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Editorial: Sustainable seaweed aquaculture: Current advances and its environmental implications

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Editorial on the Research Topic
Sustainable seaweed aquaculture: Current advances and its environmental implications

Seaweed aquaculture is one of the fastest growing aquaculture sectors in the world (FAO, 2018). To constantly improve seaweed aquaculture, significant research has been undertaken, including:

- Breeding and genetic improvement: advance seaweed aquaculture through the selection of new seaweed strains that are better suited for cultivation, more disease and stress (climate change) resistant, and more nutritious for human consumption (Charrier et al., 2015; Fort et al., 2019).
- Automation and optimization of seaweed aquaculture systems: development of automation techniques for cultivation and seaweed harvesting and optimisation of culture conditions, making the process more efficient and cost-effective (Solvang et al., 2021).
- Biorefining of seaweed biomass: improved methods to extract valuable compounds for commercial applications such as biofuels, pharmaceuticals, and cosmetics, which can increase the economic value of the harvested seaweed biomass (Sadhukhan et al., 2019).

In addition to improving the productivity of seaweed aquaculture systems, research has started focussing on the environmental impacts/benefits that intensive seaweed farming will bring (Campbell et al., 2019). This includes a further understanding of the effects of seaweed aquaculture on marine nutrients and carbon cycling (Duarte et al., 2017). Especially the potential use of seaweed aquaculture for carbon sequestration, which has become of interest in recent years (DeAngelo et al., 2022). Seaweeds can also extract pollutants and excess nutrients from the surrounding seawater, improving water quality and supporting the health of other marine organisms (Smart et al., 2022). This has been applied to Integrated multi-trophic aquaculture (IMTA), combining the cultivation of fed aquaculture species (principally finfish) and organic particulate extractive aquaculture species such as bivalves and/or seaweeds, with the aim to create a more balanced system (Chopin et al., 2001; Troell et al., 2009) and to improve social acceptance of finfish aquaculture. Seaweed aquaculture can increase the diversity of species in an area, as it provides new habitats for a wide range of marine organisms and can help in diversifying the aquaculture sector (Corrigan et al., 2022).

The Research Topic "*Sustainable Seaweed Aquaculture: Current Advances and its Environmental Applications*" has brought together several articles which highlight state of the art of the research in this field (Figure 1).

The contribution "*Implications of Genetic Structure for Aquaculture and Cultivar Translocation of the Kelp Ecklonia radiata in Northern New Zealand*" by Nepper-Davidsen et al. highlighted the importance of understanding genetic structure of different populations of *E. radiata* in New Zealand. The results of the Bayesian analysis of population structure, redundancy analysis and measurements of genetic differentiation showed high levels of genetic variation and indicated that genetically distinct sub-populations are likely to be present between and within regions on the North Island in New Zealand. Based on these findings the authors suggested that brood stock not to be translocated outside their natural habitat (Figure 1A).

The contribution "*Upscaling cultivation of Saccharina latissima on net or line systems; comparing biomass yields and nutrient extraction potentials*" by Boderskov et al. investigated the yields of a vertical line, horizontal line, and a net setup for *S. latissima* aquaculture. Their research showed that a net cultivation system resulted in highest biomass yields compared to the vertical and horizontal line setup. The study demonstrated that the production yield of *S. latissima* can be increased by optimizing cultivation infrastructure (Figure 1B).

The publication "*Eisenia arborea (Areschoung) domestication and mariculture development on the Pacific coast of Baja California, México*" by Zertuche-Gonzalez et al. aimed to explore the potential for cultivation of *E. arborea* as an alternative to the wild-harvesting of this valuable species, commonly used as abalone feed in Mexico and exported to Asia for human consumption. The research was successful in completing the life cycle of the species in laboratory and cultured sporophytes were deployed at sea on long-line systems at three different sites and in different seasons to investigate the potential site and

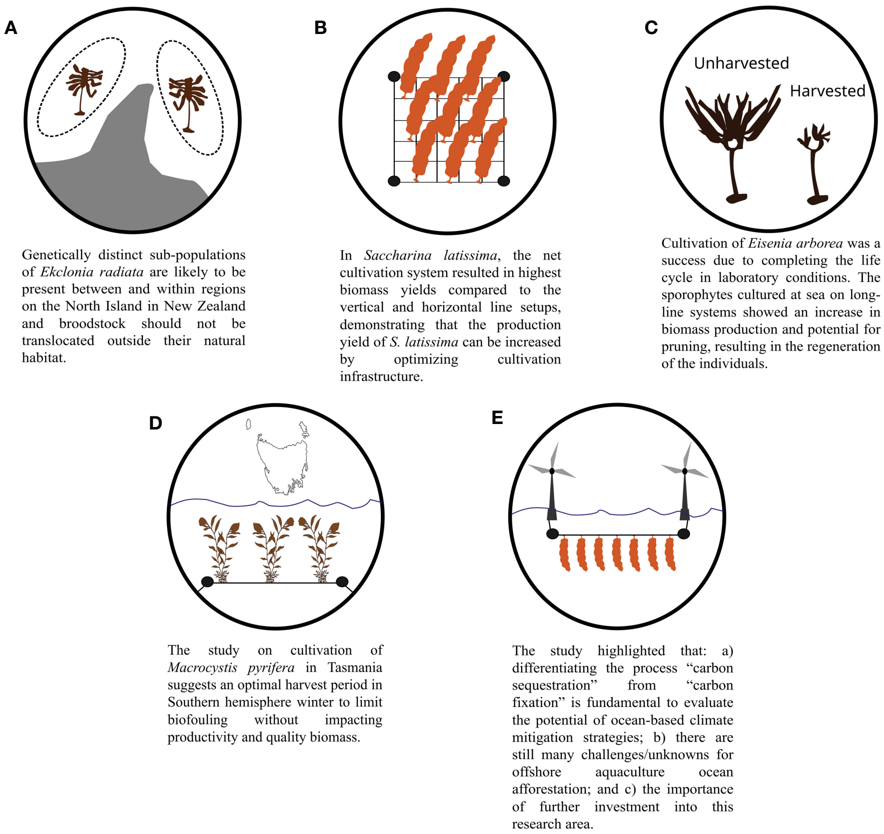

FIGURE 1
Main findings about the state of the art of seaweed aquaculture presented by the studies that contributed to The Research Topic Sustainable Seaweed Aquaculture: Current Advances and its Environmental Applications. The contributions of **(A)** Nepper-Davidsen et al., **(B)** Boderskov et al., **(C)** Zertuche-González et al., **(D)** Biancacci et al., and **(E)** (Ross et al.) are highlighted.

temporal variations. The results reported a significant increase in biomass production and showed that periodical pruning is possible, resulting in the regeneration of individuals, thereby ensuring multiple harvesting from a single seeding and making the process overall more cost-effective (Figure 1C). Furthermore, the potential for the cultivation of *E. arborea* in Mexico under various environmental conditions is promising particularly considering the species' tolerance to warmer waters which is becoming increasingly relevant in the current climate change scenario.

The contribution "*Optimisation of at-sea culture and harvest conditions for cultivated Macrocystis pyrifera: yield, biofouling and biochemical composition of cultured biomass*" by Biancacci et al., investigated the temporal and spatial variability of cultivated *M. pyrifera* in yield, biofouling, and biochemical composition amongst two cultivation sites, at two depths (1 and 5 m) from harvests between July–November 2020.

The results suggest an optimal harvest period in Southern hemisphere winter months (July – August) to limit biofouling without impacting productivity and ensuring good quality biomass. The biochemical composition varied temporally and spatially for many of the components analysed, overall highlighting that the species has a composition conducive to human and animal consumption (Figure 1D).

This study provides a better understanding of the variation in growth and quality of cultivated *M. pyrifera* biomass in the region relevant to inform future management and development of kelp aquaculture in south-eastern Australia.

The contribution "*Seaweed afforestation at large-scales exclusively for carbon sequestration: Critical assessment of risks, viability and the state of knowledge*" by Ross et al. investigated the (1) ecological feasibility; (2) technical feasibility; (3) economic feasibility; (4) co-benefits and risks; and 5) governance and social considerations of seaweed offshore aquaculture at large scale exclusively for carbon sequestration. Firstly, the study highlighted the importance of differentiating the process "carbon sequestration" from "carbon fixation" which is fundamental in studies evaluating the potential of ocean-based climate mitigation strategies. Overall, the study underlines the challenges and unknowns for offshore aquaculture ocean afforestation, including ecological impacts on benthonic and/or phytoplankton communities, challenging biogeochemical conditions, and difficulties in its definition and legality of operation, to be considered as a strategy for climate mitigation. The study highlighted the importance of further investment into this research area, before promoting the concept as a potential ocean-based climate mitigation strategy (Figure 1E).

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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