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Research article

Conserving seaweeds: knowledge, attitudes, and practices from industry and conservation stakeholders in South Sulawesi, Indonesia

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ABSTRACT

Seaweed cultivation is estimated to sustain over 6 million livelihoods worldwide, particularly in low-income tropical regions, such as Indonesia. The wild stocks that underpin this industry, however, are increasingly threatened by anthropogenic pressures (e.g. climate change and overexploitation) that undermine its productivity and resilience. Although seaweed cultivation has been proposed as a nature-based solution to conserve biodiversity and support livelihoods, its long-term viability depends on the sustainable use and management of seaweed habitats by stakeholders. This study conducted a knowledge, attitudes, and practices (KAP) survey of seaweed industry and conservation stakeholders in South Sulawesi, Indonesia (n = 99 of which 87 respondents were based in South Sulawesi), to assess perspectives on seaweed conservation. Despite knowledge and supportive attitudes towards seaweed conservation being high, these were not consistently matched by sustained action. Key barriers to sustainable practices included a lack of understanding of the threats to wild seaweeds, livelihood instability that constrained conservation-aligned behaviour, and practical limitations (notably insufficient resources and technical support). To address these challenges, this study recommends risk-reducing mechanisms to support practice adoption (e.g., peer-to-peer learning, strengthened extension support, and risk-buffering finance), alongside co-designed seaweed monitoring programs, and targeted ocean literacy initiatives. Collectively, these measures could help translate stakeholder support into tangible seaweed conservation action, supporting a more sustainable seaweed sector that safeguards seaweed habitats and secures coastal livelihoods.

1. Introduction

Seaweeds form the world's second largest aquaculture industry by weight after finfish, with rapid economic growth over the last two decades largely driven by demand across food, agricultural, and industrial markets (FAO, 2024). Seaweed farming is practiced in over 50 countries worldwide and supports the livelihoods of more than six-million people, particularly in low-income tropical regions, such as Indonesia (Corrigan et al., 2025; Cottier-Cook et al., 2021).

Indonesia is the world's second-largest producer of seaweed after China, contributing primarily to the global carrageenan and agar markets through the cultivation of tropical red seaweed species (notably *Kappaphycus* spp. and *Eucheuma* spp.) (Rimmer et al., 2021). Indonesia's coastal accessibility, low cultivation costs, and low labour requirements make seaweed farming an attractive and reliable income option for many small-scale producers, especially in economically marginalised regions, such as South Sulawesi, Indonesia's largest seaweed production hub (FAO, 2013; Rimmer et al., 2021). Beyond income, the Indonesian seaweed industry also fosters significant human and social capital by supporting female empowerment and enhancing household resilience and well-being (FAO, 2013).

Nevertheless, the sustainability of Indonesia's seaweed industry is

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interwoven with the health of its marine ecosystems and its diverse seaweed habitats (Cottier-Cook et al., 2023). Indonesia is home to more than 300 species of red, green, and brown seaweeds (Basyuni et al., 2024) and these wild stocks provide the genetic diversity and seed material necessary to sustain the long-term development of the industry. However, these wild stocks, like many worldwide, are increasingly impacted by a growing suite of stressors including climate change, pollution, biodiversity loss, habitat degradation, overharvesting, pests and diseases, monoculture expansion, and poor farming practices (Corrigan et al., 2025). Loss of seaweed habitats also negatively affects the recruitment, growth, and survival of associated marine fauna and wider marine functioning (Corrigan et al., 2025; Mineur et al., 2015). Protecting and conserving seaweed habitats is, therefore, essential to maintain ecosystem productivity and the long-term viability of the seaweed industry (Cotas et al., 2023).

Unregulated seaweed farming may potentially damage natural seaweed populations, through introduction of invasive species, increased competition, over-collection or physical damage to seaweed habitats and the use of unsustainable farming practices, intensifying the risk of wider biodiversity loss (Monagail et al., 2017). For instance, selective breeding of seaweeds for higher yields (Cohen et al., 2025) or stress resistance (Lu and Liu, 2024) is becoming more common, however, this may lead to reduced genetic diversity in wild populations. Effective and enforced regulatory frameworks and industry standards are, therefore, critical to prevent negative environmental impacts and ensure seaweed aquaculture is managed sustainably to support many of the Sustainable Development Goals (Spillias et al., 2022). Furthermore, monitoring and detection frameworks that assess the health and distribution of natural seaweed populations are currently limited, raising concerns that declines or shifts in distribution of seaweeds may be going unnoticed (Campbell et al., 2019). Targeted management and monitoring strategies are, therefore, critical to protect seaweed habitats and the marine biodiversity they support from threats, including poor farming practices (Rebours et al., 2014).

Conversely, sustainably managed and appropriately regulated seaweed aquaculture could act as a potential nature-based, climate-resilient solution to help mitigate many global challenges, including climate change, food insecurity, and ecosystem degradation (Corrigan et al., 2025). Sustainable seaweed cultivation depends on all stakeholders operating in an ecologically responsible manner, whether they are directly involved in seaweed aquaculture, or indirectly involved through their influence on coastal ecosystems. However, conflicts can emerge between stakeholders over the use of marine spaces, such as between farmers and tourism operators (e.g. divers or marine ecotourism providers) (Cottier-Cook et al., 2021). These competing stakeholder interests highlight the need for a shared understanding of marine spaces to reach equitable and practical compromises on the best use of seaweed resources (Bjørkan and Billing, 2022).

Environmental awareness strongly influences individual and group-level behaviours, and a close relationship exists between knowledge, attitude, and practices (KAP) (Liobikienė and Poškus, 2019; Malekzadeh et al., 2022). Insights from KAP surveys can guide targeted educational campaigns, context-specific governance, and more effective seaweed conservation strategies going forwards (Kambey et al., 2025, manuscript under review). Few KAP surveys have been conducted on seaweeds so far, except for a few surveys conducted on seaweed cultivation, conservation, and biosecurity in countries such as Malaysia and the Philippines (Kambey et al., 2021; Mateo et al., 2021). There remains, however, a limited understanding of how stakeholder knowledge, attitudes, and practices shape the conservation of seaweeds, particularly in ecologically and economically sensitive regions like Indonesia.

This study, therefore, aims to assess the KAP of stakeholders engaged in, or whose activities influence, Indonesia's seaweed sector and its wider marine ecosystems, using South Sulawesi as a case study. Here, “seaweed conservation” is used in a broad sense to encompass the maintenance, enhancement, and restoration of biodiveristy, including conserving wild seaweed habitats and associated biodiversity, mitigating pressures linked to cultivation, and supporting efforts that strengthen the long-term sustainability of the sector. Emphasis is placed on understanding the awareness of stakeholders towards the threats facing seaweeds, and the perceived barriers stakeholders face to effective seaweed conservation and protection. By assessing how different stakeholders engage with and contribute to seaweed conservation through a KAP framework, we hope to identify knowledge gaps, conflicting priorities, and practical barriers to conservation.

2. Material and methods

2.1. Data collection

A KAP survey adapted from Kambey et al. (2021) and Mateo et al. (2021) was conducted between November 2024 and February 2025. A total of 99 stakeholders participated, with 87 surveys completed in-person in South Sulawesi and 12 completed online due to geographic constraints (Fig. 1). Purposive sampling was used to invite only those stakeholders with relevant experience or expertise for in-depth insights (Etikan et al., 2015). Local government officials dealing with marine and fishery-related activities helped to identify experienced farmers, whilst expert referrals and online verification (e.g., company websites) were used to identify all other participants.

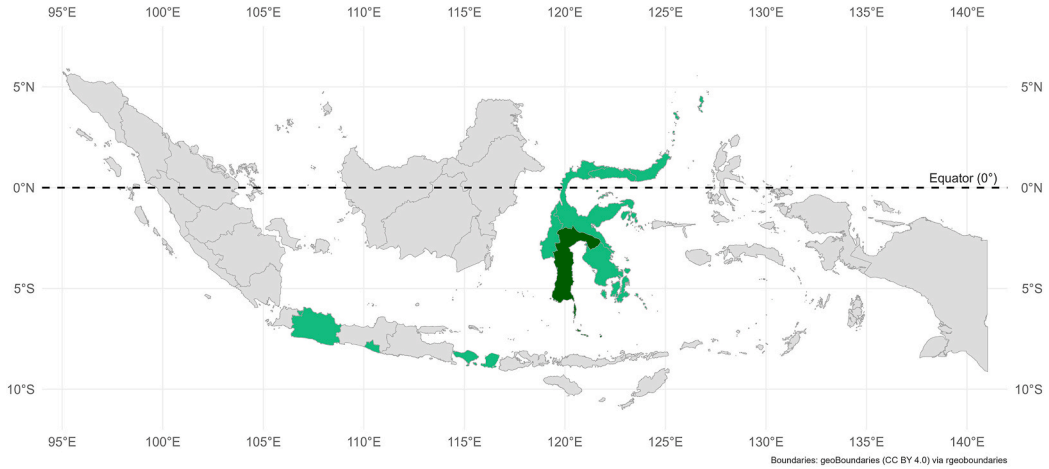

Fig. 1. Map of Indonesia showing the locations of the KAP survey participants (n = 99). The core study area was South Sulawesi (dark green, n = 87), while additional surveys were conducted in other regions (light green, n = 12).

Table 1
Summary of stakeholders who participated in KAP survey, categorised into groups (directly-involved seaweed stakeholder (DISS) and indirectly-involved seaweed stakeholder (IISS) groups).

Stakeholder group	Stakeholder type	Description	Number of participants
DISS	Seaweed farmers	Individuals involved in growing, cultivating, and harvesting seaweed	50
	Manufacturers	Processors and exporters of seaweed products	10
	Industry professionals	Experts in seaweed aquaculture or seaweed-related industry development	5
IISS	Government officials	Government employees involved in marine policy or regulation	11
	Academics	Researchers or lecturers affiliated with universities or marine research institutes	10
	Non-government organisation/ environmental group	Representatives from non-governmental organisations working to address marine-focused environmental or social issues	6
	Aquaculture company	Commercial businesses involved in the farming of aquatic organisms (non-seaweed)	4
	Tourism operators	Providers of marine-based recreational activities (e.g. scuba diving)	3

Survey participants were categorised at the study design stage into two stakeholder groups: (i) Directly Involved Seaweed Stakeholders (DISS), comprising individuals with hands-on engagement in seaweed-related activities, and ii) Indirectly Involved Seaweed Stakeholders (IISS), comprising people who did not work with seaweeds directly, but whose decisions more broadly impacted seaweed ecosystems. The composition of DISS and IISS stakeholder groups are presented in Table 1 to characterise the sample, with analysis and interpretation restricted to group-level comparisons.

2.2. KAP survey design

The KAP questionnaire comprised a demographic section followed by 47 mixed-format questions, offered in both English and Indonesian (Supplementary Material 1). The survey contained four sections: i) Basic demographic information which included participants' gender, age, educational level, length of employment, and income stability. Income stability was defined as the ability to maintain a consistent level of income over a one-year period, with minimal external disruptions (e.g. weather, political or economic instability) (Bernhardt and Donnelly, 2021), ii) Knowledge questions which assessed participants' understanding of seaweeds, their ecological functions, and general marine conservation principles (e.g. habitat protection, pollution prevention, sustainable harvesting), iii) Practice questions which evaluated participants' alignment of behaviours with conservation principles, and iv) Attitude questions which examined participants' views on the importance of conservation and their perceived barriers to effective seaweed conservation, restoration and protection. To reduce social desirability bias (i.e., the under-reporting of socially undesirable attitudes and behaviours) (Paulhus, 1984), attitude questions were presented after knowledge and practice questions.

Questionnaire scoring and indexation were adapted from Jia et al. (2017) and Kambey et al. (2025, manuscript under review). Four question types were used: i) open-ended, evaluated qualitatively (unscored), ii) close-ended binary: 'Yes' (1), 'Not sure' (0), and 'No' (0), iii) multiple-choice, scored based on the most conservation-aligned response(s) (1-0) (i.e. responses that best support sustainable seaweed resource use and the protection of seaweed ecosystems), and iv) ordinal response scales i.e., Very Important (3) to Not Important (0), or Always (4) to Never (0). Score ranges and scales were occasionally reverse-coded to align scoring direction with conservation-favourable outcomes. See Supplementary Material 1 for complete KAP questionnaire.

2.3. Data analysis

2.3.1. Assessment of group-level responses

Quantitative analysis was used to assess group-level stakeholder responses (DISS vs. IISS) across each KAP domain (i.e. knowledge/attitude/practice). Each domain comprised numerous categories and sub-categories. Group level scores were calculated using normalised indices and are presented as proportions with a range between 0 and 1 (equations (1)–(3)). A score closer to 1 indicates stronger knowledge/attitude/practice, and a score closer to 0 indicates weaker knowledge/attitude/practice. Equations used to calculate normalised mean scores for component questions, sub-categories, full categories, and overall KAP indices:

$$\text{Component question score} = \frac{\sum \text{Participant scores}}{(\text{Maximum score of component question} \times n)} \quad (1)$$

$$\text{Category/subcategory score} = \frac{\sum\sum \text{Scores of all relevent questions}}{(\text{Maximum possible score for category/subcategory} \times n)} \quad (2)$$

$$\text{KAP Index} = \frac{\sum\sum \text{Participant scores in each domian}}{(\text{Maximum score across } K/A/P \text{ categories} \times n)} \times 100 \quad (3)$$

Only answered responses were treated as valid and were included in denominator calculations to minimise bias. Individual level KAP index scores (equation (3)) were reported as ± standard error of the mean (SEM) and classified as "Good" (≥75 %), "Fair" (50-75 %), and "Poor" (<50 %), following Mateo et al. (2021). This allowed mean KAP scores to be compared across groups, despite different question formats. Category and sub-category scores were computed as normalised group-level proportions (DISS or IISS level) to standardise response scales and distributions. Consequently, individual variability (i.e., SEM) was not reported for these scores. See Supplementary Material 2 Table 1 for a summary of scoring and question structures, in addition to which questions make up each respective KAP domain, category, and sub-category.

2.3.2. Statistical analysis

Statistical analysis was conducted in R (v.4.4.1) using RStudio and Microsoft Excel. KAP domain scores were compared between DISS and IISS groups, with normality assessed using the Shapiro-Wilk test. As at least one group per domain deviated from normality ($p < 0.05$), non-parametric methods were applied.

All demographic variables (except for age – already numeric) were coded numerically for analysis; for example, binary coding was applied to gender (male = 0, female = 1), and ordinal coding to education level (0 = no formal education through 5 = higher education). A two-stage approach assessed both univariate and multivariate analysis to determine both individual and combined predictor effects, suitable for proportional, bounded scores (0-1) with non-normal distributions and a sample size of 99.

Univariate associations between demographic variables and KAP outcomes were explored using Kruskal-Wallis tests (education level and employment length), Mann-Whitney U tests (gender and income

stability), and Spearman's rank correlations (age and inter-domain KAP relationships). Multivariate associations were then estimated using beta regression, with a Smithson-Verkuilen transformation applied to shift exact 0 and 1 values into the (0,1) range. For each group, demographic and inter-domain KAP models (each KAP domain predicted by the other two, e.g. knowledge predicted by attitudes and practices) were applied. Multicollinearity was assessed using variance inflation factors (VIF). All predictors returned values < 4, indicating no evidence of problematic collinearity. Coefficients are reported on the logit scale and are back-transformed to the original proportion scale for interpretability. Precision parameters (phi) were also estimated. Statistical significance was set at $p \leq 0.05$ for all analyses. The main text reports multivariable-adjusted associations only, with full univariate and multivariable outputs provided in Supplementary Material 3.

3. Results

3.1. Participant demographic information

Approximately two-thirds of participants were male (DISS: 61.5%; IISS: 67.6%), and one-third female (DISS: 38.5%; IISS: 29.4%). Participants were predominantly aged between 25 and 50 years (DISS: 66.2%; IISS: 58.8%), or older than 50 years (DISS: 21.5%; IISS: 35.5%). Ethnically, participants primarily identified as Indonesian, from Makassarese, Bugis, and Javanese backgrounds.

Education level differed between groups, with almost all the IISS participants holding higher education degrees (91.2%), compared to 26.2% of the DISS group. Nearly all IISS participants reported stable incomes (91.2%), whereas the majority of the DISS group (76.9%) (including all 50 farmers) reported unstable incomes. Both groups also had comparable employment durations. Supplementary Material 2 Table 2 provides a summary of demographic information by stakeholder group.

3.2. KAP assessment

3.2.1. Knowledge

Overall, knowledge scores across categories were rated as "good", except for the Marine conservation knowledge category, where both groups scored "fair" (Table 2).

3.2.1.1. Marine ecosystem knowledge. Marine ecosystem knowledge was "good" for both groups (DISS: 0.88; IISS: 0.84). The DISS group's knowledge was significantly higher than the IISS group for the *Awareness of marine ecosystems* sub-category (DISS: 0.94; IISS: 0.82; MWU-test; $p = 0.022$). Both groups showed "good" knowledge of the *Ecological functions of seaweed*. At component question level, each group recognised the socio-economic value of seaweed (mean question scores: >0.95) but neither group scored above "fair" regarding its environmental benefits (mean question scores: <0.75).

3.2.1.2. Marine conservation knowledge. Marine conservation knowledge was "fair" for both groups (DISS: 0.65; IISS: 0.72). For the *Conservation of cultivated and wild seaweeds* sub-category, both groups scored equally (0.81). At the component question level, both groups understood

Table 2

KAP domains, categories, and sub-categories of questions within the KAP survey. Category and sub-category scores presented as normalised group-level proportions (directly-involved seaweed stakeholder (DISS) and indirectly-involved seaweed stakeholder (IISS) groups). Scores closer to 1 indicate stronger knowledge/attitude/practice, and scores closer to 0 indicates weaker knowledge/attitude/practice. Mann-Whitney *U* test results determined statistical significance between group scores. KAP score classification: "Good" (≥0.75), "Fair" (0.50-0.75), and "Poor" (<0.50), following Mateo et al. (2021). An (*) indicates statistical significance between DISS and IISS groups at $p \leq 0.05$ level (two-tailed Mann-Whitney *U* test).

Normalised KAP scores					Mann-Whitney U (MWU) Test				
Domain/Category/Sub-category	DISS score (n = 65)	Rating	IISS score (n = 34)	Rating	DISS Median (IQR)	IISS Median (IQR)	U	Z	*p*-value
Knowledge									
1. Marine ecosystem knowledge	0.88	Good	0.84	Good	0.917 (0.25)	0.833 (0.25)	1106	0.008	0.994
a. Awareness of marine ecosystems	0.94	Good	0.82	Good	1.00 (0.17)	1.00 (0.33)	843	−2.291	0.022*
b. Ecological functions of seaweed	0.79	Good	0.87	Good	1.00 (0.50)	1.00 (0.50)	1247	1.261	0.207
2. Marine conservation knowledge	0.65	Fair	0.72	Fair	0.714 (0.24)	0.774 (0.28)	1271	1.227	0.220
a. Conservation of cultivated and wild seaweeds	0.81	Good	0.81	Good	0.833 (0.33)	0.833 (0.33)	1084	−0.167	0.867
b. Factors impacting wild seaweed habitats	0.58	Fair	0.68	Fair	0.571 (0.29)	0.714 (0.14)	1370	2.004	0.045*
3. Seaweed conservation in Indonesia	0.82	Good	0.86	Good	0.917 (0.19)	0.979 (0.17)	1251	1.115	0.265
a. Urgency for seaweed protection	0.90	Good	0.85	Good	1.00 (0.00)	1.00 (0.00)	1057	−0.568	0.570
b. Seaweed ecosystem changes	0.79	Good	0.87	Good	0.833 (0.29)	0.958 (0.25)	1297	1.471	0.141
Attitude									
1. Risk perception and management	0.90	Good	0.94	Good	1.00 (0.17)	1.00 (0.08)	1303	1.614	0.107
a. Farming and cultivation risk management attitudes	0.95	Good	0.95	Good	1.00 (0.00)	1.00 (0.00)	1147	0.434	0.664
b. Wild seaweed population risk management attitudes	0.85	Good	0.93	Good	1.00 (0.25)	1.00 (0.17)	1246	1.220	0.222
2. Attitudes towards seaweed conservation, use, and management	0.85	Good	0.96	Good	0.933 (0.23)	1.00 (0.07)	1465	2.809	0.005*
a. Wild seaweed conservation and preservation	0.81	Good	0.96	Good	1.00 (0.33)	1.00 (0.00)	1440	2.847	0.004*
b. Sustainable resource use and management	0.90	Good	0.96	Good	1.00 (0.17)	1.00 (0.00)	1308	1.824	0.068
c. Seaweed ecosystem education	0.84	Good	0.97	Good	1.00 (0.33)	1.00 (0.00)	1380	2.698	0.007*
3. Attitudes towards seaweed conservation governance	0.83	Good	0.93	Good	0.933 (0.30)	1.00 (0.20)	1409	2.329	0.020*
a. Environmental monitoring and awareness	0.79	Good	0.93	Good	0.833 (0.42)	1.00 (0.17)	1426	2.610	0.009*
b. Responsible seaweed sourcing	0.83	Good	0.83	Good	1.00 (0.33)	1.00 (0.33)	1046	−0.513	0.608
c. Support for regulation and community conservation involvement	0.87	Good	0.96	Good	1.00 (0.17)	1.00 (0.04)	1335	2.017	0.044*
Practice									
1. Traditional and contemporary practices	0.52	Fair	0.67	Fair	0.50 (0.25)	0.667 (0.33)	1581	3.541	<0.001*
a. Seaweed harvesting behaviours	0.60	Fair	0.73	Fair	0.50 (0.25)	0.750 (0.38)	1440	2.514	0.012*
b. Seaweed information sharing	0.37	Poor	0.55	Fair	0.25 (0.75)	0.625 (0.50)	1446	2.587	0.010*
2. Resource security and management	-		-		-	-	-	-	-
3. Community led conservation practices	0.53	Fair	0.71	Fair	0.50 (1.00)	1.00 (0.50)	1325	1.753	0.080

the importance of protecting seaweed habitats, but their knowledge of which habitats require protection differed. The DISS participants most frequently selected cultivated species only (46.2% of group), whereas the IISS group favoured wild species only (38.2%). A sizable proportion of each group selected both cultivated and wild species (DISS: 44.62%; IISS: 35.3%), but this did not represent a majority view. The IISS group showed significantly higher awareness of the *Factors impacting wild seaweed habitats* compared with the DISS group (IISS: 0.68 vs. DISS: 0.58; MWU-test: $p = 0.045$) (Table 2).

3.2.1.3. Seaweed conservation in Indonesia. Both groups scored "good" on their knowledge of Seaweed conservation in Indonesia (DISS: 0.82; IISS: 0.86). No significant differences were found for either sub-category. Within the *Seaweed ecosystem changes* sub-category, participants were invited to provide examples of perceived/observed changes in wild seaweed populations (optional open-ended question), these are summarised in Table 3.

3.2.2. Attitude

The attitudes of both DISS and IISS groups towards seaweed conservation were rated as "good" across all categories and sub-categories (Table 2).

3.2.2.1. Risk perception and management. Both groups scored equally for *their Farming and cultivation risk management attitudes* (0.95). At component question level, both groups strongly supported protecting cultivated seaweed habitats and favoured mitigating their exposure to disease risks (mean question scores >0.90). Within the *Wild seaweed population risk management attitudes* sub-category (DISS: 0.85; IISS: 0.93) both groups recognised the importance of protecting wild seaweeds from environmental shocks and overharvesting (mean component question scores: >0.83).

3.2.2.2. Attitudes towards seaweed conservation, use, and management. The IISS group scored higher across all sub-categories with significant differences in the *Wild seaweed conservation and preservation* (IISS: 0.96; DISS: 0.81; MWU-test: $p = 0.004$) and *Seaweed ecosystem education* (IISS: 0.97; DISS: 0.84; MWU-test: $p = 0.007$) sub-categories. Within the *Sustainable resource use and management* sub-category (DISS: 0.90; IISS: 0.96), both groups supported harvesting regulations for farming (mean component question scores >0.85).

Although not a scored section of the KAP assessment, participants were invited to reflect on barriers to seaweed conservation, restoration, and protection in Indonesia. Forty of the 99 participants (40.4%) provided open-text responses, thematically summarised in Table 4. The most frequently cited barrier was limited public awareness, education, and engagement of seaweeds and their habitats (identified by 25% of all participants).

Table 3
Examples of observed changes in seaweed populations as reported by directly-involved seaweed stakeholder (DISS) and indirectly-involved seaweed stakeholders (IISS), grouped into themes.

Emerging themes	Observed changes
Changing environmental conditions	-Increases in pollution, water temperature, and heavy metals exposure within seaweed habitats
Declining abundance and resource availability	-Declines in abundance, density, biomass, and species richness -Changes in availability, accessibility and distribution of wild stocks -Complete disappearance of some wild species -Decline in nutrient availability in surrounding water
Altered growth and seasonal timing	-Inconsistent and slowed growth rates -Phenological changes (e.g., altered blooming times) -Extended harvesting periods
Morphological changes	-Observed structural changes (e.g., texture, weight, and colour)
Reduced resilience and health	-Lower resistance to disease -Compromised physiological condition in response to environmental pressures

Table 4
Summary of perceived anthropogenic barriers preventing effective conservation, restoration, and protection of seaweeds in Indonesia.

Theme	Summary	DISS participants (% of responders)	IISS participants (% of responders)
Limited public awareness, education, and engagement	A widespread lack of understanding of seaweeds, their ecology, and their ecosystem functions	8 (12.5%)	17 (48.6%)
Policy and regulatory conflicts	Non-existent, unclear or weak regulation for marine space or resource management	2 (3.1%)	15 (42.9%)
Challenges in marine management, monitoring, and evaluation	Limitations of marine conservation strategies, including data management inadequacies, uncertainty of monitoring capabilities, inefficient collaborative efforts, and difficulties in assessing strategy effectiveness (e.g., no take-reserves)	5 (7.8%)	9 (25.7%)
Financial barriers	Lack of mechanisms to support sustainable seaweed cultivation (e.g., subsidies, incentives)	4 (6.3%)	7 (20.0%)
Seaweed market and livelihood instability	Price fluctuations that destabilise local community incomes	3 (4.7%)	7 (20.0%)
Unsustainable and harmful marine farming practices	No formally recognised sustainable cultivation methods and the continued use of destructive farming practices that bring long-term degradation to seaweed habitats	2 (3.1%)	5 (14.3%)
Cultural attitudes and resistance to change	Conflicts between traditional practices, cultural norms, and collective perceptions that influence how communities value or devalue seaweeds and their ecosystems	1 (1.6%)	5 (14.3%)
Gaps in scientific research and evidence	Environmental and technical knowledge gaps concerning the condition and state of national seaweeds stocks	-	5 (14.3%)
Pollution and waste mismanagement	Contamination of marine ecosystems arising from improper disposal and inadequate management of waste materials	2 (3.1%)	2 (5.7%)

3.2.2.3. Attitudes towards seaweed conservation governance. Significantly higher attitude scores are found for the IISS group compared to the DISS group in the *Environmental monitoring and awareness* (IISS: 0.93; DISS: 0.79; MWU-test: $p = 0.009$) and *Support for regulation and community conservation involvement* (IISS: 0.96; DISS: 0.87; MWU-test: $p = 0.044$) sub-categories (Table 2). At component question level, IISS participants placed greater importance on monitoring wild seaweed populations than the DISS group (mean question scores: IISS: 0.89; DISS: 0.69). Attitudes towards *Responsible seaweed sourcing* were also the same for both groups (0.83).

3.2.3. Practice

Neither group scored above "fair" in any practice category or sub-category (<0.75), though the IISS group consistently outperformed the DISS group (Table 2).

3.2.3.1. Traditional and contemporary practices. Significantly higher practice scores for the IISS group are found in both the *Seaweed harvesting behaviours* (IISS: 0.73; DISS: 0.60; MWU-test: $p = 0.012$) and *Seaweed information sharing* (IISS: 0.55; DISS: 0.37; MWU-test: $p = 0.010$) sub-categories. The latter was the only sub-category where a "poor" score was recorded across the surveys, by the DISS group.

3.2.3.2. Community led conservation practices. Both groups scored "fair" for *the Community-led conservation practices* category (DISS: 0.53; IISS: 0.71). This category comprised of two component questions, with the IISS participants expressing greater willingness to engage in translocation if it meant protecting vulnerable seaweed stocks (mean question scores: IISS: 0.62; DISS: 0.52) and showed a stronger readiness to engage in community-led restoration (mean question scores: IISS: 0.79; DISS: 0.54).

3.2.3.3. Resource security and management. The *Resource security and management category* was unscored, although it did assess sustainable sourcing practices. Many participants supported using natural seaweed seed stocks when cultivated stocks fail (DISS: 56.9%; IISS: 54.5%). A willingness to cultivate new species was also high (supported by DISS: 73.8%; IISS: 52.9%), however, 41.2% of the IISS group left this question unanswered and 5.9% were unsure.

3.2.4. KAP index

Overall, the IISS group scored higher than the DISS group across all KAP domains (Fig. 2). However, both groups achieved "good" scores for knowledge (DISS: 76.0% ± 14.4; IISS: 79.5% ± 13.4) and attitude (DISS: 85.7% ± 14.4; IISS: 94.2% ± 8.0), while practice scores were lower and rated "fair" for both groups (DISS: 52.4% ± 18.2; IISS: 67.3% ± 15.5). See Supplementary Material 2 Table 3 for KAP index scores by stakeholder type (descriptive only).

3.3. Factors impacting the KAP scores

Multivariate analysis indicated that few demographic characteristics remained independently associated with KAP outcomes once all variables were jointly considered (Fig. 3). For the DISS group, income stability was independently associated with practices, and attitudes bidirectionally with both knowledge and practices. For the IISS group, age and income stability emerged as independent predictors of knowledge, while age was independently associated with practices. As in the DISS group, attitudes remained associated with knowledge.

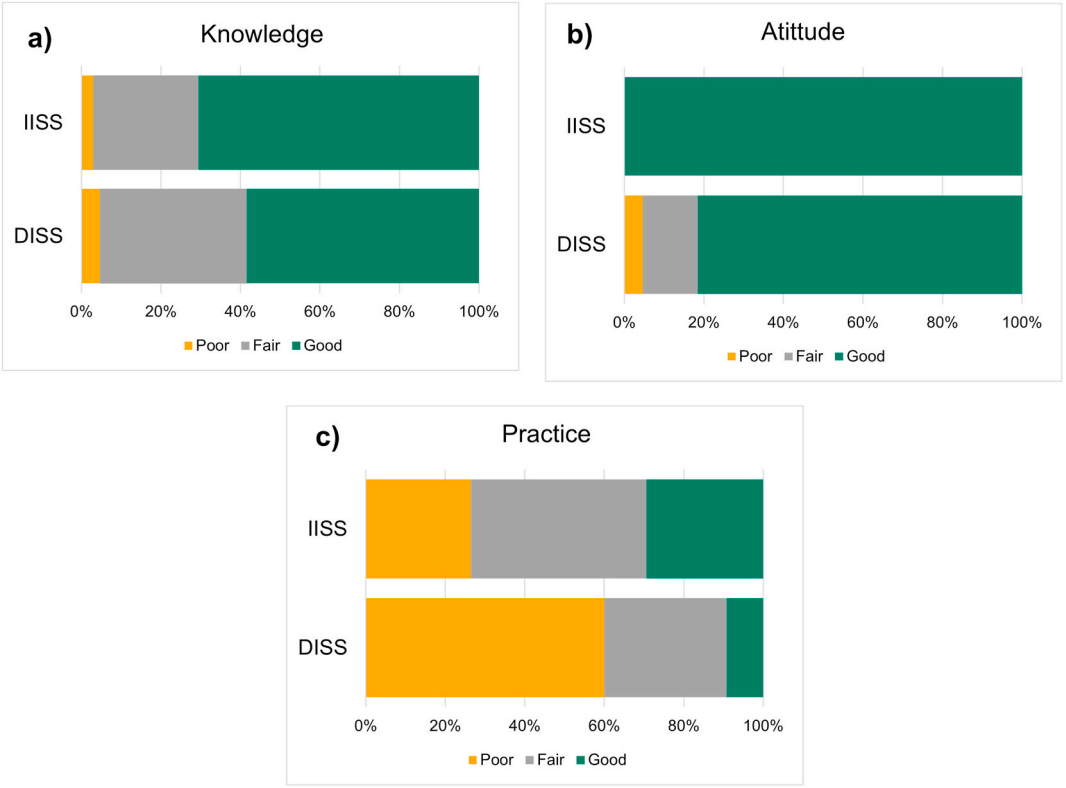

Fig. 2. a, b, c. The Knowledge, Attitudes, and Practice index scores for participants within the directly-involved seaweed stakeholder (DISS) and indirectly-involved seaweed stakeholder (IISS) groups.

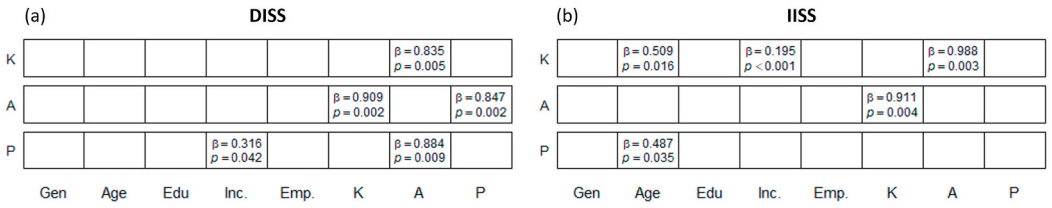

Fig. 3. Multivariate associations between demographic factors and KAP domain scores for (a) directly-involved seaweed stakeholder (DISS) and (b) indirectly-involved seaweed stakeholder (IISS) groups. Cells report back-transformed adjusted beta coefficients (β) from beta regression with corresponding test p-values. Only statistically significant associations are displayed ($p < 0.05$). Blank cells indicate non-significant associations. Abbreviations: Gen = "Gender", Edu. = "Education Level", Inc. = "Income Stability", Emp. = "Employment Length, K = knowledge, A = attitude, P = practice.

4. Discussion

While stakeholders demonstrate strong conceptual support for the conservation of seaweed habitats, notable gaps remain in their ability to translate their support into action. Three primary challenges emerged: i) stakeholders have a limited understanding of threats facing wild seaweed habitats, ii) livelihood instability and risk-exposure shape conservation-aligned decision making and iii) practical constraints limit capacity to implement sustainable practices. By capturing perspectives from a range of stakeholders, this research has been able to identify where opportunities exist for more inclusive and ecologically informed seaweed management strategies in Indonesia and other seaweed producing countries globally.

4.1. Socioeconomic variables and conservation engagement

After accounting for interdependencies between KAP scores, demographic characteristics showed only limited independent associations with KAP outcomes. For the DISS group, the clearest socioeconomic signal was the association between income stability and practices, which suggests livelihood security may condition the feasibility of pro-conservation behaviours. Many aquaculture-dependent regions of Sulawesi experience high levels of socio-economic inequality (Qur'ani et al., 2023), and previous studies have highlighted that the success of conservation in Indonesia can be hindered by economic pressures (Von Essen et al., 2013), including in seaweed-farming areas (Wijayanto et al., 2022). In the IISS group, the positive relationship between age and knowledge likely reflects accumulated experience and/or long-term exposure to relevant information, consistent with age-related improvements in knowledge found in other marine conservation contexts (e.g., perceptions towards sharks) (Afonso et al., 2020). Taken together, the results suggest that while demographic attributes may shape engagement, they do not themselves guarantee conservation action alone. Efforts to strengthen conservation engagement should pair attitudinal approaches with measures that reduce livelihood-related barriers.

4.2. Stakeholder knowledge, attitudes, and practices

4.2.1. Knowledge

Most participants recognised the social, economic, and ecological importance of seaweeds, understood why seaweed conservation mattered and demonstrated a good awareness of conservation strategies; however, awareness of threats to wild seaweed populations was notably weaker. Aside from climate change, impacts from overharvesting, habitat degradation, pollution, and aquaculture expansion (e.g., fish or shrimp farms) were not well understood. Despite the increased understanding and documentation of these threats in scientific literature (Corrigan et al., 2025), there were clear gaps in local understanding. This gap may reflect the tendency of marine resource-dependent stakeholders to downplay ecological risks due to immediate livelihood concerns (Xue, 2025). The Indonesian seaweed industry's narrow commercial focus (e.g. *Kappaphycus* spp. and *Eucheuma* spp.) (Nuryartono et al., 2021), coupled with limited recognition of non-cultivated species, has likely further reduced awareness of the threats facing wild habitats. To raise awareness and build support for future conservation efforts, national ocean literacy initiatives that champion the value of all marine spaces remain imperative to improve local knowledge of seaweed ecosystems (e.g. the South Coast Seaweed initiative, Australia) (Kelly et al., 2025).

Both groups understood the importance of conserving seaweed habitats, but their conservation priorities differed in ways that reflect their relationships with seaweed resources. The DISS group showed greater awareness of the need to protect cultivated seaweeds, which was consistent with the tendency of marine resource users to prioritise conservation actions that safeguard livelihood value (Börger et al., 2014). In contrast, the IISS group more frequently acknowledged the significance of conserving wild seaweed habitats, suggesting greater orientation toward broader ecosystems values. Given the differing motivations between the two groups, tailored awareness-raising interventions are required. For DISS stakeholders, framing broader seaweed habitat conservation through farm-relevant outcomes (e.g., crop security, the safeguarding of genetic diversity, and pest and disease management) might be most compelling, whereas for IISS stakeholders, improving ecological literacy may more directly strengthen social support for wild seaweed habitat conservation. Cross-stakeholder knowledge exchange can also complement these approaches through mutual learning by connecting ecological experts with groups less familiar with seaweed ecology (Favretto et al., 2022). This is particularly relevant given limited public recognition of seaweed ecosystem services has contributed to their historic neglect in international conservation agendas (Beattie et al., 2025; Corrigan et al., 2025). Sustained, targeted engagement and knowledge sharing efforts are therefore key for raising overall awareness and supporting the conservation of all seaweed ecosystems (Kelly et al., 2025).

Examples of perceived changes in local seaweed populations, including reports of slowed growth, phenological shifts, extended harvesting periods, and reduced abundance and diversity (Table 3), are consistent with pressures reported in other Sulawesi-based seaweed studies (Basyuni et al., 2024; Langford et al., 2023a). Given the predominantly structured survey design, and the optional format of the open-ended prompt, these responses are interpreted as readily recalled concerns rather than an exhaustive account of ecological change. Nevertheless, opportunities and support for systematic monitoring of long-term seaweed change can remain limited. This can constrain the ability of stakeholders to interpret observations consistently and translate them into evidence for decision making in the face of ecological shifts (Valero et al., 2017; UNFCC, 2023). Co-designed participatory monitoring could facilitate this by integrating stakeholder and traditional ecological knowledge into a small set of comparable indicators that are tracked over time (e.g., growth anomalies, disease incidence, seasonal timing shifts), thereby strengthening early warning and adaptive management. In doing so, a more complete ecological picture can begin to be built, one that can inform seaweed conservation and resource management, while supporting the long-term sustainability of the seaweed aquaculture sector (Cottier-Cook et al., 2022).

4.2.2. Attitudes

Overall, attitudes were supportive towards the management, conservation, and governance of seaweed habitats. The IISS group, in particular, strongly valued wild seaweed protection, public education, and marine governance (Table 2). The DISS group also expressed general support, however, they were more cautious when it came to regulating marine spaces. For stakeholders reliant on seaweed farming, conservation measures, like marine protected areas or stricter harvesting rules, raised concerns about equity, fairness, access, and potential losses of income. This echoes findings from previous studies where perceived trade-offs from conservation have reduced community support for conservation-aligned practices (Bennett and Dearden, 2014; McNeill et al., 2018).

Stakeholders also identified perceived barriers to seaweed conservation, including a lack of public awareness, unclear policies, unstable markets, and a lack of funding and technical support (Table 4). When communities face uncertainty or feel excluded from decision making, their trust in conservation weakens (Young et al., 2016). This has been reported in other marine sectors, where new fishing regulations were perceived to prioritise conservation goals over local needs (Frangoudes, 2011). While this study acknowledges that overall support for seaweed conservation is high, attitudes are still deeply rooted in socio-economic realities, institutional trust, and the legitimacy of governance (Turner et al., 2016). Inclusive, transparent, and participatory governance remains essential to foster long-term public support for seaweed conservation that can benefit both people and the wider environment.

4.3. Practices

Practices were the weakest-performing domain compared to knowledge and attitudes, revealing a clear value-action gap. In the IISS group, responses to practice-related questions were often hypothetical, while support for sustainable farming practices was high in principle, stakeholder capacity for implementation was limited. In contrast, practices for the DISS group appear largely determined by capabilities and opportunities to act under resource and risk constraints, such that applying more sustainable practices remains difficult despite a reported willingness to do so. This interpretation is reinforced by the multivariate finding that income stability was independently associated with practices in the DISS group (Section 3.3). More generally, when livelihoods are insecure, immediate financial needs take precedence, and new farm or habitat-protection practices become economically irrational if they increase short-term production risk, labour demands, or financial costs without reliable compensation (Mariño et al., 2019).

In South Sulawesi, these trade-offs are shaped by market volatility, limited resources, and a lack of policy and technical support (PAIR, 2023), which together can lock value-chain actors into low-risk, familiar routines even when better practices are known. Although frameworks and guidance for sustainable cultivation and post-harvest management exist (e.g., the Indonesian Seaweed Roadmap) (UNIDO, 2025; Waters et al., 2019), uptake ultimately depends on trusted local proof. Seaweed farmers in the region have been found to rely on peer observation and word-of-mouth for new technology and technique uptake, with adoption occurring only once practices are seen to succeed under local conditions (Langford et al., 2023b). The fair practice scores observed here are therefore best interpreted as a product of risk exposure and limited access to locally validated pathways for change. Comparable dynamics have been reported elsewhere in the region, where Filipino seaweed farmers have requested greater support to manage production risks and improved access to markets to enable smoother transitions to better farming practices (Suyo et al., 2021).

Bridging the value-action gap therefore requires context-specific interventions, that reduce risk and avoid unintended harm to livelihoods and seaweed ecosystems. Peer-to-peer farmer demonstration structures (e.g., farmer field schools or pilot farms), could test priority practices under local conditions (e.g., sustainable cultivation methods, disease awareness, and prevention mechanisms) using farmer-defined success metrics (e.g., yield stability) to improve technology uptake whilst reducing individual risk (Swanepoel et al., 2020). Complementing demonstration, expanding extension services through greater deployment of trained field officers could improve translation of guidance into routine practice, as reported in West Sulawesi seaweed farming areas (Fatchiya et al., 2025). Finally, risk protection, through appropriately designed insurance or contingency financing mechanisms (e.g., climate insurance) could improve livelihood buffering, and enable conservation-aligned decision-making without exacerbating livelihood concerns (Hobday et al., 2025). Given short seaweed cultivation cycles, such support is likely to be most effective when delivered continuously across seasons, maintaining an awareness of exemplary practices throughout the year (PAIR, 2023). Together these measures provide a possible pathway to strengthen adaptive capacity and support for sustained practice change that protects seaweed habitats and associated livelihoods.

4.4. Limitations of the study

Although this study interviewed a wide range of stakeholders on seaweed conservation, its modest sample size (n = 99) and regional focus mean its findings should not be presumed to represent all seaweed and conservation-related stakeholders in South Sulawesi nor Indonesia more widely. Seaweed-related industries are established across the Indonesian archipelago, and each area retains a unique and diverse mix of political, cultural, and geographical contexts (Rimmer et al., 2021). Additional limitations include the studies cross-sectional design, meaning relationships between KAP domains should be interpreted as associations rather than causal pathways. Heterogeneity within stakeholder groupings (particularly the IISS group) may also have obscured stakeholder-specific patterns. Finally, self-reported questions (e.g., practice questions) are susceptible to social desirability bias, a factor which may have influenced responses and, in turn, research findings (Krumpal, 2013).

Instead, these findings should be considered as a snapshot of a wider reality. This is a preliminary step towards understanding the potential for seaweed conservation to be integrated into the global seaweed sector and should be reviewed in parallel with other KAP surveys undertaken regionally (i.e., Malaysia, Kambey et al. (2025, manuscript under review)).

5. Conclusion

This KAP study indicated that whilst knowledge and attitudes in support for seaweed conservation were high, these have yet to translate into consistent, sustainable action in practice. Bridging this value-action gap requires role-specific interventions that reduce risk and strengthen enabling conditions to support a sustainable seaweed sector:

Directly Involved-Seaweed Stakeholders (DISS):

- **Enable low-risk practice change** - by supporting peer-demonstration mechanisms (e.g., farmer field schools/pilot farms), alongside reliable extension support, and risk-buffering finance (e.g., contingency funds/climate insurance mechanisms) to make adoption feasible while safeguarding livelihoods.

Indirectly Involved-Seaweed Stakeholders (IISS):

- **Strengthen the enabling environment** - through inclusive, participatory decision-making and co-designed monitoring that

integrates stakeholder and traditional ecological knowledge into shared indicators for detecting, monitoring, and assessing seaweed ecosystem change.

Cross-cutting:

- **Raise recognition of wild seaweed habitats** - by using ocean literacy and targeted communication programmes to expose wider audiences and decision makers to the value of all seaweed ecosystems, not only those delivering direct socio-economic benefits.

Given the ecological and socio-economic importance of seaweed habitats, future research should build on this study by adapting the KAP framework across other seaweed producing regions. Comparative insights across geographies can reveal shared challenges and region-specific barriers which can help to shape more targeted, globally relevant strategies for seaweed conservation. Expanding this evidence base would support the integration of seaweeds into international biodiversity, conservation, and blue economy agendas, where they remain critically underrepresented.

CRediT authorship contribution statement

Shaun Beattie: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cicilia S.B. Kambey:** Writing – review & editing, Methodology, Data curation. **Sophie Corrigan:** Writing – review & editing. **Juliet Brodie:** Writing – review & editing. **Phaik Eem Lim:** Writing – review & editing. **Sze-Wan Poong:** Writing – review & editing. **Rohani Ambo-Rappe:** Writing – review & editing, Data curation. **Dahlan Dahlan:** Data curation. **Elizabeth J. Cottier-Cook:** Writing – review & editing, Funding acquisition, Conceptualization.

Ethics

Ethical clearance granted by Indonesia's National Research and Innovation Agency (BRIN; Ref: 848/SIP/IV/FR/11/2024).

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2026.128964.

Data availability

The survey data that supports the findings of this study is openly available on the THREDDS data server, ID: KAP Survey Data Indonesia 2025 (GlobalSeaweedSUPERSTAR)

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