Jiangsu's coastal waters support the growth of *Neopyropia*, the extensive cultivation area and high cultivation density inevitably restrict growth due to the limited carrying capacity of the sea area (Shan, 2022). Taking the outer radial sandbars of Dafeng District in Yancheng City as an example, the laver cultivation scale once spanned a continuous distribution of

13,000 hectares. However, the excessive scale of cultivation adversely affected seawater exchange within the cultivation area (Shan, 2022). As a result, laver in the center parts of the cultivation zone could not receive sufficient nutrient replenishment, leading to deficiencies essential for growth (Shan, 2022). Additionally, the close proximity of cultivation facilities also facilitates the rapid spread of diseases, further reducing laver yields (Shan, 2022).

Concurrently, some marine areas in Jiangsu Province have been engaged in aquaculture activities that do not comply with regulations established by the Chinese government (Figure 2C). This noncompliance has exacerbated the scope and cultivation density of laver cultivation activities, creating additional challenges. Lin et al. (2021) identified two special utilization zones and six port shipping areas in Jiangsu Province where unreasonable or illegal laver cultivation activities occurred. These activities involved a total of 135.84 hectares, primarily concentrated in locations such as Tianwan Nuclear Power Plant Special Utilization Zone, Ganyu Port Special Utilization Zone, Shiqiao Port Shipping Area, Xuwei Port Shipping Area, Ganyu Port Shipping Area, Lvsi Port Shipping Area, Xiaomiao Hong Port Shipping Area, and Jinniu Port Shipping Area (Lin et al., 2021).

2.4 Impacts of green tides disaster

Green seaweed blooms have persisted in the SYS for eighteen consecutive years (Zhang et al., 2019b; Xia et al., 2024b), predominantly caused by *U. prolifera*, which has led to significant adverse effects on marine aquaculture and related fisheries industries (Cao et al., 2023; Yao et al., 2024). On the one hand, the attachment of various *Ulva* species to laver cultivation facilities (Han et al., 2013; Huo et al., 2015) competes with *Neopyropia* for ecological niches and nutrients (Figure 2D), thereby impeding laver growth. On the other hand, removing attached green seaweeds during production incurs substantial labor costs for laver farmers (Sun et al., 2022a). Notably, the outbreak of large-scale green tide disasters near laver cultivation areas is rarely observed globally, with no similar reports from other countries or regions' laver cultivation areas.

To effectively mitigate the scale of green tide outbreaks, the Ministry of Natural Resources of the People's Republic of China is currently focusing on reducing the biomass of *U. prolifera* attached to laver cultivation rafts in Jiangsu Province (Liu et al., 2021b; Xia et al., 2022; He et al., 2023; Sun et al., 2022b), and has taken measures to curb illegal occupation of marine areas for seaweed cultivation (Jiangsu Laver Association, 2020). Additionally, laver farmers are encouraged to proactively adjust their raft cultivation schedules, including withdrawing facilities in advance during the production cycle and conducting early cleanup of green seaweeds (Figure 2E). These measures are aimed at maximizing ecological benefits (Sun et al., 2022a). However, these actions also impacted seaweed yields in Jiangsu Province, posing challenges to the long-term formation of a "common interest group" that balances fishery production and green tide control. For instance, in 2021, Jiangsu Province collectively retired approximately 4,000 hectares of laver cultivation and reduced the area of sea used for laver cultivation by about 6,400 hectares. By May 8, 2021, all laver cultivation facilities were brought ashore, prematurely ending the laver production period spanned the late 2020 to mid-2021. This adjustment resulted in a revenue reduction of 1-1.2 billion RMB Yuan for the province's laver cultivation industry (Diao and Ma, 2021) and led to widespread dissatisfaction among regional laver farmers about the potential economic impacts of green tide disaster management. Furthermore, since 2023, the funds allocated for green tide disaster prevention have nearly approached the actual direct economic benefits of laver cultivation in Jiangsu Province. Taking 2024 as a case in point, the annual investment in green tide prevention special funds (including both central and local government financial allocations) has exceeded one billion RMB Yuan, underscoring the financial burden of addressing this ecological challenge.

2.5 Impacts of golden tides disaster

The phenomenon of golden tide disasters impacting the laver cultivation industry is currently observed only in the marine regions of Jiangsu Province. The proliferation of *Sargassum horneri*, the primary species responsible for golden tides, has posed significant challenges to laver cultivation activities in Jiangsu Province in recent years. Since 2016, large-scale gatherings of drifting *S. horneri* have been frequently observed in the coastal waters off Jiangsu during winter and spring (Wang et al., 2023). The arrival of the golden tide "algal mat" in the laver raft cultivation area (Figure 2F) led to the structural collapse of some rafts (Zhuang et al., 2020). Moreover, golden tide seaweed entangled in the laver cultivation nets hinders *Neopyropia* from conducting photosynthesis effectively, leading to damage during its growth stage. To address this issue, laver farmers are compelled to manually remove *S. horneri* tangled around the rafts, which not only increases labor costs but also causes the detachment of *Neopyropia* during this process. Such disruptions often result in significant financial losses, amounting to hundreds of millions of RMB Yuan for local laver farmers (Liu et al., 2021c). For instance, from the winter of 2016 to the spring of 2017, the golden tide disaster severely impacted the laver cultivation industry in Jiangsu Province, causing economic losses of up to 500 million RMB Yuan in the laver cultivation industries of Yancheng and Nantong cities (Liu et al., 2018). Currently, there is no effective method to mitigate the golden tide macroalgal biomass at their source, as the origin of recent golden tide outbreaks in China remains unclear (Wang et al., 2024). Therefore, when laver cultivation activities are affected by golden tide disasters, manual clearance remains the only viable approach to minimize economic losses.

3 Optional strategies for the sustainable development of laver cultivation in Jiangsu Province

3.1 Cultivating heat-resistant laver varieties

Given the current climate warming trend, effective alleviation measures are challenging (Liu et al., 2021b). In areas where *N.*

yezoensis is no longer suitable for growth, it could be worthwhile to gradually attempt the cultivation of heat-resistant strains, such as *N. haitanensis* (Zhou et al., 2023), which can contribute to the sustainable development of the laver cultivation industry in Jiangsu Province. Following the successful pilot cultivation of *N. haitanensis* in the SYS (Figure 2G), some laver farmers have opted to cease the cultivation of *N. yezoensis* in favor of *N. haitanensis*, while others have initiated experiments in the rotation planting of *N. yezoensis* and *N. haitanensis*. Taking 2024 as an example, Lianyun District People's Government of Lianyungang City has encouraged laver farmers to engage in the rotational cultivation of *N. haitanensis* and *N. yezoensis* (Liandao Subdistrict, 2024). Laver farmers in Liandao Subdistrict have collectively piloted the cultivation of *N. haitanensis* over an area of approximately 800 hectares, achieving a bountiful harvest in October 2024, with an estimated annual yield of 15 tons per hectare (live weight), resulting in an annual output value of up to 130 million RMB Yuan (Liandao Subdistrict, 2024). At present, the Jiangsu Provincial Government's promotion of the pilot rotational planting and cultivation scheme for *N. yezoensis* and *N. haitanensis* has achieved initial success and is deemed worthy of further promotion and application.

3.2 Promoting standardization and orderliness in laver cultivation

At present, the Chinese government has focused on addressing the illegal occupation of maritime areas for aquaculture, explicitly prohibiting the establishment of new aquaculture projects that occupy natural coastlines or fall within ecological protection red lines (Ministry of Natural Resources of the People's Republic of China, 2024). It has gradually cleared areas of illegal and unlicensed *Neopyropia* cultivation and withdrawn cultivation within the ecological red line areas (Figure 2C). Meanwhile, efforts are underway to optimize the spatial planning and layout of laver cultivation by adhering to principles of high-quality, ecological, and standardized development. These efforts gradually transferring laver cultivation rafts from nearshore tidal flats to deeper sea areas and strengthening the management and supervision of no-culture zones, limited-culture zones, and aquaculture zones (Jiangsu Laver Association, 2020; Lianyungang Municipal Bureau of Agriculture and Rural Affairs, 2021). In addition, research and promotion of technologies to prevent the attachment of *Ulva* on laver cultivation rafts are being carried out (Jiangsu Provincial Bureau of Geology, 2024). Efforts are also being made to strengthen the management of aquaculture waste, such as discarded *Ulva* species by promoting the centralized treatment and resource utilization of aquaculture production waste. These measures aim to reduce the initial biomass of *U. prolifera*, the dominant species in green tide outbreaks in the SYS, providing a scientific basis for the ecological cultivation of laver and green tide prevention.

Simultaneously, relevant government departments are researching the resource and environmental carrying capacities under the guidance of superior authorities to provide theoretical and scientific foundations for determining the appropriate cultivation scale of *Neopyropia* in Jiangsu Province. In response to excessive laver cultivation density, the government recommends reducing high-density cultivation and gradually guiding farmers and enterprises to control cultivation density within a reasonable range (Lianyungang Municipal Bureau of Agriculture and Rural Affairs, 2021). Appropriately reducing cultivation density also helps slow the spread of diseases during the cultivation process. To address these issues, Shan (2022) suggests controlling the continuous distribution scale of laver cultivation rafts and reducing the overall cultivation area. Furthermore, the government or industry associations could coordinate to divide the continuous distribution areas into several smaller zones, increasing the spacing between these zones to allow for sufficient seawater exchange. At the same time, individual farmers or aquaculture enterprises could reduce the density of raft arrangements, expanding the current spacing from approximately 4 meters to 6-7 meters (Shan, 2022). This approach will ensure seawater exchange, reduce disease incidence, and effectively increase the yield per unit area of laver cultivation.

3.3 The industrial chain could transition to regions at higher latitudes

There is a significant demand for *N. yezoensis* cultivated in China (Li et al., 2023) from countries including Japan, the United States, and South Korea. To meet this demand, it is crucial to maintain the cultivation scale of *N. yezoensis* in Jiangsu Province (Figure 1) and other regions of China. Yang et al. (2021) reported that in the lower-salinity marine waters of Nantong City, elevated ocean temperatures suppress the activity of antioxidant enzymes and the expression of related genes within *N. yezoensis*, rendering the seaweed more vulnerable to disease and decay. To address these issues, a progressive relocation of the *N. yezoensis* cultivation industry from the southern coastal waters of Jiangsu Province to the cities of Yancheng and Lianyungang is imperative. Notably, parts of this industry have already been transferred to the marine areas of Shandong and Liaoning provinces in China, where the colder seawater conditions during the same cultivation period are more conducive to *N. yezoensis* growth and can mitigate the risk of disease and decay (Yang et al., 2021). Moreover, it is anticipated that by 2050, the suitable growth range for *N. yezoensis* in the East Asian region will expand to include the Sea of Okhotsk in Russia (Zhou et al., 2023). Shifting the *N. yezoensis* industrial chain towards higher-latitude regions is expected to enhance both yield and quality.

Furthermore, considering the frequent outbreaks of green tides and other biological disasters in mid- and low-latitude regions (Yao et al., 2024), as well as the impact of ocean warming, algal bloom outbreaks, are expected to occur earlier and expand further (Qi et al., 2022). Gradually relocating the laver cultivation industry to higher-latitude regions may help reduce the impact of algal bloom disasters and ensure the sustainable development of the industry.

3.4 Transformation of the laver fishery economic model

The laver cultivation industry, characterized by its labor-intensive nature, requires substantial labor input throughout the production cycle while typically yielding modest economic returns. In the future, integrating the laver cultivation cycle with Integrated Multi-Trophic Aquaculture (IMTA) models (Kang et al., 2013) may help mitigate significant monoculture risks and unlock considerable economic potential (Lianyungang Municipal Bureau of Agriculture and Rural Affairs, 2021). For example, in 2021, Lianyungang City established a new Integrated Multi-Trophic Aquaculture (IMTA) management model incorporating the co-cultivation of shellfish and seaweeds. Demonstration farming under this model produced positive results, achieving an economic benefit of 3.19 million RMB Yuan and generating significant carbon sequestration effects (Ministry of Education of the People's Republic of China, 2023). With the establishment of IMTA systems and supporting infrastructure, additional opportunities for developing recreational and ecotourism farms, such as "new energy+" marine farms (Yi and Li, 2024), can emerge. This synergy between agriculture and recreational fishing has the potential to maximize economic benefits and increase income for laver farmers. However, the adoption and refinement of such development models still require ongoing feasibility studies and remain highly dependent on the maturity of the service industry at the national level. Currently, local governments at various levels in China are gradually formulating relevant laws and regulations. For instance, from January 1, 2025, to December 31, 2029, the Shandong Provincial Government will permit recreational fishing activities within marine ranching areas (Shandong Provincial Department of Agriculture and Rural Affairs, 2024). This initiative is expected to promote the integration of marine aquaculture with recreational fishing, enhancing the overall income of farmers.

In addition, by further integrating laver cultivation into carbon emission trading markets and exploring blue carbon economic development pathways, future carbon sink revenues could support both the advancement of laver cultivation and the stabilization of marine ecosystems, thereby achieving mutually beneficial outcomes. For example, leveraging the blue carbon value of laver (Cangnan County People's Government, 2022), Yonggui Aquaculture Family Farm in Rudong County has secured a "laver carbon credit loan" valued at 1.75 million RMB Yuan, using future revenue rights from carbon reduction and sequestration generated by laver cultivation as collateral (The People's Government of Nantong Municipality, 2023). Notably, the Chinese government is actively promoting the regulation and orderly development of carbon sink trading. The "Interim Regulations on the Administration of Carbon Emission Rights Trading", effective May 1, 2024 (The State Council of the People's Republic of China, 2024), provide institutional guarantees for carbon emission rights trading at the national legislative level. However, the realization of specific economic, ecological, and social benefits still depends on the establishment of a comprehensive carbon sink trading accounting standard system. At present, the transformation of the laver fishery economic model is still in its early exploratory stage and requires further practical innovation and robust government policy support.

4 Conclusion

This opinion article systematically outlines the current state of the laver (*N. yezoensis*) cultivation industry in Jiangsu Province, the challenges it faces, and strategies for sustainable development. Jiangsu Province, as the world's largest cultivation area for *N. yezoensis*, plays a critical role in local economic development and provides a substantial supply of high-quality laver to the global market. However, factors such as climate change, diseases, high-density cultivation, green tides, and golden tide disasters pose severe threats to laver cultivation. To address these challenges, we propose key development strategies, including the cultivation of heat-resistant laver varieties, improving standardization and order in laver cultivation practices, relocating the industry chain to higher latitude regions, and transforming the laver fishery economic model. The implementation of these strategies will support the sustainable development and industrial upgrading of Jiangsu Province's laver cultivation industry, as well as the formulation of long-term aquaculture development strategies. Additionally, these measures will contribute to marine ecosystem protection, achieving a win-win situation for both economic and ecological benefits.

Author contributions

JL: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. WL: Conceptualization, Formal analysis, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing. JX: Conceptualization, Formal analysis, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

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