A Systematic Review of the Scientific Literature to Identify Challenges for the Sustainable Development of Seaweed Farming in Indonesia

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Abstract

Seaweed aquaculture plays a vital role in the blue economy, contributing to economic growth, enhanced livelihoods, and providing ecosystem services such as carbon sequestration and nutrient cycling. However, the industry is hindered by several challenges, such as limited species diversity, technological gaps, and competition over marine space. This study aimed to assess the current state, challenges, and prospects of seaweed aquaculture, with a particular emphasis on Indonesia. A systematic review was conducted in accordance with PRISMA guidelines, focusing on the development of species diversity, cultivation technologies, and site suitability in Indonesia. The findings reveal that seaweed aquaculture in Indonesia is primarily dominated by species like *Kappaphycus alvarezii*, *Gracilaria* sp., and *Euchema cottonii*. This underscores the necessity for species diversification and the adoption of advanced cultivation technologies. Key areas identified for future research include the optimization of cultivation techniques, expansion of suitable farming areas, and the integration of digital technologies and genetic analysis to boost productivity and sustainability. In addition to technological advancements, socio-economic research on seaweed farming demonstrates its significant contribution to coastal community livelihoods, offering income opportunities and increased resilience. Furthermore, research on strategic planning, biosecurity, and supportive policy frameworks is crucial for the sustainable development of the seaweed aquaculture sector in Indonesia.

Keywords

seaweed farming · PRISMA · cultivation technology · GIS · IMTA · blue economy

1. Introduction

Seaweed aquaculture is crucial for the blue economy as it promotes economic growth, livelihood improvement, and providing ecosystem services such as carbon sequestration and nutrient cycling . The industry generates billions of dollars annually and provides employment opportunities, particularly in coastal and remote areas (FAO, 2020). Seaweeds also help reduce climate change impacts by absorbing carbon dioxide and supporting marine biodiversity (Duarte et al., 2017). It also contributes to food security by providing nutrient-rich food, animal feed, eco-friendly biofuels, and bioplastics (Laurens et al., 2020).

Despite the significant potential of seaweed cultivation, various worldwide challenges impede these efforts. The restricted range of seaweed species currently under cultivation is a significant concern. Currently, only a few species, such as Eucheuma and Gracilaria, are farmed commercially. This leads to a high dependency on these species and reduces the potential ecological and economic benefits of diversifying other species (Valderrama et al., 2015). Diversifying the types of cultivated seaweeds is crucial for enhancing marine ecosystem resilience and providing a broader range of products in the market.

Technologically, seaweed farming has undergone significant advancements in recent years, enhancing production efficiency and sustainability. Modern techniques, such as floating rafts and longline systems, have improved the quality and quantity of seaweeds harvested (Buschmann et al., 2017). Genetics and biotechnology have led to increased resistance to diseases and weather conditions, thereby improving resilience and productivity (Khan et al., 2023). Digital technology and the Internet of Things (IoT) have also improved the real-time monitoring of environmental conditions and seaweed growth (Bachtiar et al., 2022). However, developed countries have access to advanced farming technologies, whereas developing countries rely on less efficient and sustainable methods, resulting in differences in productivity and quality (Hafting et al., 2015).

Determining marine space allocation for seaweed farming is complicated by stakeholder conflicts. The complex zoning process involves fishers, tourism operators, and conservationists (Gentry et al., 2017). Methods for analyzing farming locations have evolved with technology and multidisciplinary approaches. Geographic Information Systems (GIS) and remote sensing are prominent, using satellite and drone data to assess environmental parameters crucial for farming suitability (Thomas et al., 2019) (Ashikur et al., 2021). Ecology-based modeling simulates interactions between

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environmental and biological factors (Gentry et al., 2017). Integrating spatial data with seaweed population dynamics models aids in efficient and sustainable zoning, reducing conflicts with other sectors like fisheries and tourism (Sanchez-Jerez et al., 2016).

As an archipelagic nation with a coastal area of 95,181 km², Indonesia is the world's second-largest seaweed producer (IBEKA, 2023). Indonesia plans to produce 12 million tons of seaweed by 2024 to improve fishermen's welfare and mitigate climate change impacts (FAO, 2020; Ministry of Marine and Fisheries of The Republic of Indonesia, 2021). However, this target faces challenges in species diversity, cultivation techniques, site suitability, and environmental issues. Achieving this goal requires further research on current and future seaweed farming conditions, considering global technological advancements.

This study addresses: (a) to what extent the diversity of species, technologies, and methods for determining marine areas for seaweed cultivation have developed in Indonesia, (b) to what extent the techniques and methods of seaweed cultivation can be further developed in Indonesia, and (c) to what extent the results of previous research will be beneficial to Indonesia's future plans for seaweed culture. A comprehensive understanding of the current landscape and future prospects is needed to contribute to strategic planning and sustainable development of this vital sector. The objective is to evaluate the status and potential development of seaweed cultivation in Indonesia through a systematic literature review, providing insights for the strategic planning and sustainable development of this sector.

2. Material and methods

2.1 Materials

A systematic review was conducted, focusing on seaweed aquaculture research in Indonesia. The study used Scopus and Web of Science (WoS) databases to identify relevant articles. Predetermined inclusion criteria and search strings ensured reproducibility and accuracy. These databases were chosen for their broad coverage across disciplines (Haddaway et al., 2015), including aquaculture and marine biology (Mongeon & Paul-Hus, 2016), providing a thorough representation of available literature. Using multiple databases is essential to ensure comprehensive coverage, as each database may index different journals and publications (Bramer et al., 2017), also minimize bias and ensure a more comprehensive overview of existing research on seaweed aquaculture in Indonesia.

2.2 Methods

This study utilized a systematic review approach, a review that adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. This protocol, introduced in 2009, provides a 27-item checklist and a four-phase flow diagram to enhance the transparency and accuracy of systematic reviews (Page et al., 2021). PRISMA proposes a standardized framework for executing systematic reviews, highlighting essential principles including the precise formulation of research questions, systematic and exhaustive literature searches, explicit inclusion and exclusion criteria, and meticulous documentation of the review process to guarantee transparency and reproducibility. PRISMA was initially developed in the medical field and has gained widespread recognition across multiple disciplines for its comprehensiveness and ability to improve consistency in reporting (Calderon-Monge & Ribeiro-Soriano, 2024; Chiu et al., 2023; Pahlevan-Sharif et al., 2019). Its widespread adoption and endorsement by numerous journals and organizations highlight its effectiveness in addressing the common issue of incomplete reporting in systematic reviews (Page et al., 2021).

Prior to initiating the literature search process, a comprehensive search protocol was developed that encompassed the inclusion criteria and analysis methods. This approach ensured a rigorous and reproducible review process. The PRISMA methodology was followed in four key phases: identification, screening, eligibility, and inclusion. During the identification phase, an extensive search of scientific literature was conducted on June 15, 2024, focusing on seaweed aquaculture in Indonesia. The search aimed to collect all relevant literature published up to May 2024. This comprehensive examination aimed to provide insights into the current state of seaweed aquaculture research in Indonesia and to identify potential areas for future investigation.

2.2.1 Literature Search

A literature search was conducted in Scopus and Web of Science (WoS) databases using the boolean string "seaweed AND aquaculture AND Indonesia." Search results were downloaded in RIS format and consolidated in Mendeley reference management software. An initial screening process eliminated duplicate entries. The bibliographic information of unique results, including titles, authors, abstracts, publication years, and journal names, was then exported to a spreadsheet for further analysis using Microsoft Excel.

2.2.2 Data Collection and Screening

Two reviewers conducted a secondary screening of titles and abstracts to retain publications focused on seaweed aquaculture in Indonesia. Full-text versions of relevant papers were obtained, with unavailable ones excluded. Both reviewers independently assessed the full texts for eligibility, with a third reviewer resolving any discrepancies. This dual-review process aligns with systematic review best practices, enhancing reliability and validity while minimizing bias and ensuring thoroughness (Kittel et al., 2011; Sutton et al., 2021).

Data on research methodology, seaweed species, study locations, and primary findings were extracted using Microsoft Excel. Studies conducted outside Indonesia were excluded.

3. Results

3.1. Publication screening

The systematic search in Scopus and Web of Science databases yielded 227 records. After removing 39 duplicates, 188 publications were screened by title and abstract, resulting in 106 exclusions. The 106 papers were excluded because they focused on topics such as seaweed’s bioactive compounds, post-harvest processing, or non-seaweed aquaculture. Studies conducted in other countries like India or Malaysia, without any connection to Indonesia, were also excluded. However, we retained multinational studies in our review if Indonesia was one of the research locations. Four more papers were omitted due to inaccessible full-text PDFs. Upon conducting a detailed full-text analysis, we removed an additional five papers because they did not focus on seaweed aquaculture as their main research topic. The final sample comprised 73 articles meeting all inclusion criteria (Fig. 1).

Fig. 2 shows the temporal distribution of seaweed aquaculture research publications in Indonesia from 2006 to 2024. The field emerged in 2006, with a notable increase in review articles from 2014 onwards. 2021 and 2022 saw a decline in publications, likely due to the COVID-19 pandemic restricting field research. However, 2023 has shown signs of recovery in research activities. This analysis provides insights into the field's evolution and current state in Indonesia.

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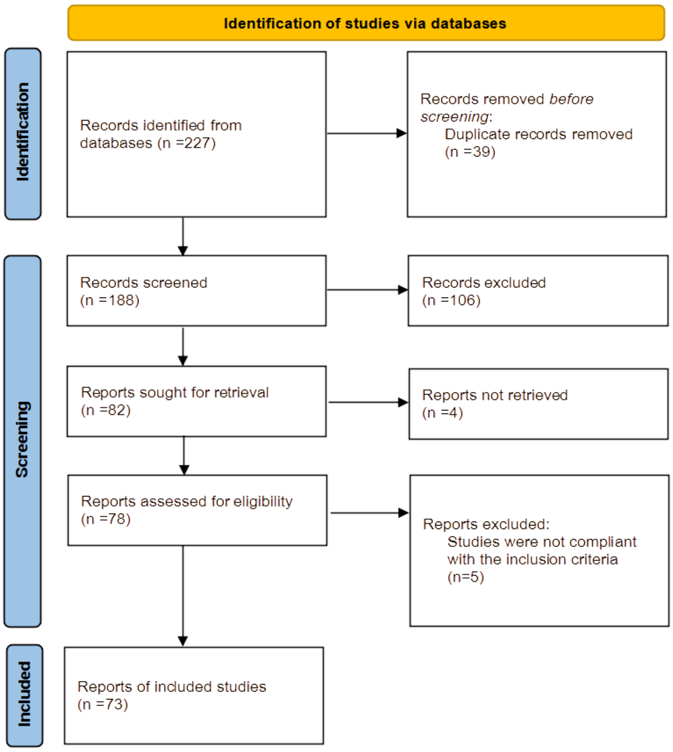

Fig 1. PRISMA flow diagram showing the literature collection and selection process for the systematic review

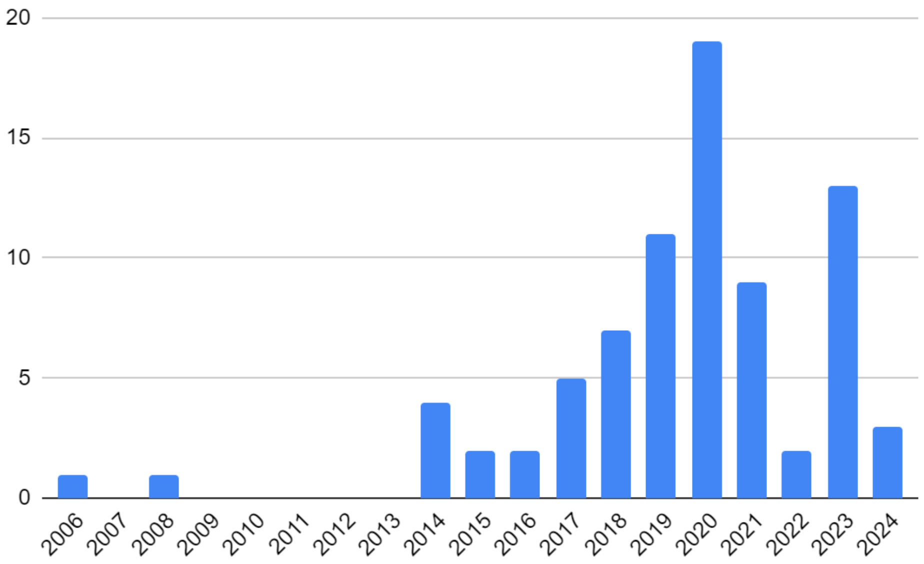

Fig 2. Distributions of articles included in the systematic review (2006–2024)

The publication types for seaweed aquaculture research in Indonesia predominantly comprise journal articles, which account for 65.75% (n=48) of the total publications. International conference proceedings represent 32.88% (n=24), highlighting their role as a secondary platform for disseminating research findings. In contrast, book chapters are notably underrepresented, with only one publication (1.37%) identified. This distribution reflects researchers' strong preference for peer-reviewed journal articles as the primary medium for communicating their findings, while conferences serve as an important alternative for presenting emerging research.

Nine articles were published in the AACL Bioflux journal, while Biodiversity, Ocean and Coastal Management, Journal of Applied Phycology, and Aquaculture Reports each published two articles. The remaining 31 articles appeared in various other journals. Additionally, 21 out of 24 proceedings were published in the IOP Conference Series: Earth and Environmental Science, with four from the 2nd International Symposium on Marine Science and Fisheries (ISMF2) - 2019, and 17 from other conferences or seminars.

3.2 Data Source for seaweed aquaculture research in Indonesia

In scientific studies, data sources significantly influence the reliability and validity of conclusions. Data can be primary (original, first-hand) or secondary (preexisting, gathered for different purposes).

Of 76 papers analyzed, 51 used primary data (70%), 12 used secondary data (16%), and 10 used both (Fig. 3). Secondary data in seaweed research falls into three categories: policies and regulations (Kambey et al., 2020; Mantri et al., 2023); statistical or production data (Oktopura et al., 2020; Rimmer et al., 2021; Sondak et al., 2017a); and data from research articles, conference proceedings, literature reviews, and geospatial sources (Andréfouët et al., 2018; Du et al., 2023; Kunzmann et al., 2023; Ulfiasari et al., 2020).

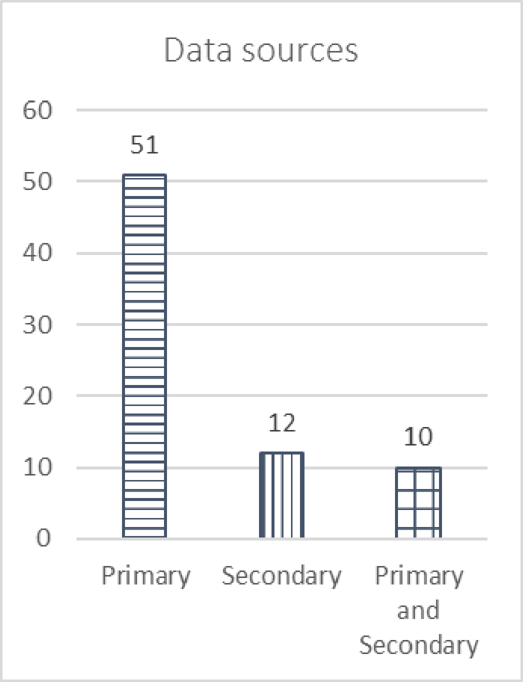

Fig 3. Data sources

The primary data consisted of experiments (laboratory experiments or field experiments), observations (direct observation or participant observation), surveys (questionnaires, interviews, online surveys), field studies, and focus group discussions. The largest type of primary data was field experiments/observations, with a total of 31 papers (Fig. 4). Eight papers used laboratory experiment data, 12 used survey data types, and at least a combination of field experiments/observations and FGD/questionnaires/interviews.

Almost all studies that use survey data can be obtained through direct interviews with relevant stakeholders or by filling out questionnaires (Andréfouët et al., 2021; Asian et al., 2015; Darma et al., 2018; Domínguez-May et al., 2017; Geo et al., 2020; Irfan et al., 2020; Nuryadi et al., 2023; Soejarwo et al., 2018; Sulistiawati et al., 2020; Teniwut et al., 2020; Zamroni et al., 2019). Only one study used telephonic interviews (Langford et al., 2021), due to the current COVID-19 outbreak.

Data sources from laboratory experiments were divided into two categories: first, samples from the field were taken to the laboratory for testing and second, the research was conducted entirely in the laboratory. (Lumbessy, 2019) conducted laboratory experiments to determine the effect of using cultivation media on body weight gain and survival of the seaweed *Gracilaria salicornia* in semi-sterile cultivation. Several research using data from field samples taken to the laboratory (Arbit et al., 2019; Harwinda et al., 2018; Lim et al., 2014; Prasedya et al., 2023; Rahman et al., 2020; Wenno et al., 2015). Meanwhile, data sourced from field experiments or observations are used to analyze the suitability (Adibrata et al., 2023; Aris et al., 2020; Ihsan et al., 2020; Rejeki et al., 2018; Rintaka & Berlianty, 2023; Syam et al., 2020; Syamsuddin et al., 2023; Yulianto et al., 2017), growth, productivity and production of seaweed (Aslan et al., 2021; Aslin et al., 2019; Hajar et al., 2020; Hasanah et al., 2020; Kasim & Mustafa, 2017; Marcelien et al., 2019; Nurdin et al., 2023; Nursidi et al., 2017; Parenrengi et al., 2020; Rejeki et al., 2016; Satriani et al., 2023; Sukiman et al., 2014; Syamsuddin & Azis, 2019; Wahyuningtyas et al., 2020; Wijayanto et al., 2020), as well as the content of certain ingredients in seaweed (Fakhraini et al., 2019; Komariyah et al., 2019; Lim et al., 2014; Mashoreng et al., 2019; Wenno et al., 2015; Yasir et al., 2021) and seaweed extracts as biofilters or as growth agent (Indarjani & Nurhayati, 2022; Mulyani et al., 2020; Rahman et al., 2020; Shimoda et al., 2006; Widowati et al., 2021; Windarto et al., 2024).

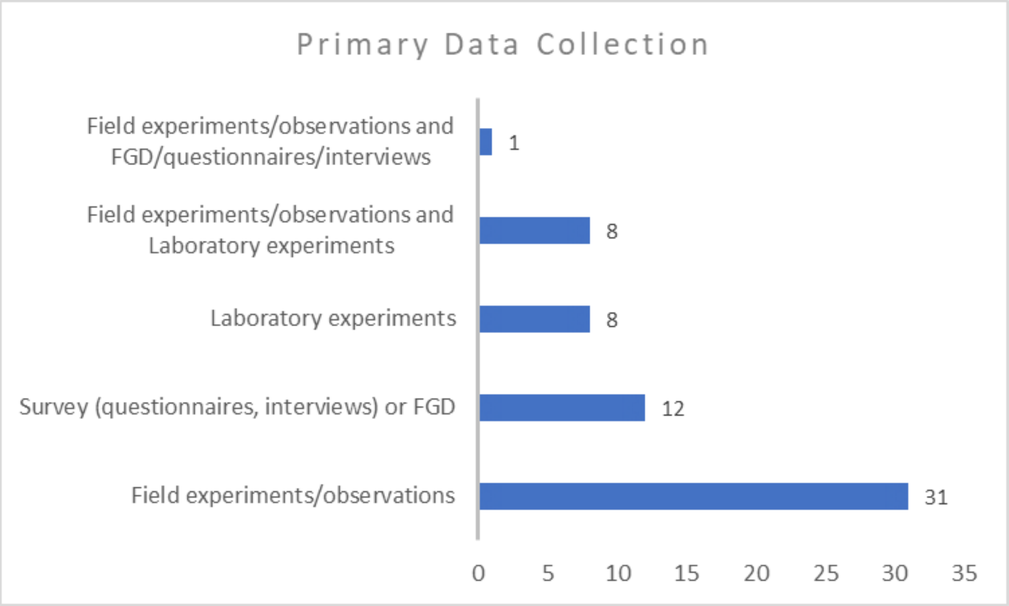

Fig 4. Types of primary data collection

3.2 Data analysis used in seaweed culture research

Various data analysis methods have been applied to optimize the development of seaweed cultivation research, with the majority being statistical analysis, followed by geospatial and environmental analysis, socio-economic analysis, innovative farming and technology development, media growth, genetic analysis, and others (Fig. 5).

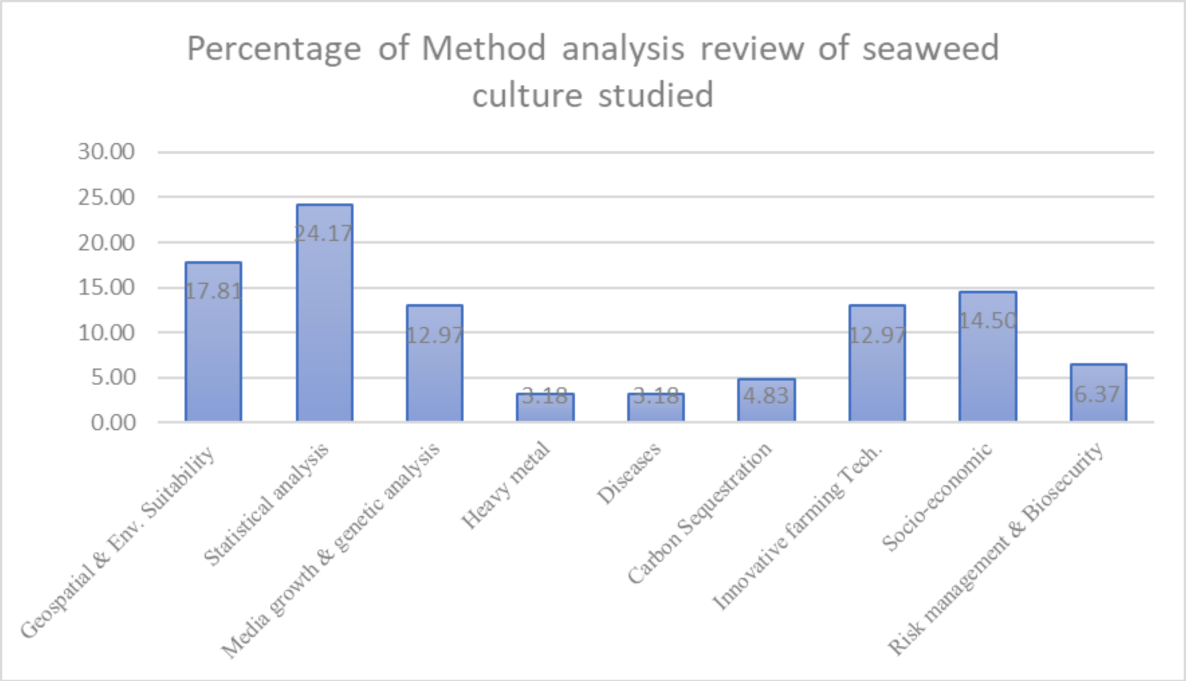

Fig 5. Percentage of types of analysis in research papers addressing seaweed farming

3.2.1 Statistical Analysis

Statistical analysis is crucial in seaweed cultivation research for optimizing growth conditions, evaluating interacting factors, guiding data-driven decisions, and validating results. About 24.17% of reviewed studies used statistical methods to analyze seaweed growth and environmental interactions (Fig. 5). Notably, 13.7% combined ANOVA with other methods, such as BNJ test for biomass production (Sukiman et al., 2014), Tukey HSD for growth analysis (Hidayatulbaroroh et al., 2018), and Duncan's post-hoc test for cultivation comparisons (Rejeki et al., 2018).

6.8% performed descriptive statistical analysis (Fig. 5), used for identifying optimal regions for the seaweed industry (Pari et al., 2024), managing ice-ice disease (Tokan, 2016), analyzing seasonal production (Irfan et al., 2020), and daily growth rates (Parenrengi et al., 2020). Comparative analysis of aquaculture commodities used methods like Revealed Comparative Analysis (RCA), symmetric comparative analysis (RSCA), Index of Trading Specialization (ISP), and Constant Market Share Analysis (CMSA) (Oktopura et al., 2020). Some studies emphasized cooperative-based management in seaweed cultivation (Nuryadi et al., 2023).

3.2.2 Geospatial and Environmental Suitability Analysis

Geospatial and environmental suitability analysis is vital for optimizing aquaculture, particularly seaweed farming. By integrating various physical (Aris et al., 2020) and water quality parameters (Ihsan et al., 2020), researchers can identify optimal areas for sustainable seaweed aquaculture. GIS-based and remote sensing methods are commonly employed, representing 15.1% of the methods used, with GIS accounting for 10.9% and remote sensing 4.2% (Fig. 5). Suitability matrices (Syamsuddin et al., 2023) can be developed using the Analytical Hierarchy Process (AHP) (Soejarwo et al., 2018; Wibowo et al., 2023), expert justifications (Adibrata et al., 2023), or decision-making models like TOPSIS and Multi-Criteria Evaluation (MCE) (Rintaka & Berlianty, 2023). Geostatistical models (Yulianto et al., 2017) and scoring and weighting techniques are commonly used for seaweed aquaculture analysis. Remote sensing and image processing assess coastal waters, either alone (Mualam et al., 2022; Nurdin et al., 2023) or in combination with GIS (Ulfiasari et al., 2020). The integration of GIS, remote sensing, and decision-making models facilitates comprehensive aquaculture management, ensuring sustainable and productive practices.

3.2.3 Socio-Economic Aspects of Seaweed Cultivation

Seaweed farming significantly impacts coastal communities' socioeconomic status, as shown in 14.5% of the reviewed studies. Various methods were used, including interviews combined with secondary data on farmers' income levels (Geo & Ariani, 2020), and economic and biophysical feasibility studies using water quality and economic indicators (Raja et al., 2021). Some researchers employed structured and semi-structured questionnaires and interviews (Zamroni et al., 2019), while others measured financial feasibility using R/C Ratio (Darma et al., 2018). Studies also analyzed environmental, social, and economic dynamics (Langford, 2023), conducted descriptive analysis of financial viability (Rimmer et al., 2021), and used survey methods with statistical analysis of household demographics and farming practices (Asian et al., 2015). Bioeconomic modeling was utilized to determine optimal harvesting time and assess risks (Domínguez-May et al., 2017). These diverse approaches assessed the socio-economic impacts of seaweed farming on coastal communities.

3.2.4 Commercial Cultivation and Innovations in Seaweed Farming

12.97% of the significant commercials and innovations in seaweed farming techniques across different regions has been reviewed in this study. The technique may conduct deep-water farming using hanging long lines, multiple rafts, and spider webs (Hurtado et al., 2014); improved fishing gear such as gill nets, bamboo traps, and fyke nets in seaweed culture areas (Hajar et al., 2020); seaweed seed spacing and substrate depth (Mulyani et al., 2020); straight-slipped grafting of tissue-cultured and local strains (Aslan et al., 2021); the Kaizen approach using long line, grouping, and charcoal pocket methods (Hasanah et al., 2020); and longline cultivation and plantation depths (25, 50, 75, and 100 cm) (Wahyuningtyas et al., 2020).

Meanwhile, the concept of Integrated Multi-Trophic aquaculture (IMTA) has been explored to enhance the sustainability of aquaculture practices, which covers 6.5% of the method analysis (Kunzmann et al., 2023; Rejeki et al., 2016). The study identified that in Indonesia, owing to very long coastlines and complicated legislation, IMTA seems to be particularly suitable, as successfully tested in model regions.

3.2.5 Media growth and genetic analysis

Research on seaweed media growth and genetics has revealed various approaches and findings in recent years. We reviewed studies highlighting cultivation methods and genetic analyses to enhance seaweed production and quality. 6.4% focused on growth media, including off-bottom bagged and non-mesh bag methods (Irfan et al., 2023); culture media (Wijayanto et al., 2020); natural plant growth regulators like coconut water, shallots, maize, moringa leaves, mung bean sprouts (Windarto et al., 2024); and seaweed extract-derived bio stimulants, particularly Ascophyllum Marine Plant Extract Powder (Hurtado et al., 2024). Another 6.4% focused on genetic analysis. Satriani et al. (2023) analyzed *Kappaphycus alvarezii* genetic makeup and cultivation performance using molecular markers and DNA sequencing; (Arbit et al., 2019) examined *Gracilaria sp*. genetic characteristics with mitochondrial gene barcoding; (Marcelien et al., 2019) studied seedling types' effects on *Kappaphycus alvarezii* growth and carrageenan content; (Lim et al., 2014) explored *Kappaphycus* and *Eucheuma* genetic diversity using mitochondrial-encoded markers; and (Asian et al., 2015) selected tissue-cultured and local strains for intra-generic grafting.

3.2.6 Risk Management in Seaweed Supply Chains & Biosecurity

Only 3.18% of analytical methods addressed risk management and supply chain issues in the seaweed industry. (Teniwut et al., 2020) tackled asymmetric information and supply chain risks using the House of Risk approach, employing HOR 1 and HOR 2 to map processes and identify mitigation strategies. They also used the Analytic Hierarchy Process with a fuzzy approach to prioritize actions. Another 3.18% focused on biosecurity practices for seaweed cultivation policies and guidelines. (Kambey et al., 2020) analyzed biosecurity frameworks in Indonesian seaweed aquaculture, highlighting challenges like disease outbreaks and limited policy enforcement. (Mantri et al., 2023) assessed integrated biosecurity approaches, emphasizing regulatory guidelines, disease and pest outbreak notifications, and risk assessments for sustainable development.

3.2.7 Carbon Sequestration Potential

The study on carbon sequestration consists of 4.83% of the articles. This study was conducted by (Fakhraini et al., 2019; Mashoreng et al., 2019; Sondak et al., 2017a). Mashoreng et al. used the oxygen exchange method to measure carbon sequestration capacity, while Sondak et al. explored the potential of seaweed aquaculture beds (SABs) in the Asia-Pacific region to mitigate anthropogenic CO2 emissions.

3.2.8 Impact of Heavy Metals on Seaweed

3.18% of the literature review collectively highlights the critical need for regular assessment and management of heavy metal contamination in seaweed cultivation, as this has direct implications for environmental health and food safety. (Komariyah et al., 2019) investigated the accumulation of lead (Pb) in *Eucheuma cottonii* seaweed, using descriptive method and Mann Whitney U test and (Yasir et al., 2021) examined the metal content in *Gracilaria changii* across different cultivation locations The study utilized statistical analysis and spectrophotometry to measure concentrations of copper, cadmium, and lead.

3.2.9 Disease Management in Seaweed Cultivation

3.18% of these reviews highlighted the importance of diverse strategies in disease management. For example, (Bast, 2014) used extracts from *Avicennia marina*, which exhibited antimicrobial properties against bacteria that cause ice-ice disease. (Tuhumury et al., 2024) conducted bacterial isolation, purification, and biochemical tests to identify four pathogenic bacteria (*Vibrio alginolyticus*, *Vibrio fluvalis, Vibrio cholerae*, and *Aeromonas caviae*) as causative agents of ice-ice disease in *Eucheuma cottonii*.

3.3 Seaweed types

Recent research has shown significant interest in various seaweed species, emphasizing their ecological, economic, and health benefits. *Kappaphycus alvarezii* is the most studied, with 36 papers highlighting its commercial value, particularly in carrageenan production for food and pharmaceutical industries (McHugh, 2003). Studies have explored seaweeds' interactions with diverse marine organisms, underscoring their role in supporting marine ecosystems and potential in aquaculture. In Indonesia, efforts focus on optimizing cultivation techniques to improve yield and quality, recognizing the country's marine biodiversity and seaweed's importance in the local economy (Sujatmiko et al., 2024).

Gracilaria sp. and *Euchema cottonii* follow in second and third, with 22 and 14 studies respectively. *Gracilaria sp*. is a key agar source used in food and microbiological culture media, while *Euchema cottonii* is an important carrageenan source.

Indonesian research has explored their commercial applications and environmental benefits, such as bioremediation to absorb excess nutrients from marine waters (Jagtap & Meena, 2022; Wei et al., 2017). These studies emphasize sustainable practices, integration of seaweed farming with other aquaculture systems, enhancement of local livelihoods, and environmental conservation.

Less studied species like Caulerpa, Eucheuma denticulatum, and Sargassum have gained attention, with fewer publications. Research has explored their unique bioactive compounds and applications in food, cosmetics, and pharmaceuticals. Recent Indonesian studies highlighted Caulerpa's antioxidant and antimicrobial properties, focusing on health benefits (Wirawan et al., 2022). Sargassum species have been investigated for polysaccharides and pharmaceutical potential. The diverse research topics, from specific seaweed species to their interactions with marine organisms, reflect growing interest in using these resources for ecological and economic benefits (Smit, 2004).

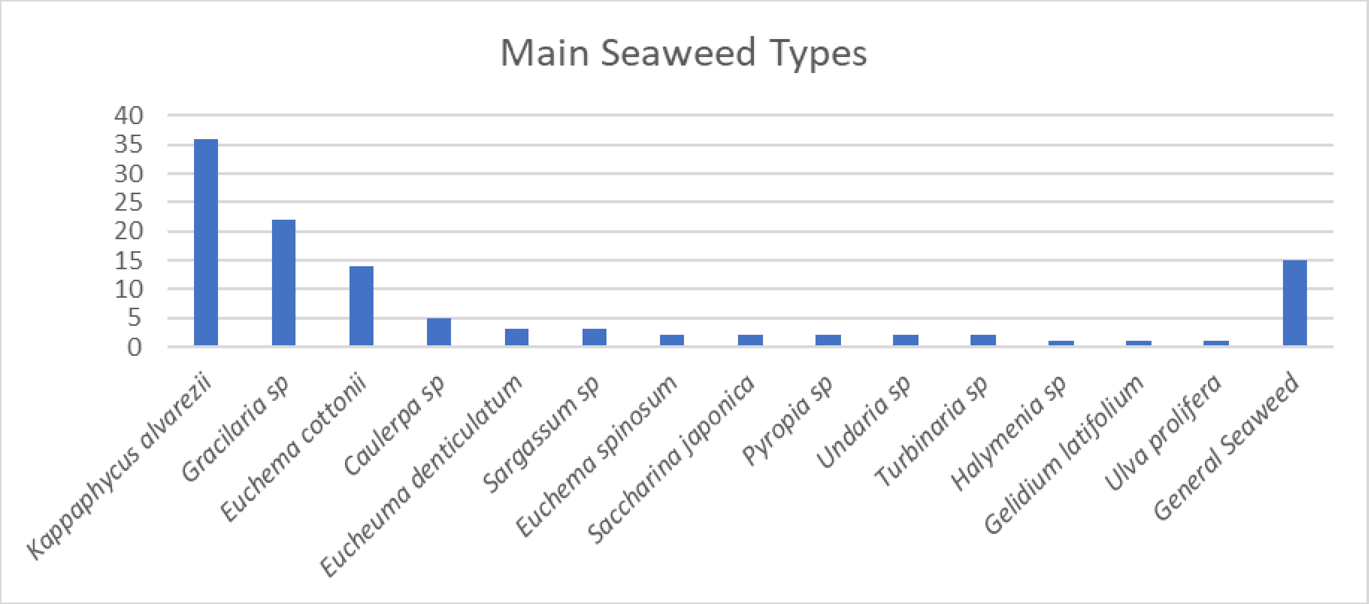

Fig 6. The diversity of seagrass species that were studied

3.4 Research sites of seaweed farming in Indonesia

This section examines the distribution of research sites where seaweed farming studies have been conducted in Indonesia (Fig. 7). In Figure 7, panel (a) shows the research year, panel (b) depicts species distribution and composition percentages, and panel (c) displays the number of studies per province. A total of 99 research locations were identified from 73 research titles, with the majority of studies focusing on South Sulawesi and Southeast Sulawesi, which together accounted for 36 sites (Fig. 7a).

Regarding species composition, studies frequently focused on *Kappaphycus sp.*, which was the dominant species in multiple research sites. In 2020, six studies explicitly examined *Kappaphycus sp.*, while other research remained more general in scope, addressing seaweed farming without specific emphasis on species diversity.

Most of the seaweed research occurred in South Sulawesi and Southeast Sulawesi, representing 26% and 10% of the total sites, respectively (Fig. 7c). In other provinces, an average of three researchers were active in each. Overall, 23 out of Indonesia's 38 provinces were identified as locations for seaweed aquaculture research.

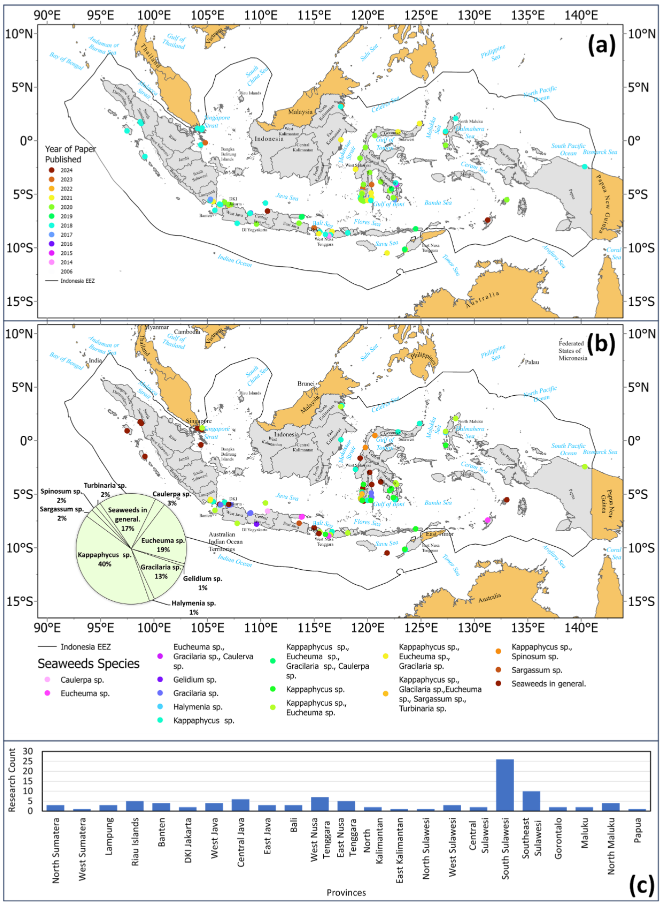

Fig 7. Map of seaweed farming research distribution in Indonesia by year (a), species (b) and province (c).

4. Discussion

The Indonesian government is focusing on downstream processing of seaweed to enhance its utility and capability in the food industry. Programs include quality seeds, satellite mapping, simplified licensing, research on seaweed quality, socioeconomic preparation, processing improvement, and market generation (Indonesia's Coordinating Ministry for Maritime Affairs and Investment, 2024).

4.1 The potential for cultivating various types of seaweed in Indonesia

Indonesia is the largest producer of the seaweed species (Fig. 6) such as Kappaphycus, Eucheuma, and Gracilaria (Perryman et al., 2017) which mainly used for carrageenan and agar. However, underutilized species like *Caulerpa sp., E. denticulatum, and Sargassum sp.* have potential in the food and cosmetic industries (Litaay et al., 2022; Nurjanah et al., 2016; Nurjanah et al., 2018). Caulerpa from the Kei Islands has antioxidant properties (Nurjanah et al., 2016), while Sargassum and Eucheuma serve as organic fertilizers rich in minerals and growth regulators that enhance crop production (Basmal, 2009). These species hold great promise for further development in cosmetics, food, and organic fertilizers.

For merit cultivation, methods may vary by species, but such as Kappaphycus, Eucheuma, and Gracilaria, use single-step vegetative propagation (Prasad Behera et al., 2022). These species are well-suited to Indonesia's tropical waters and climatic conditions, making them key candidates for sustainable seaweed farming expansion. Researchers in East Malaysia are working to develop wild seaweed for cultivation. Out of 212 types of *Kappaphycus spp*. and *Eucheuma denticulatum*, only 72 survived (Yahya et al., 2024). Similar research is needed in Indonesia to enhance the genetic diversity of seaweed, making it more resistant to pests, diseases, and environmental changes. Post-harvest handling is crucial for quality, influenced by species handling, production scale, and infrastructure (Entee, 2015; Zhu et al., 2021).

4.2 The potential for developing seaweed farming areas in Indonesia

Out of 12 million hectares of potential cultivation area in Indonesia, only 102 thousand hectares (0.8%) are currently used (UNIC, 2024). The Indonesian government should focus on expanding seaweed cultivation in suitable regions to meet growing global demand. Understanding the biophysical conditions of cultivation sites is key to preventing farming failures and ensuring high-quality yields. *E. cottoni* thrives in substrates characterized by sandy bottoms mixed with coral rubble (long-dead coral fragments). The ideal water currents are 20–40 cm/sec at depths of 2–15 meters. Optimal salinity ranges from 28 to 35 ppt, and water temperatures should remain between 20–28°C with a maximum daily fluctuation of 4°C (Ministry of Marine and Fisheries of The Republic of Indonesia, 2005).

Determining suitable seaweed cultivation sites often requires significant resources, but remote sensing and GIS offer efficient solutions for large-scale, periodic monitoring. Studies have used GIS and spatial analysis to evaluate coastal areas' suitability for aquaculture. Syamsuddin et al. (2023) and Mualam et al. (2022) identified optimal areas around Karampuang Island and Bau-Bau for sustainable farming. Other research highlighted environmental factors and water quality in site selection, as seen in Soejarwo et al. (2018) and Syam et al. (2020) studies. While Lampung Bay was found unsuitable for seaweed, Yulianto et al. (2017) offered insights for improvements. Ulfiasari et al. (2020) demonstrated LiDAR use for identifying potential areas, and Nurdin et al. (2023) applied UAV imagery for precision management of Kappaphycus alvarezii. These studies emphasize GIS and spatial analysis's role in optimizing sustainable aquaculture practices.

According to the review, most seaweed culture research in Indonesia is concentrated in South Sulawesi (26%) and Southeast Sulawesi (10%) (Fig. 7c). However, seaweed production is spread across 23 provinces (BPS, 2021). In 2020, the top five producing provinces were South Sulawesi, East Nusa Tenggara, North Kalimantan, Central Sulawesi, and West Nusa Tenggara. South Sulawesi led with 1.63 million tons of wet seaweed.

To boost seaweed production in Indonesia, expansion should target regions with low current output, such as Sumatra, Kalimantan, and Moluccas. Assessing the availability of infrastructure, such as transportation and processing facilities, is essential for efficient production and distribution (Neish, 2013). Equally important are social and cultural factors, as community acceptance and participation are crucial for sustainable development (Rimmer et al., 2021). By focusing on these underutilized areas and adopting a holistic approach to site selection and development, Indonesia can significantly increase its seaweed production and strengthen its global market presence.

4.3 Seaweed cultivation techniques

Seaweed farming innovations have improved productivity and sustainability. Advances include deep-water farming for Kappaphycus and Eucheuma, optimal nata de seaweed processing (Hurtado et al., 2014; Wenno et al., 2015), and integrated farming to boost income and reduce environmental impacts (Hajar et al., 2020; Mulyani et al., 2020). Techniques like grafting, strain selection (Aslan et al., 2021; Parenrengi et al., 2020), and strategies such as the Kaizen approach and varying planting depths have been explored (Hasanah et al., 2020; Wahyuningtyas et al., 2020). Farming methods like floating rafts, nets, and cages show benefits (Kasim & Mustafa, 2017; Mohiuddin et al., 2023; Prasad Behera et al., 2022). Studies demonstrate net-bag, floating cages, and off-bottom nets are effective for specific seaweeds, but more research is needed to determine the best approach for each species.

Seaweed cultivation offers various methods, but key challenges must be addressed for consistent yields and optimal benefits. The main issue is adopting economically viable and sustainable methods while ensuring productivity, especially on a large scale (Mendes et al., 2022). Key steps in seaweed farming include site selection, choosing a cultivation method, maintenance, harvesting, and drying, with site selection being the most crucial step, as it must be carefully tailored to specific conditions (Kim et al., 2017).

Seaweed farming uses monoculture and polyculture methods, with the latter increasingly adopting multitrophic sea farming or IMTA, growing popular in Indonesia. Monocultures are easier to manage but often cause environmental degradation. IMTA, though requiring complex management and higher initial investment, offers a more sustainable option by integrating species from different trophic levels. This integration allows waste from one species to benefit another, reducing pollution and stabilizing the ecosystem (Nobre et al., 2010).

IMTA has been shown to improve sustainability and environmental management. Studies have demonstrated its benefits in reducing coastal erosion, optimizing water quality, enhancing growth rates in degraded ponds (Rejeki et al., 2016; Shimoda et al., 2006; Widowati et al., 2019), mitigating ice-ice disease (Nainggolan et al., 2022), and managing organic waste and bacterial populations (Anggorowati & Munandar, 2022). Research further indicates that integrating species such as seaweed with fish or mollusks in IMTA systems increases productivity and environmental stability compared with monoculture (Aliah, 2016; Sukiman et al., 2014).

Challenges in IMTA implementation include species compatibility, infrastructure needs, and insufficient regulatory support. Kunzmann et al. (2023) highlight broader issues like pollutants, emerging diseases, and lack of technology and skilled manpower in Indonesia. Future research should focus on optimizing IMTA designs, assessing economic feasibility, exploring value-added product markets, enhancing technological capabilities, and developing supportive policies to maximize IMTA's potential for sustainable aquaculture in Indonesia.

4.4 The potential of media growth and genetic analysis for future seaweed culture development

Genetic studies have greatly improved seaweed farming by enhancing growth rates and identifying superior cultivars. Researchers have focused on using natural growth enhancers like PGRs and bio-stimulants from seaweed extracts to boost growth, yield, and quality (Hurtado et al., 2024; Windarto et al., 2024). Molecular marker studies have identified superior *Kappaphycus alvarezii* cultivars (Lim et al., 2014; Satriani et al., 2023) and seedlings from thallus extracts have shown higher growth and carrageenan content (Marcelien et al., 2019). Specific nutrient media and spreading techniques have also been highlighted to enhance productivity (Hidayatulbaroroh et al., 2018; Wijayanto et al., 2020). Additionally, genetic and phytochemical research has uncovered potential uses for Gracilaria in functional foods and cosmetics (Arbit et al., 2019; Prasedya et al., 2023), underscoring the role of genetics in optimizing seaweed farming.

Like many other countries, Indonesia has successfully developed tissue culture technology for seaweed cultivation. Future cultivation efforts need to consider the genetic diversity and population structure of seaweeds to obtain information for optimal management and conservation, as well as to identify valuable genetic resources.

4.5 The potential role of seaweed cultivation in carbon sequestration

Several studies have highlighted the role of seaweed farming in addressing climate change (Fakhraini et al., 2019; Sondak et al., 2017b). Fakhraini et al. showcasing the carbon sequestration potential of mature seaweeds. In addition, (Mashoreng et al., 2019) further estimated the carbon sequestration of various species, underscoring their importance in mitigating CO2 emissions.

4.6 The potential socio-economic impacts of seaweed cultivation

Various studies recognize seaweed farming's socioeconomic impact. Research highlights substantial income and economic feasibility for farmers, particularly in Southeast Sulawesi and Sabu Raijua (Asian et al., 2015; Geo & Ariani, 2020; Raja et al., 2021). Langford (2023) and Rimmer et al. (2021) underscore its transformative effect on rural communities, noting potential to lift households above poverty, though sustained benefits require supportive policies. Other studies have suggested that grass cultivation could become a significant source of livelihood for coastal communities in Tawi-Tawi and Sulu in the southern Philippines (Tahiluddin et al., 2023). Darma et al. (2018) and Zamroni et al. (2019) emphasize integrating seaweed cultivation with other livelihoods to enhance resilience. Du et al. (2023) and Andréfouët et al. (2021) highlight considering broader environmental factors, including climate change impacts and coastal socio-ecosystem vulnerability. These studies illustrate seaweed farming's significant socio-economic benefits while indicating the need for activity integration and supportive policies for long-term sustainability.

4.7 Strategic Management, Competitive Advantages, and Biosecurity in Seaweed Aquaculture

Nuryadi et al. (2023) and Oktopura et al. (2020) emphasized strategic management in aquaculture, highlighting shrimp, seaweed, tilapia, and grouper as key commodities boosting national foreign exchange. Nuryadi et al. (2023) stressed the need for strong cooperatives and partnerships to enhance seaweed aquaculture's competitiveness. Both studies emphasize effective management and collaboration for maintaining competitive advantage. Risk management and biosecurity are vital in the seaweed supply chain. Teniwut et al. (2020) identified key risks and suggested farmers' forums as mitigation. Kambey et al. (2020) pointed out gaps in Indonesia's biosecurity framework, recommending policy improvements. Mantri et al. (2023) proposed a global biosecurity framework for Gracilaria aquaculture. Future studies should emphasize robust organizational structures and biosecurity measures to safeguard the seaweed industry.

4.8 The potential of digital technology in seaweed culture

Seaweed cultivation has begun using digital technology, such as the Internet of Things (IoT), to monitor environmental changes and address issues in cultivation areas quickly and accurately. A study by (Bachtiar et al., 2022) demonstrated a success rate of over 90% in monitoring acidity, temperature, and water turbidity using IoT in aquaculture systems. Despite the growing potential of IoT in seaweed cultivation, challenges persist, such as limited internet access in rural areas, data security risks from remote access, and a shortage of IoT experts (Lim et al., 2022). As internet access expands, IoT usage in seaweed farming is expected to grow, making the process more efficient and improving farmers' livelihoods. Future research should focus on advancing IoT technology for seaweed cultivation, while government and private sector support is crucial for developing infrastructure to ensure widespread access.

5. Conclusion

Indonesia holds significant potential for expanding seaweed cultivation, as the largest producer of Kappaphycus, Eucheuma, and Gracilaria, primarily used for carrageenan and agar production. However, underutilized species like Caulerpa, Eucheuma denticulatum, and Sargassum have untapped potential in food, cosmetics, and organic fertilizers. With only a small fraction of the available 12 million hectares currently farmed, there is ample room for growth. Strategic site selection using GIS and infrastructure development can boost production to meet rising global demand.

Systematic literature reviews suggest that innovations such as Integrated Multi-Trophic Aquaculture (IMTA) and digital technologies like IoT can enhance productivity and sustainability. Seaweed farming offers significant socioeconomic benefits, improving income and resilience in coastal communities. To maximize these, future research should focus on optimizing cultivation methods, expanding farming areas, utilizing genetic analysis, and developing supportive policies for long-term industry sustainability. Moreover, seaweed's role in carbon sequestration presents a valuable opportunity for climate change mitigation, requiring robust management, biosecurity, and strategic planning.

Credit authorship contribution statement

All authors contributed equally to this work as main contributors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Adibrata, S., Pamungkas, A., Priyambada, A., Wahidin, L. O., & Hidayat, S. I. (2023). The Environmental Parameters Suitability for Multispecies-Based Mariculture in Pongok Island Waters, Bangka Belitung. *Indonesian Aquaculture Journal*, *18*(2), 133–145. https://doi.org/10.15578/iaj.18.2.2023.133-145

Aliah, R. S. (2016). Keragaan Model Budidaya Perikanan Terintegrasi Multi Tropik Di Pantai Utara Karawang, Jawa Barat. *Jurnal Teknologi Lingkungan*, *13*(1), 47. https://doi.org/10.29122/jtl.v13i1.1404

Andréfouët, S., Dewantama, I. M. I., & Ampou, E. E. (2021). Seaweed farming collapse and fast changing socio-ecosystems exacerbated by tourism and natural hazards in Indonesia: A view from space and from the households of Nusa Lembongan island. *Ocean & Coastal Management*, *207*, 105586. https://doi.org/10.1016/j.ocecoaman.2021.105586

Anggorowati, D. A., & Munandar, H. (2022). Diversity and fluctuation of cultivable Vibrio bacteria populations in an integrated multi-trophic aquaculture (IMTA) system of Holothuria scabra, Chanos chanos and Gracillaria sp. *IOP Conference Series: Earth and Environmental Science*, *967*(1), 12008. https://doi.org/10.1088/1755-1315/967/1/012008

Arbit, N. I. S., Omar, S. B. A., Soekendarsi, E., Yasir, I., Tresnati, J., & Tuwo, A. (2019). Morphological and genetic analysis of Gracilaria sp. cultured in ponds and coastal waters. *IOP Conference Series: Earth and Environmental Science*, *370*. https://doi.org/10.1088/1755-1315/370/1/012018

Aris, M., Labenua, R., & IOP. (2020). Evaluation of land suitability of Kappaphycus alvarezii cultivation in the dry and rainy season. *INTERNATIONAL CONFERENCE ON FISHERIES AND MARINE*, *584*. https://doi.org/10.1088/1755-1315/584/1/012025

Ashikur, M. R., Rupom, R. S., & Sazzad, M. H. (2021). A remote sensing approach to ascertain spatial and temporal variations of seawater quality parameters in the coastal area of Bay of Bengal, Bangladesh. *Remote Sensing Applications: Society and Environment*, *23*, 100593. https://doi.org/10.1016/j.rsase.2021.100593

Asian, L. M., Iba, W., Bolu, L. O. R., Ingram, B. A., Gooley, G. J., de Silva, S. S., Aslan, L. O. M., Iba, W., Bolu, L. O. R., Ingram, B. A., Gooley, G. J., & de Silva, S. S. (2015). Mariculture in SE Sulawesi, Indonesia: Culture practices and the socio economic aspects of the major commodities. *Ocean and Coastal Management*, *116*, 44–57. https://doi.org/10.1016/j.ocecoaman.2015.06.028

Aslan, L. M., La Embi, A., Hasriah, R., Ansa, A., Iba, W., Patadjai, A. B., Rahim, M., & Armin. (2021). Grafting of the seaweed Kappaphycus alvarezii (Rhodophyta, Gigartinales) in SE-Sulawesi, Indonesia. *AQUACULTURE RESEARCH*, *52*(3), 1327–1331. https://doi.org/10.1111/are.14972

Aslin, L. O., Supryiono, E., Nirmala, K., Nurjanah, D., & Soelistyowati, T. (2019). The effects of planting distances and seedling sources on Kappaphycus alvarezii growth. *IOP Conference Series: Earth and Environmental Science*, *278*. https://doi.org/10.1088/1755-1315/278/1/012007

Bachtiar, M. I., Hidayat, R., & Anantama, R. (2022). Internet of Things (IoT) Based Aquaculture Monitoring System. *MATEC Web of Conferences*, *372*, 4009. https://doi.org/10.1051/matecconf/202237204009

Basmal, J. (2009). Prospek pemanfaatan rumput laut sebagai bahan pupuk organik. *Squalen*, *4*(1), 1–8. https://bbp4b.litbang.kkp.go.id/squalen-bulletin/index.php/squalen/article/view/141/110

Bast, F. (2014). An Illustrated Review on Cultivation and Life History of Agronomically Important Seaplants. In V. H. Pomin (Ed.), *Seaweed: Mineral Composition, Nutritional and Antioxidant Benefits and Agricultural Uses* (pp. 39–70). Nova Science Publishers, Inc. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84956713354&partnerID=40&md5=699e5a30d2f32a1fca6119e6f117abe0

BPS. (2021). *Hasil Survei Komoditas Perikanan Potensi Rumput Laut [Survey Results of Potential Seaweed Fishery Commodities]*. Badan Pusat Statistik, Jakarta.

Bramer, W. M., Rethlefsen, M. L., Kleijnen, J., & Franco, O. H. (2017). Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. *Systematic Reviews*, *6*(1), 245. https://doi.org/10.1186/s13643-017-0644-y

Buschmann, A. H., Camus, C., Infante, J., Neori, A., Israel, Á., Hernández-González, M. C., Pereda, S. V, Gomez-Pinchetti, J. L., Golberg, A., Tadmor-Shalev, N., & Critchley, A. T. (2017). Seaweed production: overview of the global state of exploitation, farming and emerging research activity. *European Journal of Phycology*, *52*(4), 391–406. https://doi.org/10.1080/09670262.2017.1365175

Calderon-Monge, E., & Ribeiro-Soriano, D. (2024). The role of digitalization in business and management: A systematic literature review. Review of Managerial Science, 18(2), 449–491. https://doi.org/10.1007/s11846-023-00647-8

Chiu, T. K. F., Xia, Q., Zhou, X., Chai, C. S., & Cheng, M. (2023). Systematic literature review on opportunities, challenges, and future research recommendations of artificial intelligence in education. Computers and Education: Artificial Intelligence, 4, 100118. https://doi.org/10.1016/j.caeai.2022.100118

Chung, I. K., Sondak, C. F. A., & Beardall, J. (2017). The future of seaweed aquaculture in a rapidly changing world. *European Journal of Phycology*, *52*(4), 495–505. https://doi.org/10.1080/09670262.2017.1359678

Darma, R., Fudjaja, L., & Nixia Tenriawaru, A. (2018). Fishery based-processing enterprises integration for the coastal community development. *Journal of Engineering and Applied Sciences*, *13*(3), 588–595. https://doi.org/10.3923/jeasci.2018.588.595

Domínguez-May, R., Gasca-Leyva, E., & Robledo, D. (2017). Harvesting time optimization and risk analysis for the mariculture of Kappaphycus alvarezii (Rhodophyta). *REVIEWS IN AQUACULTURE*, *9*(3), 227–237. https://doi.org/10.1111/raq.12134

Duarte, C. M., Wu, J., Xiao, X., Bruhn, A., & Krause-Jensen, D. (2017). Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation? *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00100

Entee, S. (2015). *Post Harvest Processing Value Chain Literature Review Report*. Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and SNV Netherlands Development Organization. https://www.crc.uri.edu/download/GH2014_ACT022_SNV_FIN508.pdf

Fakhraini, M. S., Wisnu, W., Khathir, R., & Patria, M. P. (2019). Carbon sequestration in macroalgae Kappaphycus striatum in seaweed aquaculture site, Alaang village, Alor Island, East Nusa Tenggara. In R. Nugraha (Ed.), *IOP Conference Series: Earth and Environmental Science* (Vol. 404, Issue 1, p. 012044). https://doi.org/10.1088/1755-1315/404/1/012044

FAO. (2020). *The State of World Fisheries and Aquaculture 2020*. FAO. http://www.fao.org/documents/card/en/c/ca9229en

Gentry, R. R., Froehlich, H. E., Grimm, D., Kareiva, P., Parke, M., Rust, M., Gaines, S. D., & Halpern, B. S. (2017). Mapping the global potential for marine aquaculture. *Nature Ecology & Evolution*, *1*(9), 1317–1324. https://doi.org/10.1038/s41559-017-0257-9

Geo, L. O., & Ariani, W. O. R. (2020). Farming production analysis of seaweed and farmer's perception towards climate change effect in Southeast Sulawesi, Indonesia. *Pakistan Journal of Biological Sciences*, *23*(8), 1004–1009. https://doi.org/10.3923/pjbs.2020.1004.1009

Geo, L. O., Halim, & Ariani, W. O. R. (2020). Farming Production Analysis of Seaweed and Farmer's Perception towards Climate Change Effect in Southeast Sulawesi, Indonesia. *Pakistan Journal of Biological Sciences*, *23*(8), 1004–1009. https://doi.org/10.3923/pjbs.2020.1004.1009

Haddaway, N. R., Woodcock, P., Macura, B., & Collins, A. (2015). Making literature reviews more reliable through application of lessons from systematic reviews. *Conservation Biology*, *29*(6), 1596–1605. https://doi.org/10.1111/cobi.12541

Hafting, J. T., Craigie, J. S., Stengel, D. B., Loureiro, R. R., Buschmann, A. H., Yarish, C., Edwards, M. D., & Critchley, A. T. (2015). Prospects and challenges for industrial production of seaweed bioactives. *Journal of Phycology*, *51*(5), 821–837. https://doi.org/10.1111/jpy.12326

Hajar, M. A. I., Palo, M., Asni, A., Najamuddin, Hajar, M. A. I., Rustam, Palo, M., Asni, A., & IOP. (2020). Development of integrated seaweed culture and capture fisheries in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *564*. https://doi.org/10.1088/1755-1315/564/1/012027

Harwinda, F. K., Satyantini, W. H., Masithah, E. W., & IOP. (2018). The effects of salinity and temperature shock on Kappaphycus alvarezii seaweed spores release. *ASEAN-FEN INTERNATIONAL FISHERIES SYMPOSIUM - 2017*, *137*. https://doi.org/10.1088/1755-1315/137/1/012019

Hasanah, F. A., Nurhudah, M., Mulyono, M., & Dillon, M. (2020). Kaizen implementation in seaweed aquaculture (Gracilaria sp.) in Karawang, West Java: A productivity improvement case study. In K. Tarman (Ed.), *WORLD SEAFOOD CONGRESS 2019 - SEAFOOD SUPPLY CHAINS OF THE FUTURE: INNOVATION, RESPONSIBILITY, SUSTAINABILITY* (Vol. 414). https://doi.org/10.1088/1755-1315/414/1/012007

Hidayatulbaroroh, R., Nurhudah, M., Edy, M. H., Suharyadi, & IOP. (2018). The effect of thallus spreading method on productivity of Gracilaria sp culture. *ASEAN-FEN INTERNATIONAL FISHERIES SYMPOSIUM - 2017*, *137*. https://doi.org/10.1088/1755-1315/137/1/012002

Hurtado, A. Q., Ali, M. K. M., & Critchley, A. T. (2024). A Phyconomic Game-Changer: Extracts of Selected Brown Seaweeds as Phyco(bio)stimulants for Eucheumatoids. In *Tropical Phyconomy Coalition Development* (pp. 289–298). https://doi.org/10.1007/978-3-031-47806-2_23

Hurtado, A. Q., Gerung, G. S., Yasir, S., & Critchley, A. T. (2014). Cultivation of tropical red seaweeds in the BIMP-EAGA region. *JOURNAL OF APPLIED PHYCOLOGY*, *26*(2), 707–718. https://doi.org/10.1007/s10811-013-0116-2

Ihsan, Kasmawati, Asni, A., Ernaningsih, Asbar, Asmidar, Adimu, H. E., & Evans, G. (2020). Aquaculture management of blue swimming crab (Portunus pelagicus) using integrated submerged net cage in Pangkep Regency waters, South Sulawesi, Indonesia. *AACL Bioflux*, *13*(6), 3279–3286. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85099032253&partnerID=40&md5=9c2071a1b7958429769e85c1845f02ee

Indarjani, R., & Nurhayati, S. (2022). MACROZOOBENTHIC COMMUNITY STRUCTURES IN SEAWEED CULTURE PONDS IN MUARA GEMBONG ESTUARY, BEKASI, WEST JAVA PROVINCE, INDONESIA. *Biotropia*, *29*(2), 134–141. https://doi.org/10.11598/btb.2022.29.2.1664

Indonesia's Coordinating Ministry for Maritime Affairs and Investment. (2024). Boosting Seaweed Production, Coordinating Minister Marves: Huge Downstream Potential (Tingkatkan Produksi Rumput Laut, Menko Marves: Potensi Hilirisasi Sangat Besar). *Majalah Marves*, *XXII*(22).

Inisiatif Bisnis Ekonomi Kerakyatan (IBEKA). (2023). *Indonesia's Ocean Potential: Towards the Status of a Great Maritime State*. Potensi Laut Indonesia: Menuju Status Negara Maritim Besar. https://ibeka.or.id/potensi-laut-indonesia-menuju-status-negara-maritim-besar/

Irfan, M., Malan, S., Muchdar, F., Abdullah, N., Juharni, & IOP. (2020). Seaweed Kappaphycus alvarezii cultivation production based on season in Indari waters, West Bacan Subdistrict, Regency of South Halmahera, Province of North Mollucas, Indonesia. *INTERNATIONAL CONFERENCE ON FISHERIES AND MARINE*, *584*. https://doi.org/10.1088/1755-1315/584/1/012043

Jagtap, A. S., & Meena, S. N. (2022). Seaweed farming: A perspective of sustainable agriculture and socio-economic development. In *Natural Resources Conservation and Advances for Sustainability* (pp. 493–501). Elsevier. https://linkinghub.elsevier.com/retrieve/pii/B9780128229767000223

Kambey, C. S. B., Campbell, I., Sondak, C. F. A., Nor, A. R. M., Lim, P. E., & Cottier-Cook, E. J. (2020). An analysis of the current status and future of biosecurity frameworks for the Indonesian seaweed industry. *Journal of Applied Phycology*, *32*(4), 2147–2160. https://doi.org/10.1007/s10811-019-02020-3

Kasim, M., & Mustafa, A. (2017). Comparison growth of Kappaphycus alvarezii (Rhodophyta, Solieriaceae) cultivation in floating cage and longline in Indonesia. *AQUACULTURE REPORTS*, *6*, 49–55. https://doi.org/10.1016/j.aqrep.2017.03.004

Khan, N., Sudhakar, K., & Mamat, R. (2023). Seaweed farming: A perspectives of genetic engineering and nano-technology application. *Heliyon*, *9*(4), e15168. https://doi.org/10.1016/j.heliyon.2023.e15168

Kim, J. K., Yarish, C., Hwang, E. K., Park, M., & Kim, Y. (2017). Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services. *ALGAE*, *32*(1), 1–13. https://doi.org/10.4490/algae.2017.32.3.3

Kittel, T. G. F., Baker, B. B., Higgins, J. V, & Haney, J. C. (2011). Climate vulnerability of ecosystems and landscapes on Alaska's North Slope. *Regional Environmental Change*, *11*(SUPPL. 1), 249–264. https://doi.org/10.1007/s10113-010-0180-y

Komariyah, N. L., Pursetyo, K. T., & Sudjarwo, S. A. (2019). Analysis of Lead (Pb) Value Comparison on Seaweed (Eucheuma cottonii) in Bluto and Saronggi Sumenep Marine, Madura, East Java. *IOP Conference Series: Earth and Environmental Science*, *236*, 012065. https://doi.org/10.1088/1755-1315/236/1/012065

Kunzmann, A., Todinanahary, G., Msuya, F. E., & Alfiansah, Y. (2023). Comparative Environmental Impacts and Development Benefits of Coastal Aquaculture in Three Tropical Countries: Madagascar, Tanzania and Indonesia. *TROPICAL LIFE SCIENCES RESEARCH*, *34*(3), 279–302. https://doi.org/10.21315/tlsr2023.34.3.15

Langford, A., Waldron, S., & Saleh, H. (2021). Monitoring the COVID-19-affected Indonesian seaweed industry using remote sensing data. *Marine Policy*, *127*. https://doi.org/10.1016/j.marpol.2021.104431

Langford, Z. (2023). Globalisation and Livelihood Transformations in the Indonesian Seaweed Industry. In Z. Langford (Ed.), *Earthscan Food and Agriculture*. Routledge.

Laurens, L. M. L., Lane, M., & Nelson, R. S. (2020). Sustainable Seaweed Biotechnology Solutions for Carbon Capture, Composition, and Deconstruction. *Trends in Biotechnology*, *38*(11), 1232–1244. https://doi.org/10.1016/j.tibtech.2020.03.015

Lim, H. R., Khoo, K. S., Chia, W. Y., Chew, K. W., Ho, S.-H., & Show, P. L. (2022). Smart microalgae farming with internet-of-things for sustainable agriculture. *Biotechnology Advances*, *57*, 107931. https://doi.org/10.1016/j.biotechadv.2022.107931

Lim, P. E., Tan, J., Phang, S. M., Nikmatullah, A., Hong, D. D., Sunarpi, H., & Hurtado, A. Q. (2014). Genetic diversity of Kappaphycus Doty and Eucheuma J. Agardh (Solieriaceae, Rhodophyta) in Southeast Asia. *Journal of Applied Phycology*, *26*(2), 1253–1272. https://doi.org/10.1007/s10811-013-0197-y

Litaay, C., Arfah, H., & Pattipeilohy, F. (2022). Potensi Sumber Daya Hayati Rumput Laut di Pantai Pulau Ambon sebagai Bahan Makanan: The Potential of Seaweed Resources on the Coastal of Ambon Island as Food Ingredient. *Jurnal Pengolahan Hasil Perikanan Indonesia*, *25*(3), 405–417. https://doi.org/10.17844/jphpi.v25i3.41647

Lumbessy, S. Y. (2019). Sem-sterile Culture of Gracilaria salicornia Seaweed (Parental) on Various Media. In E. S. Prasedya & N. W. R. Martyasari (Eds.), *PROCEEDINGS OF THE 2ND INTERNATIONAL CONFERENCE ON BIOSCIENCE, BIOTECHNOLOGY, AND BIOMETRICS 2019* (Vol. 2199). https://doi.org/10.1063/1.5141331

Mantri, V. A., Kambey, C. S. B., Cottier-Cook, E. J., Usandizaga, S., Buschmann, A. H., Chung, I. K., Liu, T., Sondak, C. F. A., Qi, Z. Z., Lim, P. E., Nguyen, N. V, & Van Nguyen, N. (2023). Overview of global Gracilaria production, the role of biosecurity policies and regulations in the sustainable development of this industry. *Reviews in Aquaculture*, *15*(2), 801–819. https://doi.org/10.1111/raq.12761

Marcelien, D. R. O., Felix, R., & Sunadji. (2019). The utilization of thalus cutting results to growth and carrageenan content (kappaphycus alvarezii) in Hansisi Water, Semau District, Kupang Regency. *IOP Conference Series: Earth and Environmental Science*, *348*(1), 012086. https://doi.org/10.1088/1755-1315/348/1/012086

Mashoreng, S., La Nafie, Y. A., & Isyrini, R. (2019). Cultivated seaweed carbon sequestration capacity. *IOP Conference Series: Earth and Environmental Science*, *370*. https://doi.org/10.1088/1755-1315/370/1/012017

McHugh, D. J. (2003). A guide to the seaweed industry. In *FAO Fisheries Technical Paper*. FAO. https://www.fao.org/4/y4765e/y4765e00.htm

Mendes, M., Fortunato, D., Cotas, J., Pacheco, D., Morais, T., & Pereira, L. (2022). Agar content of estuarine seaweed Gracilaria using different cultivation methods. *Applied Food Research*, *2*(2), 100209. https://doi.org/10.1016/j.afres.2022.100209

Ministry of Marine and Fisheries of The Republic of Indonesia. (2005). *Indonesia's Seaweed Profile (Profil Rumput Laut Indonesia)*. Direktorat Perikanan Budidaya, Departemen Kelautan dan Perikanan. Jakarta.

Ministry of Marine and Fisheries of The Republic of Indonesia. (2021). *Indonesia National Action Plan for Increasing Seaweed Production and Value Added 2020–2024 (Rencana Aksi Nasional Peningkatan Produksi dan Nilai Tambah Rumput Laut 2020–2024)*. Kementerian Kelautan dan Perikanan Indonesia.

Mohiuddin, M., Banik, U., Iqbal, M. Z., Chamily, F. A., Rahman, M. M., Nahiduzzaman, M., Wahab, M. A., Rahman, M. A., & Asaduzzaman, M. (2023). Influence of cultivation systems and associated environmental factors on the growth performance of Hypnea musciformis seaweed at the south-east coast of the Bay of Bengal, Bangladesh. *Aquaculture Reports*, *32*, 101718. https://doi.org/10.1016/j.aqrep.2023.101718

Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics*, *106*(1), 213–228. https://doi.org/10.1007/s11192-015-1765-5

Mualam, A., Widigdo, B., & Zairion. (2022). ANALYSIS OF SEAWEED (Kappaphycus alvarezii) FARMING AREA BASED SUITABILITY AND CARRYING CAPACITY INDICATOR IN THE COASTAL OF BAUBAU CITY. *JURNAL ILMU DAN TEKNOLOGI KELAUTAN TROPIS*, *14*(1), 81–94. https://doi.org/10.29244/jitkt.v14i1.37659

Mulyani, S., Tuwo, A., Syamsuddin, R., Jompa, J., & Cahyono, I. (2020). Effect of kappaphycus alvarezii mariculture on the recruitment of scleractinian corals. *AACL Bioflux*, *13*(3), 1746–1757. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85089015533&partnerID=40&md5=eaf0a8e7af3706eafb0052d13800fecc

Nainggolan, P. F., Arthana, I. W., & Dewi, A. P. W. K. (2022). A Comparison of Eucheuma cottonii Seaweed Cultivation in Monoculture and Polyculture Systems. *Advances in Tropical Biodiversity and Environmental Sciences*, *6*(1), 17. https://doi.org/10.24843/ATBES.2022.v06.i01.p04

Neish, I. C. (2013). Social and economic dimensions of carrageenan seaweed farming in Indonesia. In *Social and economic dimensions of carrageenan seaweed farming*. FAO SV - 580. https://www.fao.org/4/i3344e/i3344e.pdf

Nobre, A. M., Robertson-Andersson, D., Neori, A., & Sankar, K. (2010). Ecological–economic assessment of aquaculture options: Comparison between abalone monoculture and integrated multi-trophic aquaculture of abalone and seaweeds. *Aquaculture*, *306*(1–4), 116–126. https://doi.org/10.1016/j.aquaculture.2010.06.002

Nurdin, N., Alevizos, E., Syamsuddin, R., Asis, H., Zainuddin, E. N., Aris, A., Oiry, S., Brunier, G., Komatsu, T., & Barillé, L. (2023). Precision Aquaculture Drone Mapping of the Spatial Distribution of Kappaphycus alvarezii Biomass and Carrageenan. *Remote Sensing*, *15*(14). https://doi.org/10.3390/rs15143674

Nurjanah, Ambariyanto, Supriharyono, & Yulianto, B. (2018). The Environmentally Sound Aquaculture Strategies Based on Bioaccumulation of Heavy Metal of Lead (Pb) on Seaweed of Gracilaria verrucosa on Aquaculture Areas of Muarareja Village, Tegal City. In M. A. Riyadi, T. I. Winarni, D. P. Wijayanti, M. Tsuchiya, H. Susanto, Jamari, H. Gasem, Ambariyanto, M. Zainuri, S. M. H. Faraz, G. Pals, R. Hagerman, F. Tassone, H. Sudoyo, O. K. Rajasa, C. Starger, C. N. Ravishankar, A. Sabdono, M. Barbosa, … M. Hidaka (Eds.), *3RD INTERNATIONAL CONFERENCE ON TROPICAL AND COASTAL REGION ECO DEVELOPMENT 2017* (Vol. 116). https://doi.org/10.1088/1755-1315/116/1/012042

Nurjanah, Nurilmala, M., Hidayat, T., & Sudirdjo, F. (2016). Characteristics of Seaweed as Raw Materials for Cosmetics. *Aquatic Procedia*, *7*, 177–180. https://doi.org/10.1016/j.aqpro.2016.07.024

Nursidi, Mauli, & Heriansah. (2017). Development of seaweed Kappaphycus alvarezii cultivation through vertical method in the water of small islands in South Sulawesi, Indonesia. *AACL Bioflux*, *10*(6), 1428–1435. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85037345527&partnerID=40&md5=ca4c679e15227868e6e5bd6cde08f51e

Nuryadi, A. M., Rosmalah, S., Muthalib, Z. A., Zarliani, W. O. A., Rizka, S., Zulkarnain, M. I., & Rijanto, D. A. (2023). A management design for cooperative-based seaweed cultivation business in Southeast Sulawesi Province, Indonesia. *AACL Bioflux*, *16*(4), 1878–1886. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85167396045&partnerID=40&md5=d83a1dbccc66182c824a7bf7c306be2e

Oktopura, A. A. D., Fauzi, A., Sugama, K., & Mulyati, H. (2020). Determination of aquaculture priority commodities based on market competitiveness using multiple tool analysis. *AACL Bioflux*, *13*(1), 439–449. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85133830399&partnerID=40&md5=35fb356b433c7b6ed796eeffcbb6fe46

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, n71. https://doi.org/10.1136/bmj.n71

Pahlevan-Sharif, S., Mura, P., & Wijesinghe, S. N. R. (2019). A systematic review of systematic reviews in tourism. Journal of Hospitality and Tourism Management, 39, 158–165. https://doi.org/10.1016/j.jhtm.2019.04.001

Parenrengi, A., Dworjanyn, S., Syah, R., Pong-Masak, P. R., & Fahrur, M. (2020). Strain Selection for Growth Enhancement of Wild and Cultivated Eucheumatoid Seaweed Species in Indonesia. *SAINS MALAYSIANA*, *49*(10), 2453–2464. https://doi.org/10.17576/jsm-2020-4910-11

Pari, R. F., Wijayanta, A. T., Ramadhan, W., Hardiningtyas, S. D., Kurnia, K. A., Firmansyah, M. L., Hana, A., Abrar, M. N., Wakabayashi, R., Kamiya, N., & Goto, M. (2024). Prospecting Ulva lactuca seaweed in Java Island, Indonesia, as a candidate resource for industrial applications. *Fisheries Science*. https://doi.org/10.1007/s12562-024-01799-6

Perryman, S. E., Lapong, I., Mustafa, A., Sabang, R., & Rimmer, M. A. (2017). Potential of metal contamination to affect the food safety of seaweed (Caulerpa spp.) cultured in coastal ponds in Sulawesi, Indonesia. *AQUACULTURE REPORTS*, *5*, 27–33. https://doi.org/10.1016/j.aqrep.2016.12.002

Pessarrodona, A., Howard, J., Pidgeon, E., Wernberg, T., & Filbee-Dexter, K. (2024). Carbon removal and climate change mitigation by seaweed farming: A state of knowledge review. *Science of The Total Environment*, *918*, 170525. https://doi.org/10.1016/j.scitotenv.2024.170525

Prasad Behera, D., Vadodariya, V., Veeragurunathan, V., Sigamani, S., Moovendhan, M., Srinivasan, R., Kolandhasamy, P., & Ingle, K. N. (2022). Seaweeds cultivation methods and their role in climate mitigation and environmental cleanup. *Total Environment Research Themes*, *3–4*, 100016. https://doi.org/10.1016/j.totert.2022.100016

Prasedya, E. S., Fitriani, F., Saraswati, P. B. A., Haqiqi, N., Qoriasmadillah, W., Hikmaturrohmi, H., Nurhidayati, S. Z., & Ariati, P. E. P. (2023). Evaluation of bioprospecting potential of epiphytic Gracilaria edulis harvested from seaweed farm in Seriwe Bay, Lombok, Indonesia. *Biodiversitas*, *24*(10), 5343–5351. https://doi.org/10.13057/biodiv/d241016

Rahman, M. M., Haque, S. M., Galib, S. M., Islam, M. A., Parvez, M. T., Hoque, M. N., Wahab, M. A., Egna, H., & Brown, C. (2020). Mud crab fishery in climate vulnerable coastal Bangladesh: an analysis towards sustainable development. *Aquaculture International*, *28*(3), 1243–1268. https://doi.org/10.1007/s10499-020-00523-2

Rahman, S. A., Mutalib, Y., Sangkia, F. D., Athirah, A., Marlan, Kadir, M., Pattirane, C. P., & IOP. (2020). Evaluation of inhibitory potential of mangrove leaves extract Avicennia marina for bacteria causing ice-ice diseases in seaweed Kappaphycus alvarezii. *3RD INTERNATIONAL SYMPOSIUM MARINE AND FISHERIES (ISMF) 2020*, *564*. https://doi.org/10.1088/1755-1315/564/1/012056

Raja, M. A., Primyastanto, M., & Musa, M. (2021). Biophysical and economic feasibility status of the seaweed cultivation in Sabu Raijua Regency, East Nusa Tenggara, Indonesia. *AACL Bioflux*, *14*(4), 2471–2477. http://www.bioflux.com.ro/docs/2021.2471-2477.pdf

Rejeki, S., Ariyati, R. W., Widowati, L. L., & Bosma, R. H. (2018). The effect of three cultivation methods and two seedling types on growth, agar content and gel strength of Gracilaria verrucosa. *Egyptian Journal of Aquatic Research*, *44*(1), 65–70. https://doi.org/10.1016/j.ejar.2018.01.001

Rejeki, S., Wisnu Ariyati, R., Lakhsmi Widowati, L., Ariyati, R. W., & Widowati, L. L. (2016). Application of integrated multi tropic aquaculture concept in an abraded brackish water pond. *Jurnal Teknologi*, *78*(4–2), 227–232. https://doi.org/10.11113/jt.v78.8213

Rimmer, M. A., Larson, S., Lapong, I., Purnomo, A. H., Pong-masak, P. R., Swanepoel, L., Paul, N. A., Pong-Masak, P. R., Swanepoel, L., & Paul, N. A. (2021). Seaweed aquaculture in indonesia contributes to social and economic aspects of livelihoods and community wellbeing. *Sustainability (Switzerland)*, *13*(19). https://doi.org/10.3390/su131910946

Rintaka, W. E., & Berlianty, D. (2023). Analysis of suitable site for seaweed aquaculture development in the Indonesian Sea (a case study of Fisheries Management Region-713), with the application of numerical model data. *IOP Conference Series: Earth and Environmental Science*, *1251*(1), 012031. https://doi.org/10.1088/1755-1315/1251/1/012031

Sanchez-Jerez, P., Karakassis, I., Massa, F., Fezzardi, D., Aguilar-Manjarrez, J., Soto, D., Chapela, R., Avila, P., Macias, J., Tomassetti, P., Marino, G., Borg, J., Franičević, V., Yucel-Gier, G., Fleming, I., Xb, X., Nhhala, H., Hamza, H., Forcada, A., & Dempster, T. (2016). Aquaculture's struggle for space: the need for coastal spatial planning and the potential benefits of Allocated Zones for Aquaculture (AZAs) to avoid conflict and promote sustainability. *Aquaculture Environment Interactions*, *8*, 41–54. https://doi.org/10.3354/aei00161

Satriani, G. I., Soelistyowati, D. T., Alimuddin, A., Arfah, H., & Effendi, I. (2023). Molecular Assessment of Kappaphycus alvarezii Cultivated in Tarakan based on cox2-3 Spacer. *Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology*, *18*(1), 52–64. https://doi.org/10.15578/squalen.736

Shimoda, T., Suryati, E., & Ahmad, T. (2006). Evaluation in a shrimp aquaculture system using mangroves, oysters, and seaweed as biofilters based on the concentrations of nutrients and chlorophyll a. *JARQ-JAPAN AGRICULTURAL RESEARCH QUARTERLY*, *40*(2), 189–193. https://doi.org/10.6090/jarq.40.189

Smit, A. J. (2004). Medicinal and pharmaceutical uses of seaweed natural products: A review. *Journal of Applied Phycology*, *16*(4), 245–262. https://doi.org/10.1023/B:JAPH.0000047783.36600.ef

Soejarwo, P. A., Fitriyanny, W. P., Heriati, A., & Hakim, A. R. (2018). Selection of sustainable seaweed and grouper aquaculture development strategy: a case of Pulau Panjang, Serang Regency Banten Province. In A. Isnansetyo, I. D. Puspita, N. M. Adzahan, Suadi, D. W. K. Sari, & A. D. Jayanti (Eds.), *2ND INTERNATIONAL SYMPOSIUM ON MARINE AND FISHERIES RESEARCH* (Vol. 139). https://doi.org/10.1088/1755-1315/139/1/012039

Sondak, C. F. A., Ang, P. O., Beardall, J., Bellgrove, A., Boo, S. M., Gerung, G. S., Hepburn, C. D., Hong, D. D., Hu, Z., Kawai, H., Largo, D., Lee, J. A., Lim, P.-E., Mayakun, J., Nelson, W. A., Oak, J. H., Phang, S.-M., Sahoo, D., Peerapornpis, Y., … Chung, I. K. (2017a). Carbon dioxide mitigation potential of seaweed aquaculture beds (SABs). *Journal of Applied Phycology*, *29*(5), 2363–2373. https://doi.org/10.1007/s10811-016-1022-1

Sondak, C. F. A., Ang, P. O., Beardall, J., Bellgrove, A., Boo, S. M., Gerung, G. S., Hepburn, C. D., Hong, D. D., Hu, Z., Kawai, H., Largo, D., Lee, J. A., Lim, P.-E., Mayakun, J., Nelson, W. A., Oak, J. H., Phang, S.-M., Sahoo, D., Peerapornpis, Y., … Chung, I. K. (2017b). Erratum to: Carbon dioxide mitigation potential of seaweed aquaculture beds (SABs) (Journal of Applied Phycology, (2017), 29, 5, (2363–2373), 10.1007/s10811-016-1022-1). *Journal of Applied Phycology*, *29*(5), 2375–2376. https://doi.org/10.1007/s10811-017-1147-x

Sujatmiko, W., Karnaningroem, N., Santoso, I. B., & Aliah, R. S. (2024). Current status of environmental water quality of Kappaphycus alvarezii seaweed cultivation in the Seribu Islands, Indonesia and the concept of sustainable development by using a System Dynamic Model approach. *IOP Conference Series: Earth and Environmental Science*, *1307*(1), 12027. https://doi.org/10.1088/1755-1315/1307/1/012027

Sukiman, Faturrahman, Rohyani, I. S., & Ahyadi, H. (2014). Short Communication: Growth of seaweed Eucheuma cottonii in multi trophic sea farming systems at Gerupuk Bay, Central Lombok, Indonesia. *NUSANTARA BIOSCIENCE*, *6*(1), 82–85. https://doi.org/10.13057/nusbiosci/n060113

Sulistiawati, D., Ya'la, Z. R., Jumiyatun, & Mubaraq, dan Z. (2020). Water quality study in several seaweeds culture sites in the post-earthquake-tsunami Palu Central, Sulawesi Province. *Journal of Physics: Conference Series*, *1434*, 012035. https://doi.org/10.1088/1742-6596/1434/1/012035

Sutton, P., Chartres, N., Rayasam, S. D. G., Daniels, N., Lam, J., Maghrbi, E., & Woodruff, T. J. (2021). Reviews in environmental health: How systematic are they? *Environment International*, *152*, 106473. https://doi.org/10.1016/j.envint.2021.106473

Syam, A. R., Wijaya, D., Purnamaningtyas, S. E., Mujiyanto, Syam, A. R., Wijaya, D., Purnamaningtyas, S. E., & IOP. (2020). Suitability water quality parameters for seaweed culture at Muara Gembong coastal area, Bekasi District. *ECOLOGICAL INTENSIFICATION: A NEW PARAGON FOR SUSTAINABLE AQUACULTURE*, *521*. https://doi.org/10.1088/1755-1315/521/1/012012

Syamsuddin, M. L., Faiz, H. U., Ismail, M. R., Harahap, S. A., Yuniarti, M. S., Ihsan, Y. N., Syamsudin, F., Sari, Q. W., & Aura, C. M. (2023). Aquaculture feasibility and suitability of the coastal areas of Karampuang Island, West Sulawesi, Indonesia. *AACL Bioflux*, *16*(4), 2048–2059. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85166901630&partnerID=40&md5=6d65f14efd4b777fb2d9e3b65046b82e

Syamsuddin, R., & Azis, H. Y. (2019). Comparative study on the growth, carotenoid, fibre and mineral content of the seaweed Caulerpa lentillifera cultivated indoors and in the sea. *IOP Conference Series: Earth and Environmental Science*, *370*. https://doi.org/10.1088/1755-1315/370/1/012019

Tahiluddin, A., Imbuk, E. S., Sarri, J. H., Mohammad, H. S., Ensano, F. N. T., Maddan, M. M., & Cabilin, B. S. (2023). *Eucheumatoid Seaweed Farming in the Southern Philippines*. https://doi.org/10.2139/ssrn.4386143

Teniwut, W. A., Betaubun, K. D., Marimin, M., & Djatna, T. (2020). Asymmetric Information Mitigation on Seaweed Supply Chain Using House of Risk and Fuzzy AHP Approach. *AGRITECH*, *40*(3), 242–253. https://doi.org/10.22146/agritech.27770

Thomas, J.-B. E., Ramos, F. S., & Gröndahl, F. (2019). Identifying Suitable Sites for Macroalgae Cultivation on the Swedish West Coast. *Coastal Management*, *47*(1), 88–106. https://doi.org/10.1080/08920753.2019.1540906

Tokan, M. K. (2016). The behavior in effort of healthy farming of seaweed farmers in Kupang district. *Ecology, Environment and Conservation*, *22*(4), 1587–1600.

Tuhumury, N. C., Sahetapy, J. M. F., & Matakupan, J. (2024). Isolation and identification of bacterial pathogens causing ice-ice disease in Eucheuma cottonii seaweed at Seira Island Waters, Tanimbar Islands District, Maluku, Indonesia. *Biodiversitas*, *25*(3), 964–970. https://doi.org/10.13057/biodiv/d250308

Ulfiasari, S., Ratri, S. D., & IOP. (2020). LiDAR application of intertidal coastal zoning for aquaculture in Wolo Village, Kolaka, Southeast Sulawesi. *FIFTH INTERNATIONAL CONFERENCES OF INDONESIAN SOCIETY FOR REMOTE SENSING: THE REVOLUTION OF EARTH OBSERVATION FOR A BETTER HUMAN LIFE*, *500*. https://doi.org/10.1088/1755-1315/500/1/012030

UNIC. (2024, August 1). *Increase Seaweed Production, Menko Marves: Huge Potential for Downstreaming*. https://indonesia.un.org/en/262001-increase-seaweed-production-menko-marves-huge-potential-downstreaming

Valderrama, D., Cai, J. N., Hishamunda, N., Ridler, N., Neish, I. C., Hurtado, A. Q., Msuya, F. E., Krishnan, M., Narayanakumar, R., Kronen, M., Robledo, D., Gasca-Leyva, E., & Fraga, J. (2015). The Economics of Kappaphycus Seaweed Cultivation in Developing Countries: A Comparative Analysis of Farming Systems. *Aquaculture Economics and Management*, *19*(2), 251–277. https://doi.org/10.1080/13657305.2015.1024348

Wahyuningtyas, A. F., Prayogo, Abdillah, A. A., Amin, M. N. G., Alamsjah, M. A., & IOP. (2020). The Effectivity of Plantation Depth on Seaweed Sargassum sp. Growth Using Longline Method. *8TH INTERNATIONAL FISHERIES SYMPOSIUM 2018*, *416*. https://doi.org/10.1088/1755-1315/416/1/012021

Wei, Z., You, J., Wu, H., Yang, F., Long, L., Liu, Q., Huo, Y., & He, P. (2017). Bioremediation using Gracilaria lemaneiformis to manage the nitrogen and phosphorous balance in an integrated multi-trophic aquaculture system in Yantian Bay, China. *Marine Pollution Bulletin*, *121*(1–2), 313–319. https://doi.org/10.1016/j.marpolbul.2017.04.034

Wenno, M. R., Wattimena, M. L., Rumakey, Z. A., & Thenu, J. L. (2015). Physic and Chemical Characteristics of Nata De Seaweed from Eucheuma cottonii And Gracilaria Sp. In R. H. Setyobudi, J. Burlakovs, M. Mel, P. G. Adinurani, & Z. VincevicaGaile (Eds.), *INTERNATIONAL SYMPOSIUM ON AQUATIC PRODUCT PROCESSING (ISAPPROSH) 2013* (Vol. 1, pp. 6–11). https://doi.org/10.18502/kls.v1i0.77

Wibowo, I. S., Mashar, A., Pratiwi, N. T. M., & Kurniawan, F. (2023). Marine Suitability Assessment for Mariculture: Combining GIS and AHP Technique in Dampier Strait Conservation Area, West Papua Province, Indonesia. *Jurnal Ilmiah Perikanan Dan Kelautan*, *15*(2), 316–330. https://doi.org/10.20473/jipk.v15i2.40172

Widowati, L. L., Ariyati, R. W., & Rejeki, S. (2019). Ecological and economical analysis for implementing integrated multi trophic aquaculture (IMTA) in an abraded area to recover aquaculture production in kaliwlingi, brebes, Indonesia. *Geo-Eco-Marina*, *2019*(25), 161–170. https://doi.org/10.5281/zenodo.3609841

Widowati, L. L., Prayitno, S. B., Rejeki, S., Elfitasari, T., Purnomo, P. W., Ariyati, R. W., Bosma, R. H., Budi Prayitno, S., Rejeki, S., Elfitasari, T., Purnomo, P. W., Ariyati, R. W., Bosma, R. H., & Aubin, J. (2021). Organic matter reduction using four densities of seaweed (Gracilaria verucosa) and green mussel (Perna viridis) to improve water quality for aquaculture in Java, Indonesia. *Aquatic Living Resources*, *34*. https://doi.org/10.1051/alr/2021002

Wijayanto, A., Widowati, I., & Winanto, T. (2020). Domestication of red seaweed (Gelidium latifolium) in different culture media. *Ilmu Kelautan: Indonesian Journal of Marine Sciences*, *25*(1), 39–44. https://doi.org/10.14710/ik.ijms.25.1.39-44

Windarto, S., Susilowati, T., Haditomo, A. H. C., & Harwanto, D. (2024). Effect of exogenous natural plant growth regulators (PGRs) on the morphology, growth, and nutrient of sea grapes (Caulerpa racemosa). *AQUACULTURE INTERNATIONAL*, *32*(3), 3545–3562. https://doi.org/10.1007/s10499-023-01337-8

Wirawan, I. G. P., Dewi, N. K. E. S., Sasadara, M. M. V., Sunyamurthi, I. G. N. A., Jawi, I. M., Wijaya, I. N., Darmawati, I. A. P., Suada, I. K., & Krisnandika, A. A. K. (2022). Phytochemical Analysis and Molecular Identification of Green Macroalgae Caulerpa spp. from Bali, Indonesia. *Molecules*, *27*(15), 4879. https://doi.org/10.3390/molecules27154879

Yahya, N., Poong, S.-W., Brodie, J., Cottier-Cook, E. J., Wilbraham, J., Mallinson, S., Kassim, A., Mansor, K. N. A. A. K., & Lim, P.-E. (2024). Comparison of two cultivation methods for domesticating wild red algal eucheumatoids for use in the seaweed industry. *Journal of Applied Phycology*. https://doi.org/10.1007/s10811-024-03325-8

Yasir, I., Tresnati, J., Aprianto, R., & Tuwo, A. (2021). Metal content of gracilaria changii originating from different seaweed cultivation areas in south sulawesi, indonesia. *AACL Bioflux*, *14*(4), 1888–1896. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85113736179&partnerID=40&md5=29d7e065fcc5492fa1aeb2c619a68874

Yulianto, H., Damai, A. A., Delis, P. C., & Elisdiana, Y. (2017). Spatial analysis to evaluate the suitability of seaweed farming site in Lampung Bay, Indonesia. *TURKISH JOURNAL OF FISHERIES AND AQUATIC SCIENCES*, *17*(6), 1253–1261. https://doi.org/10.4194/1303-2712-v17_6_18

Zamroni, A., Apriliani, T., Yusuf, R., & Kurniasari, N. (2019). Enhanching small-scale community for coastal management in Puntondo Bay, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *370*. https://doi.org/10.1088/1755-1315/370/1/012072

Zhu, X., Healy, L., Zhang, Z., Maguire, J., Sun, D., & Tiwari, B. K. (2021). Novel postharvest processing strategies for value-added applications of marine algae. *Journal of the Science of Food and Agriculture*, *101*(11), 4444–4455. https://doi.org/10.1002/jsfa.11166