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Review

Socioeconomic impacts linked to land use and land use changes affecting blue carbon ecosystems in Southeast Asia: A systematic map

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ABSTRACT

Background: Land use and land use changes are the main drivers of blue carbon ecosystem (BCE) loss and degradation, which is frequently justified on the pretext of advancing economic and social development. However, there is still a lack of comprehensive investigation of the impacts of these changes on humans and communities, especially in Southeast Asia (SEA). It is also unclear how many studies have accounted for the interconnectedness of BCEs with adjacent or upstream ecosystems, as well as the potential for cascading impacts to occur across physical, chemical, and biological connections. This information is useful to ensure holistic coastal land use planning which achieves the desired outcomes of balancing environmental sustainability, economic growth, and social equity, while effectively managing risks, engaging communities, and aligning policies for long-term resilience and resource efficiency.
Method: The systematic mapping method was conducted to consolidate and synthesise the state of evidence on the research question, '*What is the state of evidence on the socioeconomic impacts linked to land use and land use changes affecting blue carbon ecosystems in Southeast Asia?'*. A systematic map is a structured approach used to identify, categorise, assess relevant studies, and identify research gaps on a broad topic area while ensuring comprehensive coverage, transparency, and minimise bias. We conducted bibliographic searches using predefined search terms to locate relevant scientific articles. Five reviewers carried out two rounds of screening independently of each other by applying the predetermined inclusion criteria. We then systematically extracted and coded meta-data and results from the included papers, followed by analysis of the distribution and abundance of the evidence and rapid synthesis of study findings.
Results: Out of 5118 articles screened, 190 final articles were included in the database. Most of these studies are from Indonesia, followed by Vietnam, while Myanmar and Cambodia are less represented than expected, considering their significant mangrove cover. The distribution of studies by ecosystem includes 75 focused on mangroves, 2 on seagrass, 88 on non-BCEs, and 25 covering a combination of two or more ecosystems. The largest research clusters examine the impacts of aquaculture on economic living standards and the effects of urbanisation and industrialisation on general human health. Key research gaps identified include the impacts of land use and land use change on cultural and spiritual values, as well as measures of education.
Conclusions: Research connecting land use, BCEs and socioeconomic impacts, particularly studies on indirect impacts of land use on BCEs are still limited in this region. Literature on seagrass ecosystems is notably scarce. The current evidence base points to trade-offs in land use change impacts across various socioeconomic aspects. Our systematic map highlights the complexities in resolving the interlinkages between human activities and

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ecosystem response and suggests ways forward towards a more informed decision-making process in managing BCEs.

1. Introduction

Coasts are a critical focus for both the impacts of climate change on human populations and the implementation of mitigation and adaptation management initiatives. Effective and sustainable management practices of these regions require a holistic approach that integrates environmental principles with socioeconomic considerations. In this context, nature-based solutions, which leverage natural processes to address climate challenges, have emerged as a key strategy. Research shows that the effectiveness of conservation projects often depends on the active involvement of local coastal communities (Brooks et al., 2013). Without meaningful community engagement, top-down initiatives may fail to achieve long-term sustainability, as they neglect local perspectives that can be used to identify the causes of ecosystem decline and guide adaptive sustainable governance (Ruiz-Frau et al., 2019). Therefore, it is essential that nature-based solutions place human welfare at their centre and offer tangible benefits and compensations for any resulting trade-offs to foster genuine community engagement and sustainable outcomes. This generates a need to develop a comprehensive understanding of the socioeconomic impacts linked to land use and land use change (LULUC), a key driver of coastal ecosystem loss, especially in areas with the greatest mitigation potential, chief among them Southeast Asia.

A key marine nature-based solution to climate change are blue carbon projects, i.e. the sustainable management of natural marine resources to enhance carbon fluxes and storage and to generate co-benefits such as coastal defence, sustainable livelihoods, and biodiversity conservation. Blue carbon ecosystems (BCEs) refer to vegetated marine and coastal ecosystems that sequester significant amounts of carbon in their biomass and underlying sediments for millennial timescales (Lovelock and Duarte, 2019). Global degradation and losses of BCEs directly contributes to climate change through the emission of greenhouse gases and the reduction of carbon sequestration potential. Deforestation and conversion of BCEs worldwide, including mangroves, and seagrasses, are estimated to emit up to one billion tonnes of carbon dioxide to the atmosphere per year (Pendleton et al., 2012). Southeast Asia (SEA) is a critical region for studying these ecosystems due to its significant share of global BCE cover, ongoing threats from land use change, and the socioeconomic importance of these ecosystems for coastal communities. This makes the region an important focal point for our study.

Southeast Asia holds a significant portion of the world's BCEs, specifically mangrove forest cover estimated at 5.1 million hectares, and seagrass extent of 6.7 million hectares (Thorhaug et al., 2020). Approximately half of the world's mangrove cover and a quarter of its seagrass distribution are in SEA, underscoring this region's crucial role in addressing climate change impacts on a global scale (Siikamaeki et al., 2013). While tidal marshes are also recognized as important BCEs globally, their distribution and prominence in SEA are more limited compared to mangroves and seagrasses and are consequently less highlighted in the literature (Liu et al., 2022). This region is also home to an estimated population of 668 million people (The World Bank, 2020), and a large proportion of them live in the coastal areas making them hot spots of development and urbanisation (Wong et al., 2006). The combined pressures of achieving economic advancement, accommodating rising population rates, and the dual needs to both exploit and conserve natural resources have resulted in conflicting land use demands on the BCEs (Friess et al., 2016). With the rising trend of growth in coastal urban populations in SEA (Alam et al., 2023), the pressures on natural coastal and adjacent marine ecosystems are expected to intensify, underscoring the urgent need for sustainable solutions.

The primary cause of mangrove forest loss in SEA is land use change (Richards and Friess, 2016), with approximately 100,000 ha of forest cover lost between years 2000 and 2012 due to deforestation and conversion into aquaculture ponds, rice farms, oil palm plantations, and urban or industrial areas (Goldberg et al., 2020). The remaining mangroves face degradation due to LULUC associated with habitat fragmentation, exposure to pollutants, and changes in the biophysical properties of their habitats (DasGupta and Shaw, 2013). Meanwhile, seagrass cover has seen an estimated net loss of 9600 ha in the Tropical Indo-Pacific region between years 1945 and 2016, primarily driven by coastal development activities and poor water quality (Dunic et al., 2021). The construction and operation of port infrastructures, sand mining, and the creation of artificial beaches destroy intertidal and subtidal seagrass habitats (Holon et al., 2015). Additionally, the input of organic and inorganic pollutants, nitrogen waste, and suspended solids into major basins within the region, discharged from sewage treatment plants, manufacturing industries, animal husbandry, and agriculture, alters the biophysical properties of seagrass ecosystems, contributing to their degradation (Bach et al., 1998; Freeman et al., 2008; Orth et al., 2006; Van Katwijk et al., 2011; Waycott et al., 2009). BCEs are situated at the nexus of land and sea, and they experience significant impacts from LULUC that occur across the terrestrial, coastal, and marine localities (Brown et al., 2019; Quiros et al., 2017; Smale et al., 2018). Therefore, it is also important to consider the interconnectivity between the systems in holistically assessing the overall impacts from LULUC (Tulloch et al., 2021).

The state of BCEs is closely interrelated with the socioeconomic wellbeing of humans, regardless of their physical proximity to the ecosystems themselves (Gevaña et al., 2018; Jones et al., 2022; UN.ESCAP, 2024). Mangroves provide essential ecosystem services, supporting small-scale and commercial fisheries (Barbier et al., 2011; Hutchison et al., 2014; Mozumder et al., 2018), offering coastal protection from storms and typhoons (Marois and Mitsch, 2015), preventing saltwater intrusion (Hilmi et al., 2017), abating pollution (Sundaramanickam et al., 2021), and sequestering and storing carbon (Alongi, 2014). Similarly, seagrass ecosystems are essential for fish habitat and breeding grounds (Edgar and Shaw, 1995; Jackson et al., 2015) coastal protection (James et al., 2021) water purification (de los Santos et al., 2020) and carbon sequestration and storage (Fourqurean et al., 2012). Additionally, both BCEs are integral to various spiritual and religious practices, offer recreational benefits, and contribute to the community's sense of place (van Bochove et al., 2014; Syukur et al., 2019; Saefullah et al., 2023). Mangrove forests, in particular, are recognized for their significant contributions to ecotourism, providing educational and recreational opportunities that enhance local economies and promote conservation awareness (Islam et al., 2024). Through the provision of these services, BCEs and associated biodiversity play a central role in underpinning the economies, livelihoods, food security, and wellbeing of humans, either directly or indirectly. This underscores the importance of conserving and sustainably managing these coastal ecosystems to maintain the socioeconomic benefits that they provide to communities.

To date, several review studies have documented the trends and drivers of LULUC in SEA and their impacts on BCEs, especially mangroves. Richards and Friess (2016) analysed the rate of mangrove deforestation driven by various factors in SEA, while Akber et al. (2020) focused on the expansion of coastal aquaculture and its role in mangrove loss. Todd et al. (2010) examined the effects of pollution from land use on coastal ecosystems, while Thomas et al. (2017) investigated the consequences of LULUC on mangrove ecosystems. Meanwhile, studies such as Sasmito et al. (2019), Lovelock et al. (2015) and Kondolf et al. (2014), have documented how land use changes diminish mangrove biomass, alter soil carbon stocks, and increase mangroves' vulnerability to sea-level rise by affecting sediment supply dynamics. Collectively, these reviews primarily focus on the ecological impacts in BCEs linked to LULUC.

In SEA, several studies have measured socioeconomic impacts of mangrove loss through evaluating losses or gains in ecosystem service provisioning (Ng and Ong, 2022; Orchard et al., 2016). Other studies evaluated the impacts of LULUC on specific socioeconomic wellbeing indicators like livelihoods, (Ardli et al., 2022; Van Hue and Scott, 2008), including economic outcomes of intervention activities such as community-based mangrove restoration projects (Walton et al., 2006). A systematic review of socioeconomic outcomes of agricultural land use change in SEA found potential trade-offs between economic outcomes like income, with other sustainable development indicators such as economic equality (Appelt et al., 2022). However, as highlighted by van Vliet and colleagues (2016), few studies have comprehensively analysed the intertwined impacts of LULUC on ecosystems and the associated socioeconomic outcomes. Thus, holistic assessments of the direct and indirect socioeconomic impacts of LULUC, especially for the rapidly developing, biodiverse SEA region, are urgently warranted.

Here we systematically map the current knowledge regarding the socioeconomic impacts of LULUC affecting blue carbon ecosystems in SEA. The aim of this study is to answer the research question, '*What are the socioeconomic impacts resulting directly or indirectly from land use and land use change within, adjacent to, or upstream of blue carbon ecosystems on the human communities in Southeast Asia?*'. Our comprehensive compilation of studies evidences the interconnectedness of BCEs and socioeconomic factors by linking both environmental and socioeconomic trade-offs to LULUC. Uniquely, we consider both direct and indirect socioeconomic impacts of LULUC on BCEs delivering an extensive review of SEA-specific evidence. Critically, we identify regional trends and pinpoint key knowledge gaps that need to be addressed. Our holistic set of socioeconomic well-being indicators highlights underexplored factors such as education, and cultural and spiritual values. Specifically, this study aims to serve as a resource for stakeholders seeking to align economic development with ecological conservation and socioeconomic wellbeing, and thereby contribute to sustainable development outcomes for people and the planet.

2. Methods

2.1. Systematic map methodology and guidelines

The methodology for this systematic map was adapted from the guidance outlined in the Guidelines and Standards for Evidence Synthesis (Collaboration for Environmental Evidence (CEE), 2022). The preparation of this manuscript adhered to the Reporting Standards for Systematic Evidence Syntheses (ROSES) for Systematic Map Reports (Haddaway et al., 2017) to ensure comprehensive reporting. This includes detailed documentation of key methodological steps, such as the formulation of the research question, literature search, screening and validation, data extraction, analysis, and synthesis. The ROSES checklist was used to ensure that all the reporting standards for systematic map reports required by the CEE guidelines were met.

2.2. Stakeholder engagement

This paper was conceptualised by Amy Then and Maryam Jamilah based on the outputs from a workshop titled "A holistic appraisal of knowledge gaps in our understanding of the impact of terrestrial land use change on blue carbon socio-ecological systems" held at Kuching, Malaysia on January 31, 2023–February 2, 2023. The workshop was motivated by the urgent need to enhance the effectiveness of marine nature-based solutions in addressing climate change. SEA was chosen as a region of focus due to its pivotal role in global carbon sequestration and biodiversity support, both of which are increasingly threatened by rapid LULUC. The workshop aimed to compile current knowledge and identify critical data gaps regarding the connectivity between coastal vegetated ecosystems and their broader social and environmental contexts. Human activities, both directly and through the downstream impacts of LULUC, can compromise the health of these ecosystems, while human wellbeing remains intricately tied to the many benefits they provide. As a result, blue carbon initiatives must prioritise the integration of local community needs and activities into their design to ensure sustainable effectiveness and socially-just implementation. Workshop attendees consisted of practitioners, subject experts, and early career researchers from non-governmental, governmental and academic organisations. The participant's expertise was broad and interdisciplinary, encompassing, but not limited to, knowledge of: blue carbon ecosystems, coral reef ecology, biogeochemical cycling, marine and coastal monitoring systems, LULUC, socio-ecological systems, remote sensing, and integrated marine and coastal management.

2.3. Search strategy

We conducted a systematic literature search to identify studies that were relevant to the research question, '*What are the socioeconomic impacts linked directly or indirectly from land use and land use change occurring within, adjacent to, or upstream of blue carbon ecosystems on the human communities in Southeast Asia?*'. Two major journal databases were accessed: Web of Science Core Collection and ProQuest Environmental Sciences Collection. The search was limited to English language articles and no limit to the publication year was set. The literature search was conducted between June 20, 2023 and July 2, 2023. Grey literatures were not included due to time, language, and resource constraints.

Keywords and key phrases used in the final search string were generated based on the decided PECO (Population, Exposure, Comparator, and Outcome) components (Table 1). Our literature search string (Table A1) was designed to capture studies on key blue carbon ecosystems, including mangroves, seagrasses, and tidal marshes; however, the absence of studies on tidal marshes in our database reflects their relatively limited prominence in Southeast Asia compared to other regions. A literature review was conducted to identify existing definitions, indicators, and classification systems for the exposure and outcome components. LULUC are classified into seven categories based on the definitions from the System of Environmental-Economic Accounting 2012: Central Framework (United Nations et al., 2014) and the Land Cover Classification System (Di Gregorio and Jansen, 2000). All categories were considered distinct from each other, although more than one land use category can co-occur within a study area. The socioeconomic impacts were classified into seven categories, based on classifications and definitions adapted from (Eales et al., 2021) and United Nations Sustainable Development Goals Indicators (United Nations, 2016). Definitions of LULUC and socioeconomic categories are listed in Table 2. Spelling variations and synonyms of the selected keywords were incorporated into the string to maximise the capture of articles. The final search string used can be found in Table A1 in Appendix A.

2.4. Article screening strategy

Search results captured across both databases were consolidated in the EndNote reference management software and duplicate results were removed. The bibliographic data were then exported to an online systematic review screening software, Rayyan (Ouzzani et al., 2016). Screening of the search results was carried out by five reviewers and conducted in two stages, starting with the article title and abstract screening followed by the full-text screening. A screening tool containing the inclusion/exclusion criteria was developed *a priori* as a protocol for the screening process (Table A2, Appendix A). The same list of criteria were applied for both screening stages and considered the relevance of each paper based on the key population, exposure, comparator, and outcome elements, as well as the study design used and publication type. In the first screening stage, the contents of the title and

Table 1
Population, Exposure, Comparator, and Outcome (PECO) components of the systematic map and their working definitions.

	Population	Exposure	Comparator	Outcome
Components	Coastal and other human communities in Southeast Asian countries	Land use and land use changes within, adjacent to, and upstream of blue carbon ecosystems (See categories in Table 2)	Absence of land use between sites or time periods	Impacts on socioeconomic status (See categories in Table 2).
Working definition	Human populations residing in coastal zones, urban areas, peri-urban regions, and rural communities. These groups are directly or indirectly affected by land use changes and activities, with varying reliance on natural and human-made resources.	Various human activities, management practices, and alterations of a designated land area that affect the health and resilience of blue carbon ecosystems—such as mangroves, seagrass beds, and salt marshes. These activities can impact the ecosystems through habitat degradation, biodiversity loss, and alterations of physicochemical conditions and dynamics.	Specific locations or temporal intervals in which BCES are exposed to little or no LULUC activities.	Qualitatively and quantitatively measured outcomes reflecting the overall quality of life of communities, i.e. the economic living standards, material living standards, health, security and safety, education, subjective wellbeing, and spiritual and cultural values.

Table 2
Definitions of the land use and socioeconomic impact categories corresponding to the exposure and outcomes PECO terms used in the systematic map.

Land Use (Exposure)	Definition
Agriculture	Land area that is arable, under permanent crops, and under permanent pastures.
Aquaculture	Land used for the farming of aquatic organisms including fish, molluscs, crustaceans, and aquatic plants.
Forestry	Land under anthropogenically disturbed natural forests—such as through logging and harvesting of forest products—or planted stands of trees, including silviculture. This definition excludes undisturbed natural forests, as well as tree stands in agricultural production systems (such as oil palm plantations, fruit plantations, and agroforestry systems) which falls under the 'Agriculture' category and trees found in urban parks and gardens.
Intervention	Land that is totally or partially conserved, managed, rehabilitated and/or reforested as protected areas, national parks, nature reserves or wildlife sanctuaries. This includes marine parks and MPAs.
Urbanisation	Construction, usage, and operation of urban infrastructure including housing, transport, buildings, sewage, and electrical facilities.
Industrialisation	Construction, usage, and operation of industrial structures and infrastructure including ports, factories, mines, waste treatment centres, landfills, and processing facilities.
Tourism	Construction, usage, and management of infrastructure for recreation and tourism within urban or natural areas.

Socioeconomic Impact Type	Socioeconomic Impact Category (Outcome)	Definition
Economic	Economic living standards	Income, employment, employment opportunities, wealth/poverty, savings, payments, loans, and cost of goods and services.
	Material living standards	Access to, availability, and level of consumption of tangible goods and services including food, fibre, fuel, basic infrastructure (electricity, water, telecommunications, and transportation), provision of shelter, and assets owned.
Social	Health	Level of physical health, mental health, balanced nutrition, longevity/life expectancy, maternal health, infant and child health, birth control provisioning, access to health care (antibiotics, transplants), occurrence of diseases, and public health.
	Cultural and spiritual value	The existence, perception, and practice of culture, tradition and spiritual beliefs, principles, and practices linked with presence of natural resources and nature to the community.
	Education	Level of access to and quality of informal education, formal education, and education infrastructure.
	Subjective wellbeing	Measures or perception of personal happiness, satisfaction, quality of life, and conflict levels.
	Security and safety	Factors affecting the physical and social stability and protection of communities, including measures of vulnerability, resilience, perception of security, and land tenure security.

abstract of each study was assessed for relevance, particularly with emphasis on the type of publication, geographical scope, focus on BCEs, and examination of socioeconomic impacts. During this stage, reviewers were inclusive wherever there was doubt as to the relevance of an article. During the second stage, only studies with accessible full texts were included, and contents of all sections of the full text were assessed in more detail on whether they met the full list of inclusion criteria.

To ensure consistency, the screening process was piloted in each stage by having each of the five reviewers independently screen a subset of the articles (2 % in title/abstract stage; 6 % in full text stage) and then comparing outcomes (proportion of articles included or excluded). Discrepancies in outcomes were discussed to resolve misinterpretations of the inclusion/exclusion criteria, and the inclusion/exclusion criteria was adjusted accordingly based on consensus to ensure clarity and consistency in its application for the remaining articles. Then, the search results were divided equally among the five trained reviewers to be screened independently.

2.5. Meta-data extraction and coding strategy

All the included articles were randomly reallocated to the reviewers. Qualitative and quantitative meta-data were systematically extracted using a combination of thematic analysis and coding method. A standardised Excel spreadsheet template specifying the pre-determined set of meta-data variables and coding categories (Table 3) with their required formats of input was used to ensure objectivity of the data extraction. Using thematic analysis, reviewers extracted relevant text from the published articles and summarised it into concise sentences to fill in the required information, other variables were coded based on pre-determined categories.

To enhance accuracy and reliability, the data extraction was piloted using a subset of 50 articles (26 % of the final dataset). Each reviewer independently analysed these articles using the standardised template. The extracted data from this exercise were then compared and a meeting was held to discuss discrepancies in the outputs. Adjustments were made on the template based on consensus agreements during the meeting. The remaining articles were then randomly divided among the five reviewers to be independently examined using the finalised Excel template.

All articles that comprise direct effects of LULUC on the BCEs were further analysed by a single reviewer. The results and discussion sections of each paper were examined to identify the approximate direction of the impact, and each study was assigned a categorical value indicating a positive, negative, or neutral socioeconomic outcome. Where a study

Table 3
Description of meta-data that was extracted from the included studies.

Meta-data	Description
Bibliographic information	Unique information that refers to a published article including article ID, author(s), year of publication, title, journal, volume, issue, and pages.
Publication type	Either journal article, conference paper, report, or thesis.
Study design	The type of study: ● Experimental (exposure is randomly allocated/controlled) ● Observational (exposure is not allocated/ controlled) ● Modelling (models used to project future outcome of an exposure)
Country	Country where the study was conducted.
Study location	Name and coordinates of the study site. Where there is more than one study site in one study, the central coordinate between the locations was used.
Spatial scale	The scale at which the study was conducted, or data was collected: ● Local (study was conducted focusing on one localised study site at the village/city/ municipal scale) ● Regional (study was conducted focusing on more than one local study site, or one or more study sites that is at the district scale within a state) ● National (study was conducted on sites across several states or at the national scale) ● International (study involves sites in more than one country).
Temporal information	Year of data collection and time length of data collection.
Ecosystem	The ecosystem that was impacted by land use, either mangrove, seagrass, or others (terrestrial, marine, and coastal).
Description of land use or land use change	Category of LULUC, location (within BCE, adjacent to BCE, or upstream), qualitative description of the LULUC, and year that LULUC occurred.
Type of impact	The mechanism in which the LULUC affected the BCE functioning and services. Direct (LULUC directly causes change in ecosystem services); Indirect (LULUC indirectly causes change in ecosystem services through connected physical and biological components; Implied (the impact on BCE is not clear/not measured but implied through changes in the connected physical and biological components).
Impacted ecosystem services	Ecosystem services affected by the described land use - provisioning, regulating, supporting, or cultural.
Description of socioeconomic impact type and category	Type of impact (social/economic) measured in the study, category type, and qualitative description of the impact, including methods used to measure it.
Data type	Quantitative, qualitative, or mixed.
Use of comparator	Indicate whether the study included comparisons of socioeconomic impact in the absence of land use, whether in a different site or before a time period.

measured more than one socioeconomic impact, each impact was assigned a separate value. However, if the study looked at multiple land uses, each land use was assumed to have equal weightage on the impact. Where available, the quantitative value of the socioeconomic impact, and qualitative information including the type of indicator used, and method of assessment were also recorded in the Excel sheet.

2.6. Data analysis and synthesis strategy

The extracted data were examined to identify the key findings, themes, trends, and other relevant contextual information of the evidence base. Distribution of studies published by country was determined and the site coordinates were plotted on to a map that was overlaid with existing datasets of mangrove and seagrass distribution data using QGIS (Bunting et al., 2022; Stankovic et al., 2023; UNEP-WCMC & Short, 2021). A Spearman's Rank-Order Correlation test was applied to compare the correlation between the total mangrove forest cover of a country based on data by Bunting et al. (2022) and total seagrass meadow cover per country based on data by Sudo et al. (2021) with the number of studies per country in this systematic map.

Proportion of studies by the year of publication, study design, land use type, and ecosystem type were calculated. The extracted metadata were analysed using Excel and the R computing software was used to visualise the data (R Core Team, 2022). To broadly determine the direction of impacts between each land use and socioeconomic category relationship, the categorical values were converted into discrete numerical values 1, 0, and −1 respectively. The values were summed for studies that fall within the same categories and the average values, indicating the direction of impact were calculated. To ease visualisation, the mean numerical values were re-interpreted as the direction and strength of impact between each relationship, categorising values between −1 and −0.5 as "most negative", between −0.5 and 0 as "less negative", 0 as "neutral", between 0 and 0.5 as "less positive" and between 0.5 and 1 as "most positive".

Qualitative information extracted from the studies was synthesised to identify the common themes and variations within the current evidence base. Keywords extracted in the database were examined to identify the specific activities carried out within each broad land use category, and their primary impacts on a particular group or community of people.

3. Results

3.1. Number of search results and included articles

We assessed a total of 5118 articles resulting from the database search and a total 190 articles were included in the final systematic map following the screening process. A flow map was generated with the ROSES template (Haddaway et al., 2018) to present the number of studies excluded or non-retrievable at each stage (Fig. 1). The articles consist of 168 journal articles, 21 conference papers, and 1 report (see Appendix B for the full dataset of included studies).

3.2. Trend in publication size and habitat type

The temporal distribution of publications highlights a significant increase in research focus on BCEs over the past two decades (Fig. 2). From 1999 to 2010, research activity was relatively limited, with studies emerging sporadically and comprising only 12 % of the total reviewed publications. During this period, research predominantly focused on mangrove ecosystems, such as Nickerson's (1999) analysis of the socioeconomic trade-offs in mangrove conversion for shrimp aquaculture. From 2011 onwards, there was a marked growth in BCE publications, corresponding with rising global awareness of climate change and blue carbon's role in mitigation strategies. The number of publications remained low and stable until 2015, after which there was a steady increase, peaking in 2022 with three times the number of studies compared to 2016. While earlier studies largely centred on mangroves, seagrass-focused publications began to emerge in 2014 (e.g., Bennett and Dearden, 2014), though they remain underrepresented. For distribution by ecosystem, seagrass studies only make up 2 studies, while mangrove make up 75 studies, and other non-BCEs make up 88 studies (other terrestrial ecosystems 23 studies, other coastal ecosystems 51

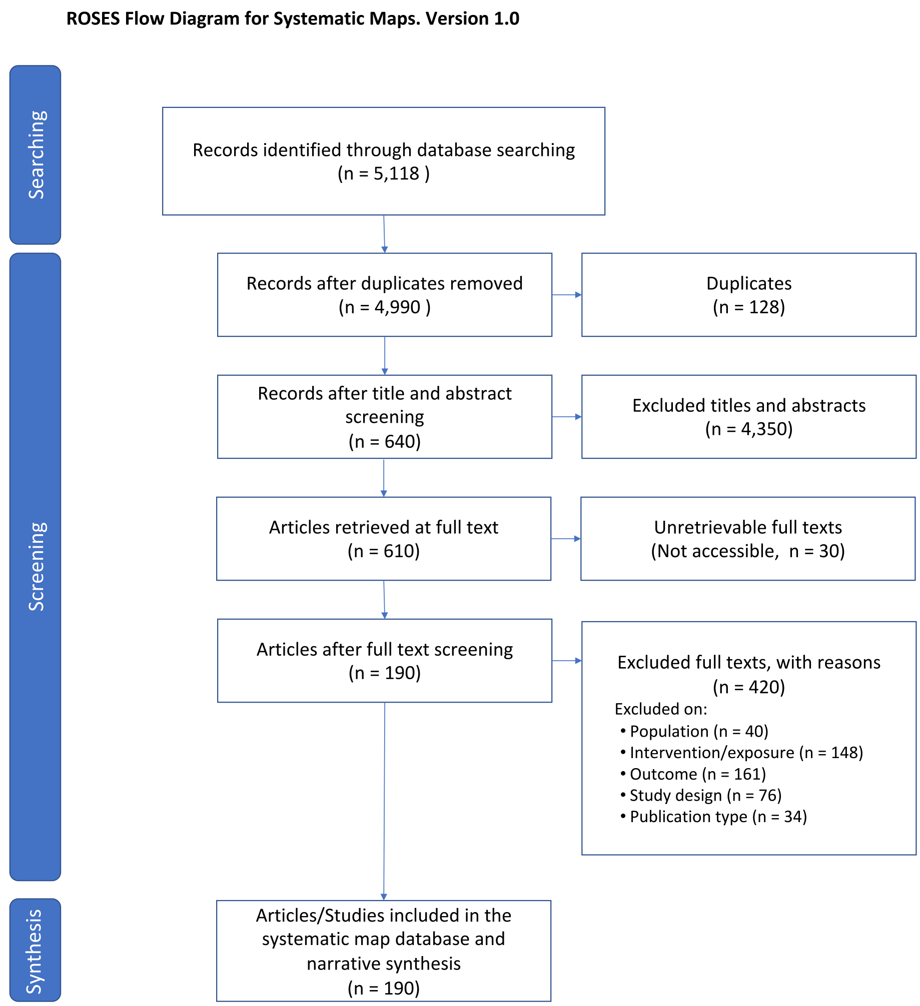

Fig. 1. ROSES (Reporting Standards in Evidence Synthesis) flow diagram. This illustrates the number of studies retrieved from the literature search, excluded during title and abstract screening and full text screening, and the final number of included studies in this systematic map.

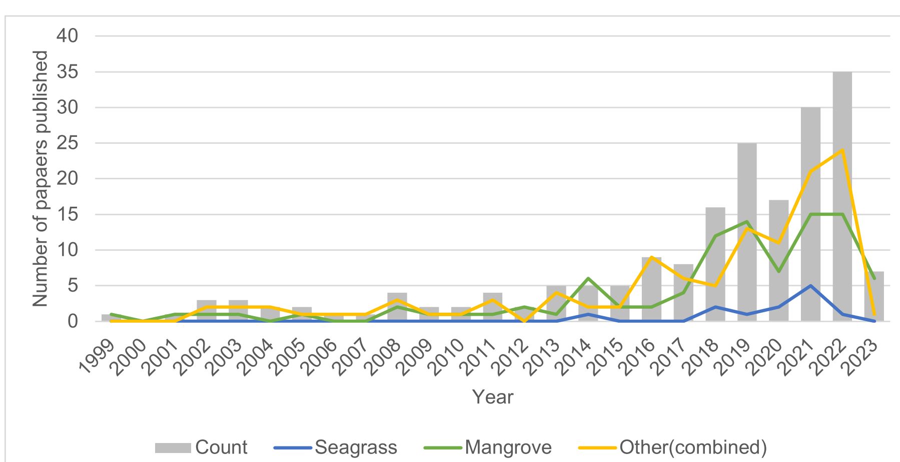

Fig. 2. The number of studies included in this systematic map by year, from January 1, 1999 to July 1, 2023. The grey bar shows total number of studies included in this systematic map per year. The blue line represents total included studies on seagrass ecosystems, the green line represents studies on mangrove ecosystems, and the yellow line represents the combined total number of studies on other terrestrial, marine, and coastal ecosystems. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

studies, and other marine ecosystems 14 studies). 25 studies include a combination of two or more ecosystems (10 of which includes seagrass and 21 of which includes mangroves.

3.3. Description of study design

In this systematic map, observational study designs were employed in 81 % of the records (154 articles), while 10 % of the records (19 articles) involved an experimental study design, 7.4 % (14 articles) applied modelling techniques, and 1.6 % (3 articles) used a combination of modelling and observational design. Among these, 43.2 % (82 articles) collected quantitative data, 38.9 % (74 articles) incorporated qualitative data, and 17.9 % (34 articles) utilised mixed data for their analysis. Comparison studies were present in 27.4 % (52 articles), while 72.6 % (138 articles) did not include a comparator.

Regarding the duration of the studies, 41.1 % (78 articles) were conducted over a period of fewer than 6 months, 17.9 % (34 articles) spanned between 6 and 24 months, 5.3 % (10 articles) lasted 2–5 years, and only 2.6 % (5 articles) extended beyond five years. 33.2 % (63 articles) did not specify the duration of the studies. In terms of spatial scale, 51.6 % (98 articles) were conducted at the local scale, 41.6 % (79 articles) within a region of a country, 5.3 % (10 articles) were conducted at the national scale, and 1.6 % (three studies) were international or transboundary in scale.

3.4. Distribution by country and study locations

The highest number of studies were conducted in Indonesia, followed by Vietnam, Malaysia, the Philippines, Thailand, Myanmar, and Singapore (Fig. 3). Two of the articles span both Malaysia and Indonesia, and one study looked at land use patterns across SEA (Luo et al., 2022). There were no included studies from Laos, Cambodia, or Timor Leste.

A Spearman correlation coefficient value of $\rho = 0.72$, indicated a strong positive correlation between the total mangrove forest cover and the number of studies published by country. However, Myanmar and Cambodia are notably under-represented in our review compared to their high total mangrove forest cover. Meanwhile, Vietnam has published a high number of studies despite having proportionately lower mangrove forest cover in SEA. As for seagrass cover, there is a moderate Spearman correlation coefficient of $\rho = 0.51$ between the total seagrass extent per country, with the number of studies per country. Cambodia has a lower number of studies than expected, despite having the second

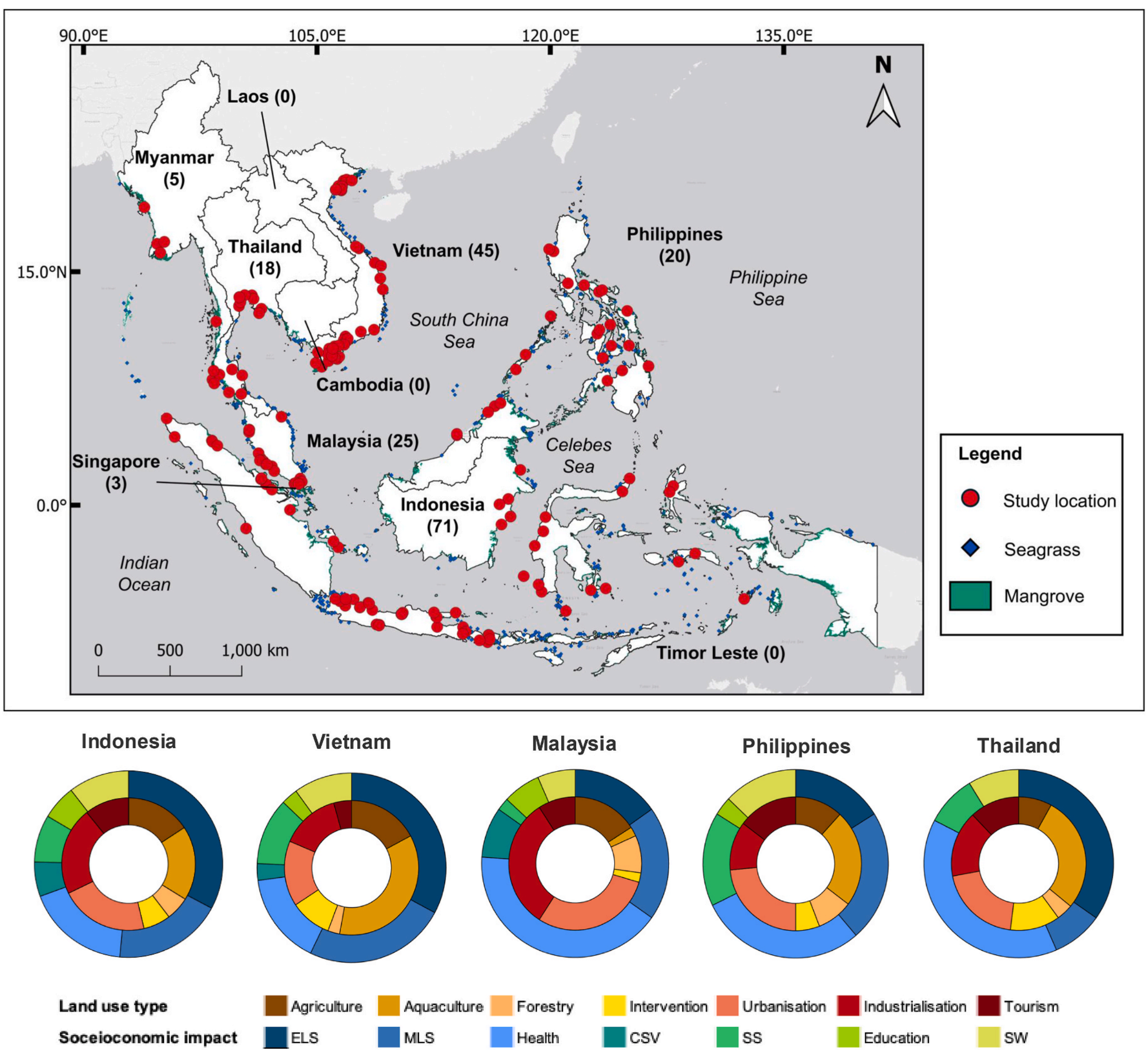

Fig. 3. Distribution of studies published across the Southeast Asian region (red points), overlaid with the estimated distribution of seagrass beds (blue diamonds) and mangrove forest cover (green shading). Donut charts represent the proportion of land use and socioeconomic impact categories within five of the countries. (Acronyms for socioeconomic impact categories: ELS – Economic living standards; MLS – Material living standards; CSV – Cultural and spiritual values; SS – Security and safety; SW – Subjective wellbeing). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

largest seagrass extent in SEA.

3.5. Description of LULUC activities

Among the types of LULUC included in the literature, aquaculture was the most common (n = 69) followed by urbanisation (n = 67), industrialisation (n = 58), agriculture (n = 48), tourism (n = 28), intervention (n = 21), and forestry (n = 16). The location of LULUC relative to the ecosystems varied, with most LULUC occurring within the BCE (45.8 %, n = 87), followed by LULUC that occurred adjacent to BCE (35.3 %, n = 67), and LULUC that occurred upstream of the BCE (16.8 %, n = 32). Three papers included both LULUC within and adjacent to BCE, while one paper included both LULUC within and upstream of BCE. A slight majority of the papers (50.5 %) did not state the starting year of the studied LULUC. Among the papers that did, the observed trend across decades was that LULUC mostly peaked in the 1990s and 2000s and started to decline in the 2010s and 2020s. The average duration of LULUC was 20 years. During the period of 1999–2010, aquaculture predominated as the primary LULUC type studied, constituting 45 % of the research. However, from 2011 to 2023, the distribution of studied LULUC types became more even, with 38 % focusing on urbanisation, 35 % on aquaculture, 32 % on industrialisation, and 26 % on agriculture. Throughout both time periods, intervention, forestry, and tourism were the least studied categories of LULUC. For seagrass habitats, the LULUC type most common within the studies were urbanisation, e.g. Sarmin et al., (2018) described seagrass degradation due to sedimentation and turbidity due to nearby infrastructural development. Tourism is the second most common LULUC associated with seagrass in our database, and it is linked with coastal degradation which threatens local livelihood and adaptive capacity (Quiros et al., 2018). Conversely, tourism activities nested within intervention measures like the Gili Mantra marine park shows contribution to the local livelihoods, even though concerns on its sustainability remain in discussion.

Some common keywords have been found to describe the type of LULUC within the studies (Fig. 4). These highlight recurring themes within each LULUC category. For instance, rice and paddy fields were prominent in the agriculture category, followed by oil palm, underscoring the socioeconomic significance of these crops and their impacts on BCEs. Similarly, the urbanisation and industrialisation categories frequently mentioned the word "waste," reflecting strong research interest in waste management and its effects on BCEs.

3.6. Description of socioeconomic impact

For practicality, we separated the social and economic categories during the coding process, in which the 'economic' category acts as the umbrella of the socioeconomic categories 'economic living standards' and 'material living standards', while the 'social' category comprise the remaining 4 categories. Our review found that 38 % of the studies that were included explored economic impacts of LULUC on human communities, 41 % evaluated social impacts, and 21 % included a combination of both. Among the socioeconomic categories that were measured, the most common one was economic living standards with (91 studies), followed by health (74 studies), material living standards (52 studies), security and safety (28 studies), subjective wellbeing (23 studies), cultural and spiritual value (16 studies), and education (14 studies).

As for mechanism of the impact, 52 % of the studies were of LULUC that directly impacted the BCE, 12 % were indirect impacts, and 48 % were implied impacts. When compared by ecosystem service, most impacts affected provisioning services (79 studies), followed by regulating services (53 studies), supporting services (32 studies), and cultural services (28 studies), while no impact on any ecosystem service was clearly indicated in 50 of the studies.

The description of socioeconomic impacts highlighted key areas within the categories (Fig. 4), such as income and livelihood in economic

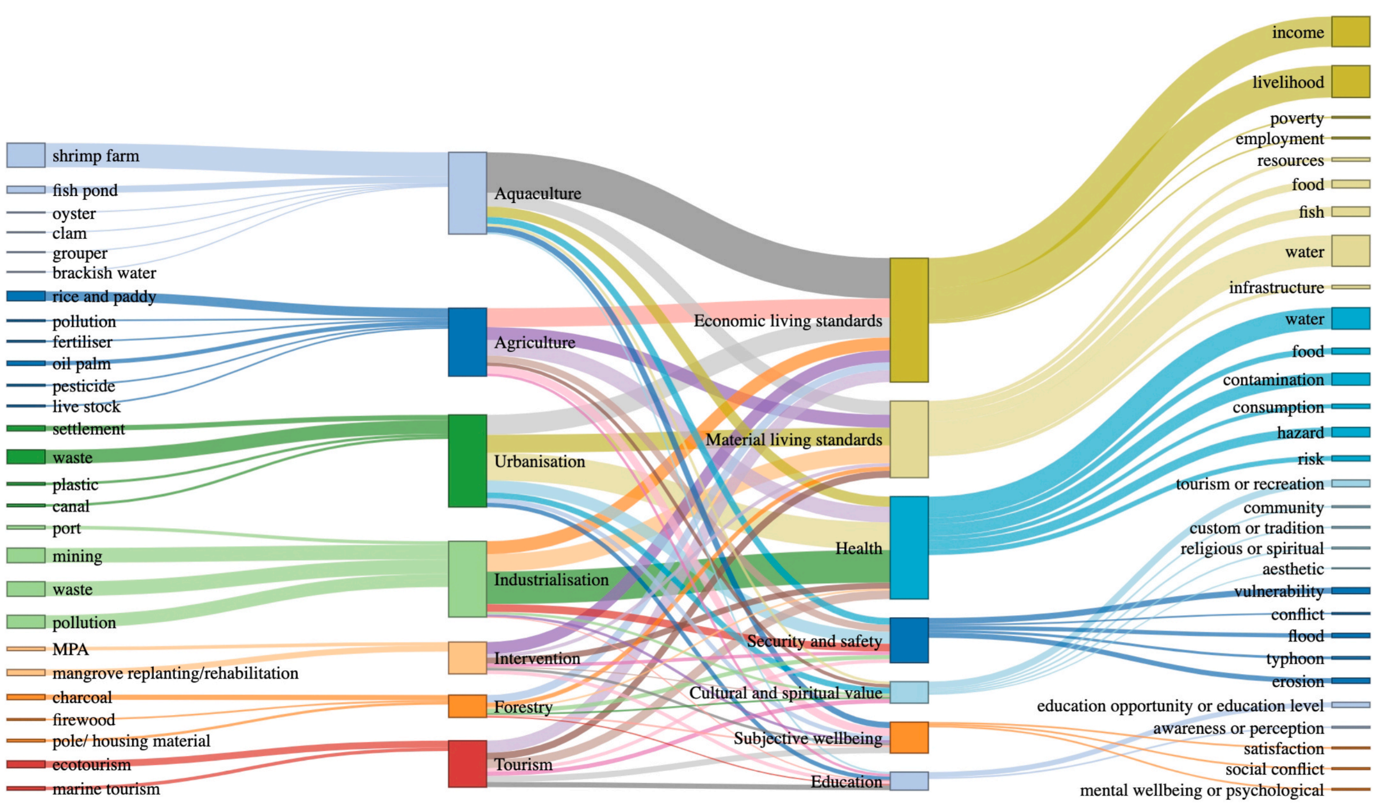

Fig. 4. Sankey diagram showing the distribution and relationships of frequent descriptive keywords in LULUC and socioeconomic categories within the systematic map.

living standards. Overlapping keywords like “water” and “food” in the health and material living standards categories emphasized risks from LULUC activities and BCE degradation to food security and clean water access. The frequent mentions of “contamination” and “hazard” also concur with the relative abundance of studies on water and fish pollution levels and its risks to community health.

3.7. Frequency of LULUC and socioeconomic impact studies

Fig. 5 highlights the distribution of studies examining the relationships between various LULUC and socioeconomic categories. Among the most researched pairs, aquaculture and economic living standards were predominant, reflecting the socioeconomic importance of aquaculture in supporting livelihoods. Industrialisation and health, as well as urbanisation’s impacts on both health and economic living standards, were also frequently studied, indicating research interest over impacts of pollution, and transitions to urban livelihood sources. Conversely, forestry-related impacts were underrepresented, with few studies exploring its effects on education, health, cultural and spiritual values, and subjective well-being. Similarly, intervention-based impacts on cultural and spiritual values were scarcely studied. These gaps underscore the need for more focused research on forestry and interventions to understand their broader socioeconomic implications, particularly in communities reliant on BCEs.

3.8. Direction of LULUC and socioeconomic impact relationships

Fig. 6 shows the distribution of socioeconomic impacts across different LULUC activities, highlighting a mix of positive, neutral, and negative effects. A majority of studies on agricultural land use report negative socioeconomic impacts across all indicators, except for cultural and spiritual values, which exhibit a neutral relationship, and education for which limited data is available. Aquaculture consistently demonstrates negative effects across all socioeconomic dimensions, except for education, where data is also limited. Forestry shows negative impacts on material living standards, health, security and safety, and education, while having a neutral association with economic living standards and cultural and spiritual values.

Interventions generally have positive effects on most socioeconomic indicators, except cultural and spiritual values and subjective wellbeing, where negative impacts are noted. Urbanisation is positively associated with economic wellbeing and education but negatively affects other categories. Similarly, industrialisation is associated with detrimental effects across all socioeconomic dimensions, but limited data is available on education and subjective wellbeing, where data are unavailable. Lastly, tourism exhibits positive associations with economic living standards and security and safety but also shows negative impacts across other socioeconomic indicators.

This distribution highlights not only the significant challenges posed by certain LULUC activities but also the potential for targeted interventions and sustainable forestry practices to generate positive socioeconomic outcomes. However, it is useful to note that this overview, while useful for visualizing broad patterns within the literature, may not fully capture the complexity of real-life impacts. Readers should exercise caution and consider the individual results of each study for a more nuanced understanding, as the impacts of LULUC activities can vary greatly depending on local contexts, study methodologies, and the specific socioeconomic indicators measured.

4. Discussion

Our systematic mapping approach tackled a complex topic pertaining to socioeconomic impacts in the SEA region, resulting from LULUC occurring within or in proximity to BCEs. This is significant given that to date, most related studies employing systematic review approaches have documented primarily the types, trends, and drivers of LULUC that have occurred across different countries (e.g. (Akber et al., 2020; Richards and Friess, 2016; Thomas et al., 2017), and the impacts of LULUC on the ecology and functioning of BCEs. Very limited work has explored the socio-ecological aspects, i.e., direct and indirect connections of LULUC on the human dimensions, especially to those that rely on BCEs for livelihoods and wellbeing. Below, we provide an overview of the characteristics of the current evidence base, informed by the selected pool of SEA studies, the knowledge clusters that represent high evidence concentration, highlights of existing research gaps, and avenues for future work.

4.1. Trends of LULUC drivers of BCE loss

An uneven distribution of socioeconomic studies across various LULUC categories can be seen during the period of over two decades. The majority of studies concentrated on industrialisation, urbanisation, aquaculture, and agriculture, consistent with previous reviews showing that these are the common land uses that replaced deforested mangroves

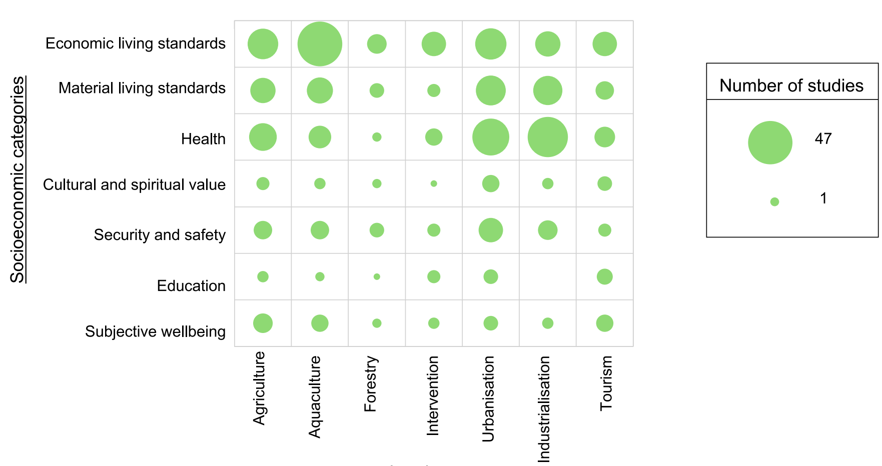

Fig. 5. A bubble chart of the frequency of socioeconomic categories linked to land use categories in the evidence base. The radius of circles indicates the number of studies in each pair.

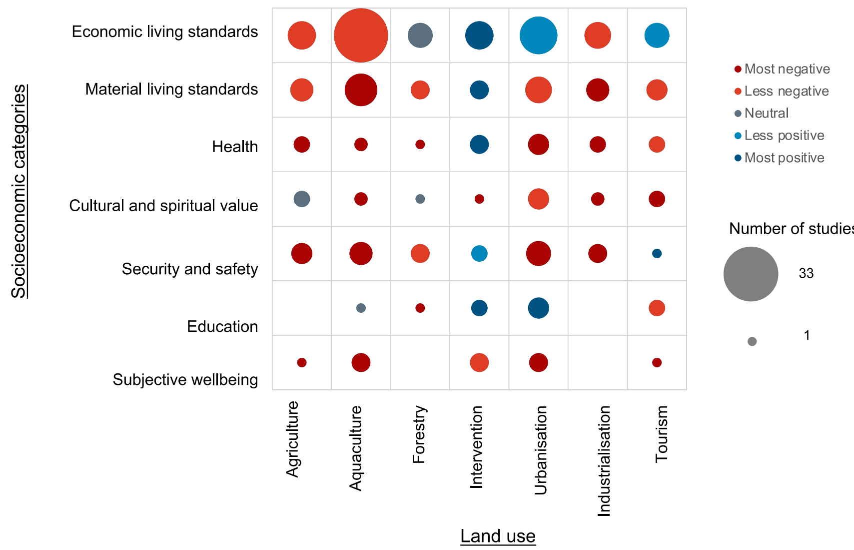

Fig. 6. A bubble heatmap illustrating the direction of impacts between land use and socioeconomic factors. Only studies with direct impact of land use on blue carbon ecosystems were included in the heatmap. The colours of the circle denote the direction of the impact, and the radius of circles indicate the size of evidence. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

in SEA (Bhowmik et al., 2022; Richards and Friess, 2016). The 1980s marked a shift in the region from being an economy primarily supported by agricultural and raw materials, to becoming major exporters of manufactured goods (Zito et al., 2014). Rapid industrialisation and concurrently, urbanisation, due to high population growth rates resulted in significant changes in land use patterns in the region (Nuissl and Siedentop, 2021). The prevalence of studies on aquaculture aligns with the significant intensification of aquaculture activities in the region since the early 2000s. Similarly, a high concentration of studies on agriculture reflects the significant growth and transformation in SEA over the past decades, driven by population growth, technological advancements, and government policies aimed at enhancing food security, boosting rural incomes, and stimulating economic growth. With major cities and over 70 % of the SEA population located near coastal ecosystems (Todd et al., 2010) the loss of BCEs driven by human activities were significant.

Within the evidence base, socioeconomic impacts of forestry are relatively under-represented despite the significance of small-scale and commercial mangrove production forests for timber and non-timber products like wood chips, charcoal, and tannins in the region (Aksornkoae and Kato, 2011). Impacts from coastal tourism were also less prominent in our findings despite being very economically important with a substantial surge in international tourism in the region over the past three decades (Trupp et al., 2020). There was also less research on outcomes of intervention activities involving BCEs such as conservation and restoration efforts, despite gaining increased global interest for their blue carbon benefits (Gerona-Daga and Salmo, 2022), although there are presently limited tangible monetary benefits due to the infancy of blue carbon projects in the region (e.g. Lee et al., 2024; Thuy and Thuy, 2019). In the present database, the main intervention activities described were marine protected areas and reserves (Zamzami et al., 2020), mangrove rehabilitation efforts (Carrie et al., 2022), and community-based interventions (Miller et al., 2020). The imbalance of concomitant studies to reflect these dynamically changing LULUC trends should be considered to ensure a holistic evidence base of socioeconomic impacts that can help inform appropriate decision making on BCE management balancing sustainable development goals with economic growth.

4.2. Disparities in socioeconomic measures

The most studied category of socioeconomic impacts in the evidence base is the economic living standard, which encompasses various monetary-based and non-monetary indicators such as income levels, employment rates, wealth distribution, and access to economic resources. As land use changes are largely driven by economic factors mediated through policies and markets (Lambin et al., 2003), decision-makers often justify conversion of natural ecosystems to alternative land use types as a means to achieve economic growth. However, our evidence base suggests that the relationship of LULUC with economic living standards is a mixture of positive and negative. Some studies show positive outcomes in terms of net revenue and income gained from the livelihood activities after LULUC, for example, aquaculture and agriculture practices generated sustainable family income in Xuan Thuy, Vietnam (Nguyen et al., 2019). However, some studies also show that the primary economic benefits mostly accrue to certain stakeholders such as landholders and commercial entrepreneurs rather than local smallholders and rural communities that reside in the area (Barbier and Cox, 2004; Primavera, 2006). Unequal distribution of economic benefits across different stakeholder groups has been shown to lead to undesirable outcomes such as widened income gaps and worsening poverty rates among marginalized groups (Adger et al., 2002; Trung Thanh et al., 2021). In addition, net cost associated with valuable ecosystem services lost due to land use changes is often not considered (Sathirathai and Barbier, 2001). Interestingly, despite the inequality and relatively low income generated, some studies show that locals still prefer these jobs generated from LULUC such as forestry, due to factors such as good employment opportunities and geographical accessibility (Satyanarayana et al., 2021).

Many studies in the evidence base have also assessed health outcomes, indicating a strong recognition of human health as a crucial element of socioeconomic wellbeing. The direct studies, primarily focusing on concerns of water pollution and contamination of marine and coastal organisms within BCEs in the region (Todd et al., 2010), mostly point to net negative human health impacts. Various types of pollution (metals, microplastics, insecticides, organochlorines, aromatic hydrocarbons, and heavy metals), detected in sediments, water, plants, fauna, and humans, from land-based activities such as mining (Lasut et al., 2010), industrial processes (Bashir et al., 2013), increased urbanisation (Dsikowitzky et al., 2011), tourism (Encarguez et al., 2019) and agriculture (Yap and Al-Mutairi, 2022) are transported to the BCEs via rivers. Indirect but consequential health impacts from LULUC activities also occur via consumption of contaminated seafood (Tran et al., 2021) and from increased disease incidences such as malaria due to changes in water properties within the BCEs (Hossain et al., 2005). Past studies have shown that mangroves provide crucial ecosystem services that contribute positively to human physical and mental health such as provision of medicines, pollution regulation, and provision of food resources through support of fisheries (Awuku-Sowah et al., 2022). For instance, coastal communities in the Kland islands of Malaysia use mangrove-derived products to improve health and treat physical illnesses. They also perceive the presence of mangroves to be ‘relaxing’ and a source for fresh air and a cooler environment (Ruslan et al., 2022). These further highlight the importance of mangrove for human health and consequently, the adverse impacts associated with its loss or degradation.

Our systematic map reveals that material living standards, one of the most frequently measured socioeconomic categories, shows an overall negative impact across the LULUC studies. This negative outcome is primarily attributed to the food insecurity due to the decline in mangrove-associated fish stocks (Rudianto et al., 2022), difficulty in accessing mangrove products for traditional housing construction materials (Kuenzer and Tuan, 2013), restricted entry to native land due to privatisation (Mabon et al., 2018), and decreased availability of clean water sources (Nguyen et al., 2019). This finding highlights the importance of land ownership and community access to BCEs as these directly impact their ability to sustain themselves, to generate income, and to improve their overall living conditions through activities such as fishing, gleaning, and harvesting timber and non-timber products (Aye et al., 2019). Secure access to land can also lead to better agricultural productivity, sustainable resource management, and economic stability in local livelihoods (Food and Agriculture Organization of the United Nations (FAO), 2002). Conversely, lack of access or insecure land tenure can contribute to poverty, food insecurity, and social conflict (Ali et al., 2014; Holden and Ghebru, 2016).

One under-represented socioeconomic measure resulting from loss of BCEs is the security and safety category. Loss of mangroves increases exposure to flood-related risks (Hadi, 2017), coastal erosion (Sarmin et al., 2018), and typhoons (Pham and Yoshino, 2016). Upstream LULUC activities such as mining and agriculture result in increased sediment loads (Anh et al., 2021) or blocked sediment transport into BCEs (Hue and Thanh, 2020) which increases coastal erosion (Vogel et al., 2022). Additionally, deforestation of mangroves which serve as a natural habitat for thousands of wildlife species, including the critically endangered Northeast Bornean orangutan (*Pongo pygmaeus morio*) in Kalimantan, cause increased occurrences of human-wildlife conflict as the wildlife encroach into human villages (Guild et al., 2022).

Another less studied socioeconomic measure is education, although access to good education is commonly linked with economic prosperity (Pillay, 2012). The lack of studies examining this dimension may be due to the lack of direct link between LULUC and education status of affected communities, making it difficult to measure the impact. Similarly, there is a lack of studies on cultural and spiritual impacts of LULUC, aside from the assessment of recreational value of the BCEs. Historically, research and development aims have mainly focused on the economic and tangible outcomes from land use, with less priority on measuring intangible impacts on the communities due to their subjective nature. Subjective wellbeing, which encompasses mental wellbeing, happiness, life satisfaction, and exposure to social conflict, are equally under-represented in the evidence base – likely due to the lack of awareness about its significance and difficulties in measuring the changes substantially, especially in retrospect.

4.3. Limitations of evidence base and methodology

4.3.1. Uneven spatial distribution of studies and under-representation of impacts linked with seagrass

There is an uneven geographical distribution of studies captured in this systematic map, with more than half the research focused on Indonesia and Vietnam. The concentration of research studies does not align with the identified hotspots of mangrove deforestation in Myanmar’s Rakhine State, Indonesian Sumatra and Borneo, and Peninsular and East Malaysia (Richards and Friess, 2016). There is a need to address the geographical disparity in research efforts, with particular attention to regions facing heightened threats of mangrove loss such as Myanmar, Laos, Cambodia, and Timor Leste. Increasing research in these regions can contribute to a more comprehensive and regionally representative understanding of the impacts of LULUC on socioeconomic outcomes in mangrove ecosystems.

In addition, the breakdown of studies in this systematic map reveals a significant lack of socioeconomic impact studies on seagrass ecosystems in SEA. Seagrass research in the region has historically lagged other ecosystems (Ooi et al., 2011). However, a review by Fortes et al. (2018) indicates a notable increase in research interest on seagrasses within the past decade. Although many of these studies focus on seagrass ecology, there is a growing emphasis on conservation and management in the literature due to the crucial ecosystem services that they provide.

4.3.2. Length of studies

The average LULUC duration (20 years) in the included studies has implications for measuring impacts. It may not capture the full spectrum of short-term and long-term effects on ecosystems and socioeconomic outcomes. Furthermore, the absence of detailed temporal information in many studies complicates the assessment of these impacts. Information on length of data collection and the length of studies are important to assess whether the impacts resulting from LULUC are immediate, delayed, or persistent over time (Hadfield et al., 2007). Since LULUC typically occur over a span of several years, the studies may not capture the full range of impacts that different LULUC can have on ecosystems and socioeconomic outcomes. Understanding the temporal dynamics of LULUC impacts is crucial for developing effective conservation and management strategies. The lack of such information hinders a comprehensive understanding of these impacts, limiting the precision and applicability of the findings.

4.3.3. Limitations in methodology

While we aimed to capture a wide range of evidence through using a large number of keywords in the search string, the search process was inherently constrained by time and resources, and thus, could not be entirely exhaustive. The choice to constrain the search to publications in English, may have excluded relevant studies, including grey literature, published in other languages. Nevertheless, given the broad coverage of keywords used in our search strategy, and that most high-impact and widely cited studies are published in English, we expect that the overall trends identified in our study are representative of the evidence base. Future studies on this topic could include grey literature and non-English sources to gain additional understanding of the deeper regional context.

Despite standardised criteria set, reviewers’ prior knowledge and interpretation biases can potentially influence their judgment during the screening and data extraction process. However, the pilot test followed by multiple discussion sessions between the reviewers ensure that the discrepancies that may arise in the article screening and data extraction process due are minimised and the dataset is accurately extracted. We also recognise that assigning categorical values to summarise the direction of impact significantly reduces the complexity of the findings in the studies which is often not straightforward to assess. While this method allows for a structured way to make broad comparisons of the socioeconomic impact across studies, the full range of nuance and context of the relationship might be lost. Future studies can build upon this study by conducting more granular analysis using the various quantitative and qualitative indicators used to measure the socioeconomic variables.

We acknowledge that our current methodology could not capture specific changes in socioeconomic status before and after significant land use changes, which is a valuable aspect for understanding the full impact on communities. To improve the insights from this systematic map further, we suggest that researchers could examine the causal relationships between the shifts in land use towards or away from BCEs and the socioeconomic status of the impacted communities by focusing on studies that explicitly include comparators such as before-and-after or longitudinal observations. This could provide a clearer picture of the dynamics involved, identifying key factors that contribute to positive or negative outcomes and offering lessons for managing such transitions more effectively.

4.4. Ways forward

Policy formulation and practical applications affecting blue carbon ecosystems should integrate a more holistic approach to land use development planning. This includes comprehensive prior assessments that account for both direct and indirect cascading impacts, such as pollution runoff, loss of ecosystem services, and economic trade-offs among stakeholders. Sustainable alternatives, such as mangrove agroforestry and integrated mangrove aquaculture, should be explored to balance environmental conservation with socioeconomic benefits. Additionally, cost-benefit valuation studies must incorporate both tangible and intangible socioeconomic indicators, including subjective wellbeing, cultural and spiritual values, and educational impacts, to ensure a more inclusive and informed decision-making process.

4.4.1. Considering interconnectivity of systems from land to sea

Effective management of BCEs requires understanding the physio-biochemical connectivity between marine populations, habitats, and terrestrial environments (Brown et al., 2019; Smale et al., 2018). Protecting and restoring BCEs necessitates considering the entire system from land to sea and across the socio-oceanographic system (Popova et al., 2023). To reflect the importance of this connectivity, our study mapped the socioeconomic impacts associated with LULUC not only within BCEs but also in adjacent and upstream habitats. Notably, over 50 % of the studies in our evidence base focused on connected systems outside the immediate boundaries of BCEs, highlighting the broader spatial dimensions of these impacts.

Studies capture BCEs crucial role as physical buffers between land and sea, as they protect against flooding and erosion, and prevent sediments from smothering marine ecosystems (Barbier et al., 2008; Dang et al., 2021). Sediment supply is crucial, with both abundance and shortage impacting BCEs. Impacts caused by changes in sedimentation due to coastal infrastructure (Cheablam and Dachyosdee, 2022; Lin et al., 2021) and other LULUC (Chen et al., 2020) can negatively affect mangroves, and seagrasses with subsequent socioeconomic impacts such as loss of access to water transportation (Anh et al., 2021). Vital BCEs also act as natural filters trapping litter and other pollutants in sediments and reducing their flow into marine environments. Some mangrove species also have phytoremediation properties to remove toxic metals from the sediment (Yap and Al-Mutairi, 2023). Hence, the loss of mangroves through deforestation and land use change caused increases in downstream pollutant flow (Tam and Wong, 1995). Beyond their regulating functions, BCEs also provide crucial habitats for various organisms, acting as fish nurseries (Marlianingrum et al., 2019) and seasonal habitats for migrating birds (Green et al., 2015). Mangrove areas can also regenerate naturally through seed transport from connected systems (Lahjie et al., 2019). While these studies recognise the biological, physical, and chemical connections of BCEs in the land-to-sea interface, few studies explicitly make this link. Only 12 % of studies in our database measured the indirect impacts of LULUC and BCEs, though such impacts are implicitly acknowledged in over 48 % of studies. Moving forward, a holistic approach to land use decisions, considering the physical, ecological, and socioeconomic interconnectivity is essential to achieve a sustainable positive outcome.

4.4.2. Increased community participation in BCE management

Interventions that foster socio-ecological inter-connectivity, especially in empowering community participation in BCE management, have been shown to produce positive impacts on BCE functioning and services. For example, Rosadi et al. (2022) demonstrate that the mangroves and seagrasses of the Gili Matra islands in Indonesia improved due to Marine Protected Area (MPA) gazettement and community-led ecotourism activities, leading to net positive economic living standards, security, and health. Similarly, a community-led mangrove conservation and fisheries intervention improved economic living standards, health, and education in West Kalimantan, Indonesia (Miller et al., 2020), and increased income, education, and access to mangroves in another case study (Handayani et al., 2020). Mangrove rehabilitation also positively impacted material living standards, security, and health due to improvements in mangrove systems (Carrie et al., 2022). Other studies in our database show that when mangroves replaced aquaculture and oil palm plantations, there were increases in economic living standards, mangrove products such as wood and fish, and subjective well-being (Basyuni et al., 2018a, 2018b). Similarly, integration of intensive shrimp aquaculture with mangrove planting in silvofishery systems also led to increased economic living standards (Basyuni et al., 2018c). These findings underscore the potential for community involvement in BCE management to mitigate trade-offs caused by LULUC.

4.4.3. Recognise role of BCEs in climate change mitigation

BCEs have significant potential for long-term carbon sequestration and storage and degradation or conversion of these ecosystems will cause significant greenhouse gas emissions (Pendleton et al., 2012). Many studies in this systematic map focus on the conservation, preservation, and restoration of BCEs, (intervention measures) but seldom include their carbon capture capabilities. Studies frequently emphasise other ecosystem services (ES), such as sustainable tourism (Hamimah et al., 2022), food security (Rudianto et al., 2022), and charcoal production (Satyanarayana et al., 2021). This suggests that carbon storage is not presently a local priority and that potential benefits are not yet integrated into national interests. Local ecosystem services (e.g., coastal protection, food, cultural services) are of more immediate importance to communities compared to the long-term, global benefits of carbon capture which has fewer tangible outcomes. Increased engagement and awareness with the local communities could be the best way forward to maximise conservation and restoration outcomes.

Blue carbon projects, aimed at protecting BCEs, generally seek to defend them from loss due to deforestation and degradation through a financing scheme involving carbon trading mechanisms (Chen et al., 2020). This provides an opportunity for generation of alternative livelihoods, creation of jobs and increase in income for local coastal communities, while minimising the adverse economic, health, and wellbeing effects from the ecosystem damage that result from unsustainable practices. However, various constraints, including commercial considerations and regulatory uncertainties, currently hinder the effectiveness of voluntary carbon markets for blue carbon projects in the region (Mack et al., 2022; Vanderklift et al., 2019). Meeting the stringent requirements of internationally verified carbon standards like Plan Vivo and the Verified Carbon Standard (VCS) can be challenging, but they are crucial (Wylie et al., 2016). Currently, there are only five blue carbon projects in SEA, specifically in Myanmar and Indonesia, listed as either "registered" or "under validation" with the VCS (Verified Carbon Standard, 2023). Further research on the feasibility of blue carbon financing mechanisms in SEA is warranted.

5. Conclusion

This systematic map provides a summary on the current state of this research topic and highlights the variability in distribution, design, and focus of studies within the SEA region. It offers initial insights into the effects of LULUC in BCEs which frequently show negative implications, and trade-offs across different socioeconomic categories. By identifying key patterns, gaps, and implications of the topic, this systematic map lays a foundation for future work and presents a case for a more holistic consideration of impacts driven by human activities.

We recommend emerging research to focus on the gaps identified within the evidence base, specifically, the socio-ecological significance between communities with seagrass ecosystems, focused research on under-represented countries like Cambodia and Myanmar, and increased examination of the least represented socioeconomic metrics, such as education, cultural and spiritual values, and subjective well-being. Economically motivated decision-making on land use must consider the complexities of socioeconomic outcomes particularly on vulnerable, marginalized coastal communities. Identifying the direct and indirect socioeconomic impacts linked to LULUC in BCEs is essential for creating effective, equitable, and sustainable management practices which not only protect vital ecosystems, but also support and enhance the livelihoods and wellbeing of the communities that depend on them.

CRediT authorship contribution statement

Maryam Jamilah: Writing – original draft, Visualization, Validation, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Amani Becker:** Writing – original draft. **Soon Loong Lee:** Writing – original draft, Visualization, Validation, Investigation. **T.E. Angela L. Quiros:** Writing – original draft. **Su Yin Chee:** Writing – original draft. **Claire Evans:** Writing – review & editing. **Yu Yang Tan:** Validation, Investigation. **Lian Lin Ti:** Validation, Investigation. **Irsyad Pishal:** Validation, Investigation. **Amy Yee Hui Then:** Writing – original draft, Supervision, Project administration.

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.ocecoaman.2025.107643.

Data availability

Data will be made available on request.

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