REVIEW

Bibliometric insight of climate change impact on mackerel (Family Scombridae): global research trend and regional gaps in southeast Asia

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ABSTRACT. The effects of climate change on mackerel species are highlighted in this review, with particular attention given to changes in spawning, distribution, physiology, and habitat loss. The PRISMA method was used to conduct a systematic literature review that examined 257 peer-reviewed publications from Scopus and Web of Science from 1990 to 2025. Results showed clustering of texts, keywords, and titles based on search terms like climate change vulnerability, impact, mackerel, southeast Asia, and world. High occurrence and link strength showed clusters of: 1) Oceanography and marine ecosystem, 2) Species-specific regional studies, 3) Fisheries and human dimensions and, 4) Fisheries management. Major study themes were found using R bibliometrix and thematic analyses based on VOSviewer: adaptation technique, marine ecosystems, stock assessment, and fishing management. Sea-surface temperature, environmental monitoring, and resilience in marine resource management are highlighted in recent research trends. Traditional fisheries are being challenged by the altered migration and spawning patterns of mackerel due to rising sea surface temperatures and changing currents, necessitating the implementation of flexible and regionally coordinated techniques. Growth, recruitment, and survival are all impacted by these changes because of decreased oxygen, productivity, and prey availability. Conflicts over fisheries may also occur as a result of transboundary fish stock migrations. Adaptive management is still limited despite increasing research because of a lack of institutional support, resources, and monitoring. It is crucial to fill important research gaps in areas including prey dynamics, socioeconomic resilience, and the effects of climate change on mackerel biology. Stronger governance, regional collaboration, and policies that strike a balance between socioeconomic demands and conservation will be necessary to ensure long-term sustainability.

Key words: Systematic literature review, PRISMA method, fisheries management.

El papel de la escolarización en la configuración de la huella pesquera en Grecia: evidencia de un enfoque ARDL aumentado

RESUMEN. En esta revisión se destacan los efectos del cambio climático en las especies de caballa, con especial atención a los cambios en el desove, la distribución, la fisiología y la pérdida de hábitat.

Se utilizó el método PRISMA para realizar una revisión sistemática de la literatura que examinó 257 publicaciones revisadas por pares de Scopus y Web of Science entre 1990 y 2025. Los resultados mostraron agrupamiento de textos, palabras clave y títulos con base en términos de búsqueda como vulnerabilidad al cambio climático, impacto, caballa, sudeste asiático y mundo. La alta ocurrencia y la fuerza de enlace mostraron agrupaciones de: 1) Oceanografía y ecosistema marino, 2) Estudios regionales específicos de especies, 3) Pesca y dimensiones humanas y, 4) Gestión pesquera. Se encontraron los principales temas de estudio utilizando R bibliometrix y análisis temáticos basados en VOSviewer: técnica de adaptación, ecosistemas marinos, evaluación de *stock* y gestión pesquera. La temperatura superficial del mar, el monitoreo ambiental y la resiliencia en la gestión de los recursos marinos se destacan en las tendencias de investigación recientes. La pesca tradicional se ve amenazada por la alteración de los patrones de migración y desove de la caballa debido al aumento de la temperatura superficial del mar y las corrientes cambiantes, lo que exige la implementación de técnicas flexibles y coordinadas a nivel regional. El crecimiento, el reclutamiento y la supervivencia se ven afectados por estos cambios debido a la disminución del oxígeno, la productividad y la disponibilidad de presas. También pueden surgir conflictos pesqueros como resultado de las migraciones transfronterizas de poblaciones de peces. La gestión adaptativa aún es limitada a pesar del aumento de la investigación debido a la falta de apoyo institucional, recursos y monitoreo. Es crucial cubrir importantes lagunas de investigación en áreas como la dinámica de las presas, la resiliencia socioeconómica y los efectos del cambio climático en la biología de la caballa. Una gobernanza más sólida, la colaboración regional y políticas que logren un equilibrio entre las demandas socioeconómicas y la conservación serán necesarias para garantizar la sostenibilidad a largo plazo.

Palabras clave: Revisión sistemática de la literatura, método PRISMA, gestión pesquera.

INTRODUCTION

Climate change is reshaping marine ecosystems through rising sea temperature, altered circulation patterns, acidification, and the degradation of critical coastal habitats (Islam et al. 2020; Habib et al. 2025). These environmental changes influence metabolic processes, growth patterns, and reproductive success in many marine species, particularly pelagic fishes that depend on predictable oceanographic conditions for spawning, feeding, and migration (Pörtner et al. 2014). Ocean acidification further disrupts physiological and sensory functions, potentially altering predator-prey interactions and competitive dynamics (Munday et al. 2009). In the context of these changing conditions, adaptive and ecosystem-based fisheries management has become essential, especially in regions where coastal communities depend heavily on marine resources for food security and livelihoods (Pinsky and Mantua 2014; FAO 2018).

Mackerel (Family Scombridae) are among the most ecologically and economically significant pelagic fishes in southeast Asia. They contribute substantially to industrial, artisanal, and small-scale fisheries and remain an important source of affordable animal protein throughout the region (FAO 2018). In southeast Asia, Indian mackerel (*Rastrelliger kanagurta*) and Spanish mackerel (*Scomberomorus commerson*) dominate regional captures due to their high abundance, diverse culinary applications, and cultural significance (Wang and Wu 2025). In particular, Spanish mackerel serves as a vital source of revenue sustaining their livelihoods and meeting local protein demand of coastal fishermen in countries like Indonesia, the Philippines, and Malaysia (Wang and Wu 2025). In recent years, research on the relationship between climate change and fisheries has moved from correlative observations to process-based and ensemble projections that measure economic consequences, range shifts, and production losses of pelagic fishes, including mackerels (Free et al. 2019). With the projection of seasonal redistributions and changed catch potential under mid to late century scenarios, species distribution and habitat suitability modeling for scombrids has grown significantly (Sun et al. 2024). Despite long-standing concerns about overexploitation, recent regional assessments suggest relatively stable or increasing catches in several southeast Asian countries, with a significant proportion of pelagic stocks classified as underfished compared to global averages (Fabro 2020).

Geographic location, economic reliance on fisheries, and great biodiversity make southeast Asia (i.e. the Philippines) especially susceptible to these effects (Macusi et al. 2020, 2025a, 2025b). Despite supporting some of the world's most diverse and productive ecosystems, this region is already seeing a decline in fish populations, a shift in the distribution of species, and an increase in the frequency of extreme weather events (Cheung et al. 2010; Barange et al. 2014). Communities that depend on fishing are facing increasing uncertainty as their livelihood are threatened by shifting species ranges, decreased catch rates, and ecosystem changes (Sumaila et al. 2011). Instead of combining population dynamics with climate forecasts at management unit scales (EEZs and shared stocks), the majority of regional studies are still short-term or single gear and concentrate on establishing a correlation between SST or ENSO and catch rates (Ren et al. 2025; Vu and Nguyen 2025). In the South China Sea and eastern Indian Ocean, there are currently few quantitative projections specifically for Indian mackerel (*Rastrelliger kanagurta*) and Narrow-barred Spanish mackerel (*S. commerson*). Most existing studies rely on short-term correlations between temperature indices and fisheries production, with limited integration of ecological processes, population connectivity, or climate-driven redistribution across national borders (Kamaruzzaman et al. 2021; Pan et al. 2024). Despite policy reports calling for climate-ready management, there is a severe implementation gap because few southeast Asian fisheries have adopted harvest control regulations, early warning indicators, or scenario-based socioeconomic planning for small-scale fishing operations (Talbot et al. 2024).

This review critically assessed the breadth and depth of southeast Asian contributions by contrasting regional studies with the global literature and synthesizing global research trends on the effects of climate change on mackerels (Family Scombridae) using a bibliometric approach. It highlights important theme gaps, unexplored study areas, and difficulties in converting science into adaptive management by contrasting regional studies with the worldwide literature. In addition to generating insights for more general worldwide comparisons, the analysis aimed to establish evidence of stronger climate-resilient fisheries governance in southeast Asia.

MATERIALS AND METHODS

Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) for systematic literature review was used (Moher et al. 2015). The four stages of this process are identification, screening, eligibility assessment, and inclusion. The Web of Science and Scopus database search phrases for the year 1990 through 2025 were used to identify every article. In order to ensure access to reliable sources and citation monitoring to uncover important studies and trends, Web of Science and Scopus were chosen for their dependable, high-quality control through rigorous peer-reviewed articles across fields like environmental science, fisheries, and climate change. Additionally, these databases offer sophisticated search capabilities for effective, methodical evaluation and analysis, avoiding duplication from less reliable sources.

The following two strings were used for article searching:

- Global: ('Climate change' OR 'Climate impact' OR 'Climate vulnerability' OR 'Climate variability' OR 'Global warming' OR 'Ocean warming' OR 'Environmental change' OR 'ENSO' OR 'El Niño' OR 'La Niña' OR 'Extreme events' OR 'Marine heatwave' OR 'Ocean acidification') AND ('Mackerel' OR 'Tuna' OR 'Bonito' OR 'Scombridae' OR 'Scomber' OR 'Rastrelliger' OR 'Scomberomorus' OR 'Katsuwonus' OR 'Thunnus') AND ('Fisheries' OR 'Fishery management' OR 'Stock assessment' OR 'Marine resources' OR 'Distribution shift'

OR 'Range shift' OR 'Habitat suitability' OR 'Species redistribution' OR 'Larval dispersal' OR 'Recruitment').

- Southeast Asia: ('Climate change' OR 'Climate impact' OR 'Climate vulnerability' OR 'Climate variability' OR 'Global warming' OR 'Ocean warming' OR 'Environmental change' OR 'ENSO' OR 'El Niño' OR 'La Niña' OR 'Extreme events' OR 'Marine heatwave*' OR 'Ocean acidification') AND ('Mackerel' OR 'Tuna' OR 'Bonito' OR 'Scombridae' OR 'Scomber' OR 'Rastrelliger' OR 'Scomberomorus' OR 'Katsuwonus' OR 'Thunnus') AND ('Fisheries' OR 'Fishery management' OR 'Stock assessment' OR 'Marine resources' OR 'Distribution shift' OR 'Range shift' OR 'Habitat suitability' OR 'Species redistribution' OR 'Larval dispersal' OR 'Recruitment') AND ('Southeast Asia' OR 'South China Sea' OR 'Indian Ocean' OR 'Eastern Indian Ocean' OR 'Coral Triangle' OR 'Indonesia' OR 'Philippines' OR 'Malaysia' OR 'Thailand' OR 'Vietnam' OR 'Brunei' OR 'Singapore' OR 'Cambodia' OR 'Myanmar').

Inclusion and exclusion criteria

Studies were included if they were written in English, focused on climate-change related impacts on mackerel or related Scombridae taxa, provided primary research data relevant to fisheries, population dynamics, or distributional change, and contained analyzable metadata such as titles, abstracts, and keywords. Review papers, book chapters, conference summaries, or theses were excluded because this bibliometric analysis aimed to examine trends in primary research rather than secondary syntheses including review articles would disproportionately influence co-occurrence networks by introducing broad synthetic keywords, obscuring patterns emerging from empirical studies. Publications were also excluded if they were not related to climate change or mackerel (Scombridae), or if they were non-original research outputs such as policy briefs or news articles.

Screening and duplicate removal

A total of 1,337 records were retrieved. Using automated duplicate detection in R (Bibliometrix) and manual verification, 680 duplicated records were removed. Titles, abstracts, and keywords of the remaining articles were screened for relevance. The eligibility assessment excluded articles unrelated to climate-change impacts on mackerel. A total of 257 articles met all criteria and were included for full bibliometric analysis. Extracted information included title, abstract, author keywords, index keywords, year of publication, journal, authorship, affiliations, citations, and document type.

Preprocessing and cleaning

Preprocessing and data cleaning followed standardized bibliometric procedures to ensure reproducibility. Keyword normalization included converting all terms to lowercase, removing punctuation, stemming plural forms, and merging synonymous expressions such as 'climate variability' and 'climate-variability' or 'distribution shift' and 'range shift'. Generic stop-words (e.g. 'model,' 'study,' 'impact,' 'analysis') and non-informative geographic abbreviations were removed to avoid noise in clustering. Author keywords referring to the same species or taxonomic group were harmonized by consolidating variations (for example, *Scomber japonicus* and *S. japonicus* were unified as '*Scomber japonicus*').

VOSviewer parameters

Co-occurrence network maps for keywords, authors, and countries were generated using standardized parameters (Van Eck and Waltman 2010). Full counting was applied as the counting method, and association strength was used for normalization. Thresholds were set at a minimum of five occurrences for keywords, two for authors, and three for countries. Network clustering followed a resolution value of 1.00, and layouts were produced using the

LinLog and Modularity algorithms. To improve interpretability, edges with a total link strength below 2 were removed from the final visualizations.

Bibliometrix parameters (R)

Bibliometric analyses were conducted using standardized Bibliometrix (R package version 4.3.1) (Aria and Cuccurullo 2017). The 'biblio-clean ()' function was applied to remove empty or inconsistent fields, and 'convert2df ()' was used to merge 'Web of Science' and 'Scopus' exports into a unified dataset. Descriptive indicators were generated with 'biblioAnalysis ()', while thematic structure and evolution were examined using 'thematicMap ()'. Network visualizations for keywords, countries, and co-authorship patterns were produced with 'networkPlot ()'. Association strength was used for normalization, and minimum frequency thresholds were set at three occurrences for terms in titles and abstracts and five occurrences for keywords.

Thematic and qualitative analysis

Keyword co-occurrence clusters were interpreted to identify dominant themes. Titles and abstracts of all included studies (n = 257) were reviewed to produce thematic summaries consistent with bibliometric clusters. Syntheses were based solely on the patterns derived from bibliometric results.

RESULTS AND DISCUSSION

Global research trend on climate change and mackerel (Family Scombridae)

Global research on climate change and mackerel is rich and multidisciplinary, integrating species biology, oceanography, ecosystem studies, and fishery management. However, regional gaps, especially in areas like southeast Asia, highlight the need for more localized, policy-relevant research to address region-specific vulnerabilities and adaptation strategies.

From 1990 to 2025, there was a noticeable rise in the number of scholarly articles about the climate change impact on mackerel in the world (Figure 1). China has 24 articles, which is the most in amount. Other countries are Japan, the United States, Australia, and various European countries, all of which have moderate contributions. Some countries, such as a large portion of South America, Africa, and parts of Asia, have made little to no contribution.

The bar graph differentiates between Single Country Publications (SCP) and Multiple Country Publications (MCP), which displays the country-by-country distribution of publications related to this study topic (Figure 2). While China has some collaborative works, the majority of its publications are single-country publications (SCP). Norway and Korea are next to China, both making significant contributions, especially in the area of international collaboration (MCP). With a balanced combination of SCP and MCP, the UK, USA, and Australia likewise exhibit significant research output. With a comparatively higher percentage of MCP, other European countries such as Spain, Denmark, Iceland, and Portugal make moderate contributions, suggesting active international collaboration. With fewer articles, Malaysia and India appear to have a lesser but developing field of study in this area. Only one or two publications are contributed by countries like Belgium and Morocco. While many other countries, particularly in Europe and North America, actively contribute through international collaborations, this figure shows that China dominates the research output. Southeast Asia, except Malaysia, is insufficiently represented, suggesting a research vacuum in the area.

There was very little research activity during the years 1987 to 2007, with only 0 to 2 articles published annually, suggesting that the topic did not receive much attention worldwide at that time-period (Figure 3). From 2008 to 2013, there was a steady rise, with publication counts exceeding
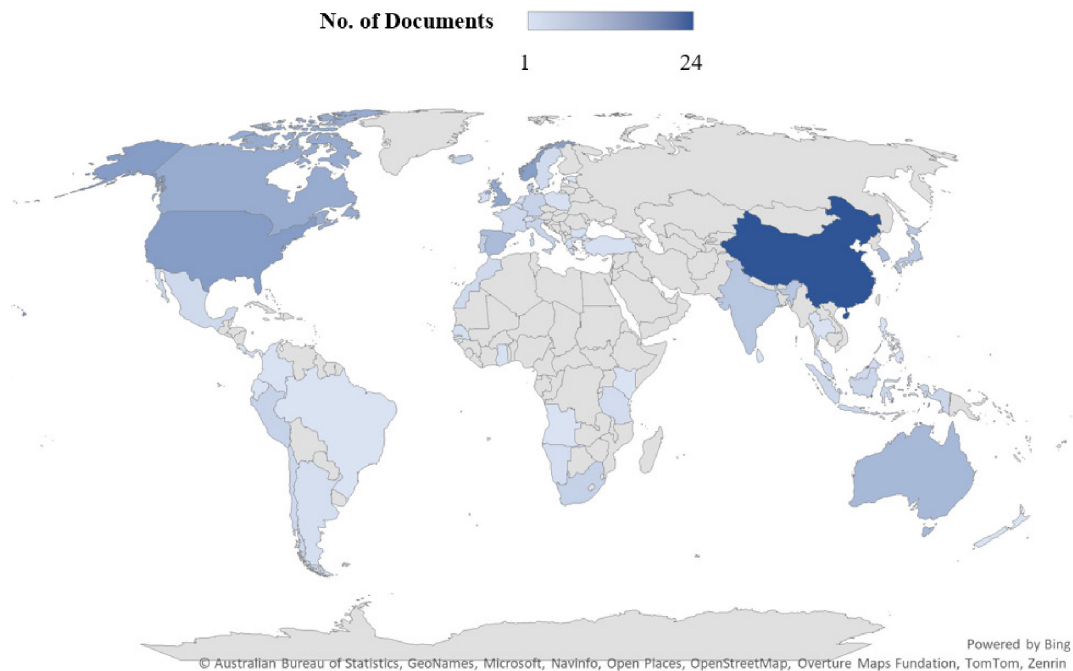
Figure 1. Number of scientific publications on the effect of climate change on mackerel populations globally from 1990 to 2025.
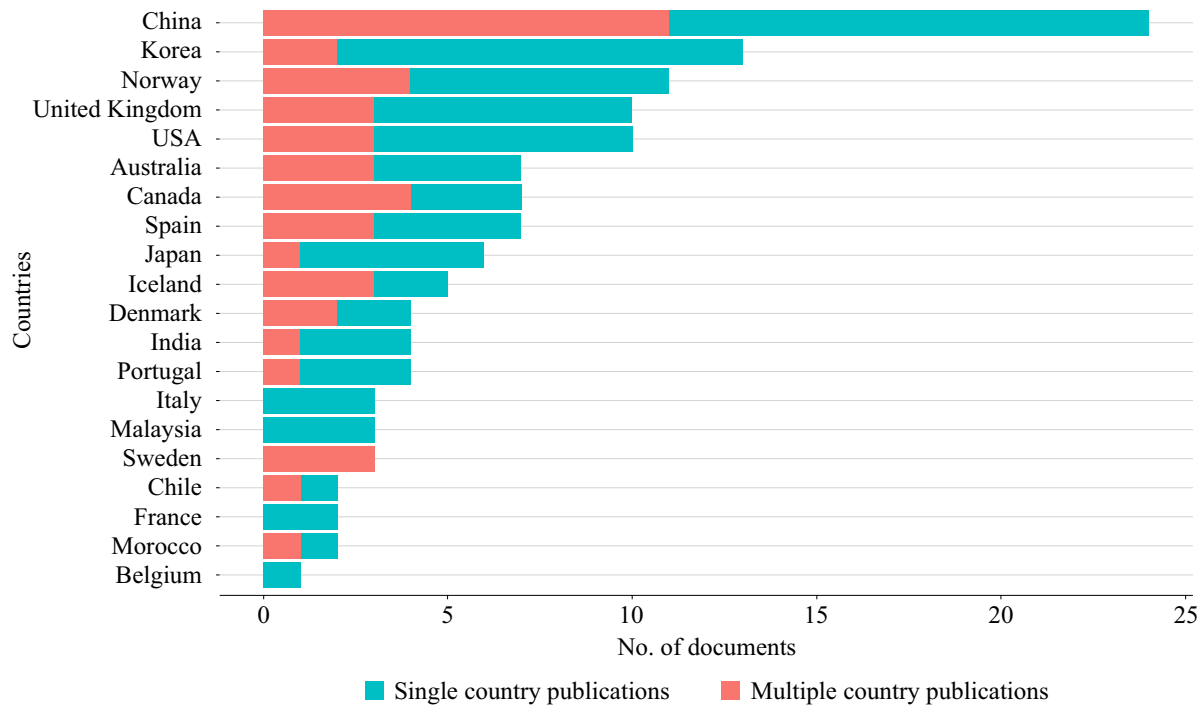

Figure 2. Most relevant countries that published articles on this topic from 1990 to 2025.

5 to 7 annually, indicating the start of a growing interest. As a result of increased global concern over the effects of climate change on fisheries, research output increased dramatically from 2014 to 2021, reaching a peak from 2019 to 2021 with over 15 articles annually. There has been a decrease in the number of articles published in recent years, from 2022 to 2025, which may be partially due to insufficient data availability. The graph shows that, from late 2000, research on this topic has grown dramatically, reaching a high in the year 2019 to 2021, coinciding with the global upsurge in fisheries and climate change research. It is important to be cautious when interpreting the fall after 2021 because it can be the result of database indexing delays rather than a real decline in research productivity.

With 11 articles each, Frontiers in Marine Science and Marine Ecology Progress Series were the two primary sources in producing research on this particular field (Figure 4). Fisheries Oceanography and ICES Journal of Marine Science came in after them with 9 articles each. Each journal, Fisheries Research and Ocean Science, had 5 articles. After that, 4 and 3 articles were given by the following journals.

Leading academic and research institutions contribute to the field determining whether the subject is dispersed throughout numerous institutions or is dominated by a small number of them (Figure 5). With 37 articles, the Institute of Marine Research is the leading contributor. Ocean University of China comes in second with 35 articles. Shanghai Ocean University comes after that with 31 publications. Mid-level contributors include Jeju National University with 11 articles, the Institute Maurice-Lamontagne with 10 articles, and the following institutes.

Tian Y is the most prolific author on this topic, having published 7 articles (Figure 6). Significant contributions were made by the four authors: Chen X, Jung S, Li J, and Liu Y, each of whom published 6 articles. Then comes Jansen T and Oskarsson GJ, each with 5 articles.

Research gap: southeast Asia context

While major oceanic basins like the Pacific and Atlantic Oceans are represented, southeast Asia does not explicitly appear, suggesting a potential regional gap in research coverage. Rising sea surface temperature, more frequent extreme
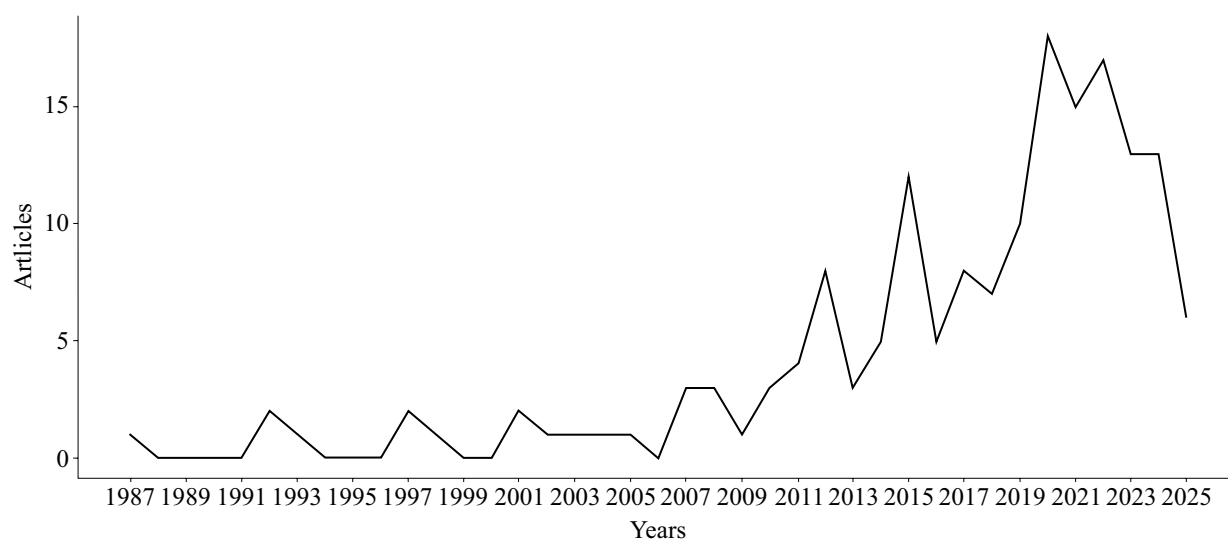

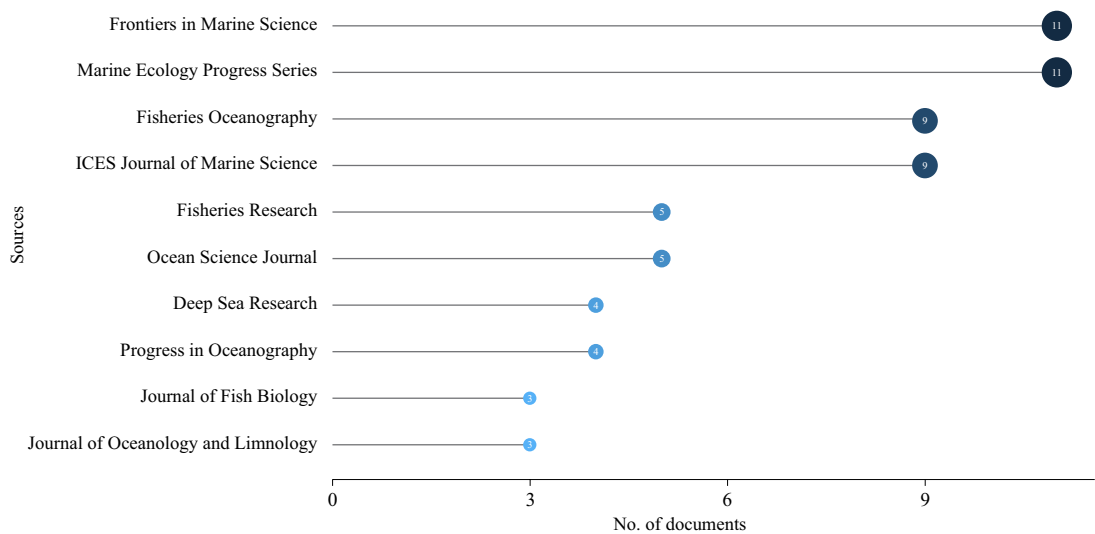Figure 3. Annual scientific production over time.
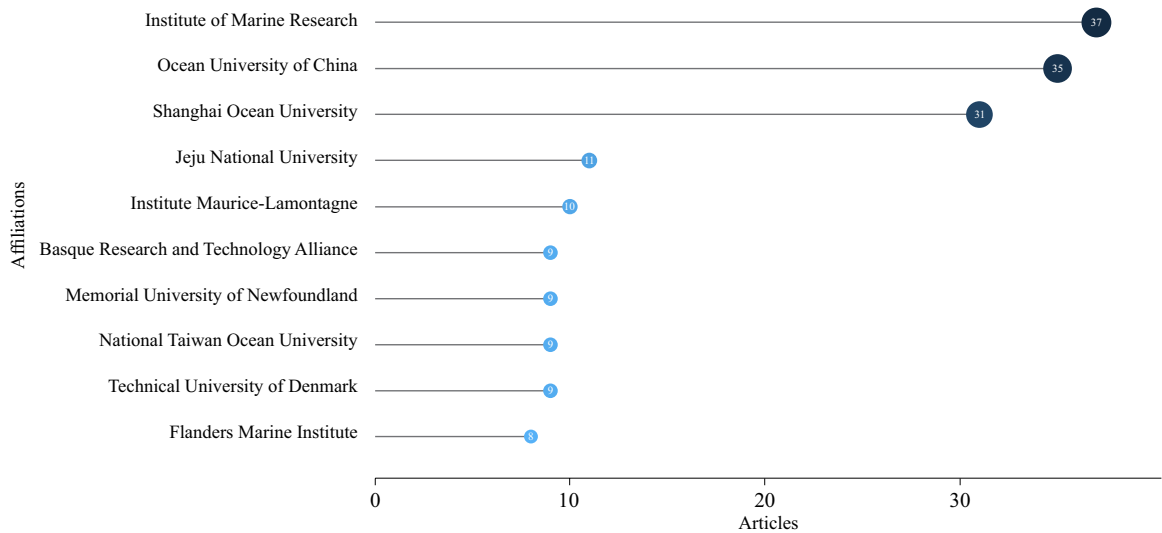
Figure 4. Most relevant sources of publications.

Figure 5. Most relevant affiliations of publications.

weather events, and ocean acidification are having a major influence on marine biodiversity and fisheries production (Islam et al. 2020). Southeast Asia is among the most vulnerable regions to climate change (Sumaila et al. 2011). A commercially valuable species in the area, Spanish mackerel (*S. commerson*), suffers difficulties because of shifting oceanographic conditions that affect their spawning cycles, migration patterns, and availability of prey (Cheung et al. 2013).

The network was generated in VOSviewer using the association-strength normalization and full counting method. Keywords were included if they appeared at least 5 times in the combined Scopus-Web of Science dataset (n = 257 articles; n = 54 keywords). Links with a total link strength < 2 were
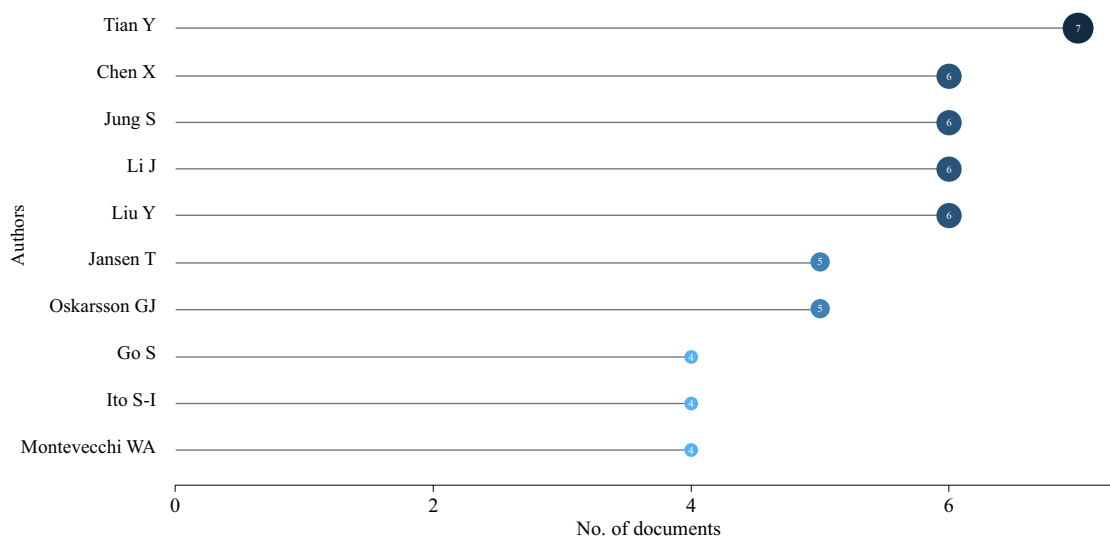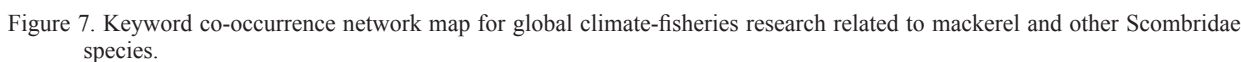
Figure 6. Most prolific authors of publications on the subject.

removed for clarity. Nodes represent keywords, and node size reflects keyword frequency. Colors represent clusters produced using the VOSviewer (Louvain-type) modularity-based clustering algorithm, identifying major thematic groups: 1) Blue cluster: climate-ecology interactions (e.g. climate change, population dynamics, ecosystems). 2) Green cluster: distribution and environmental drivers (e.g. sea surface temperature, climate models, population distribution). 3) Yellow-orange cluster: fisheries-focused terms (e.g. tuna fishery, CPUE, catch statistics). 4) Turquoise cluster: species-level taxonomy and biology (e.g. *S. japonicus*, *S. scombrus*, pelagic fish). The spatial arrangement of nodes was produced using the LinLog layout algorithm, which emphasizes cluster separation and inter-cluster link structure. A high network modularity ($Q = 0.62$), high average intra-cluster density (0.41), and a low proportion of inter-cluster links (18%), indicating strong internal cohesion and limited cross-cluster connectivity (Noack 2009) (Figure 7).

The network was generated in VOSviewer using the association-strength normalization and full counting method. Keywords were included based on a minimum occurrence threshold of 5 appearances in the regional dataset ($n = 105$ publications; $n = 39$

unique keywords. Links with very weak co-occurrence strength (total link strength < 2) were filtered to improve visual clarity. Nodes represent author keywords, with node size proportional to keyword frequency. Colors denote clusters identified by the VOSviewer modularity-based (Louvain-type) clustering algorithm, revealing major thematic structure in southeast Asian literature: 1) Yellow cluster: ecology-climate interface (climate change, ecosystems, marine ecosystem, fish). 2) Green cluster: fisheries management and environmental drivers (fisheries, fishery management, sustainable development, surface waters). 3) Pink cluster: fishery-dependent indicators and variability drivers (Indian Ocean, tuna fishery, CPUE, catch statistics, ENSO, climate variation). 4) Blue cluster: species-specific and biogeographic terms (tuna, Pacific Ocean, spatial distribution, global warming). The spatial structure of the map was generated using the LinLog layout, which enhances cluster separation by prioritizing attractive and repulsive forces among strongly and weakly related keywords, respectively. This visualization highlights the dominance of Indian Ocean-centric, catch-based, fisheries-driven research in southeast Asia compared to more mechanistic and model-based global clusters (Figure 8).

Figure 7. Keyword co-occurrence network map for global climate-fisheries research related to mackerel and other Scombridae species.

Figure 8. Keyword co-occurrence network map for southeast Asian climate-fisheries research related to mackerel and other Scombridae species.

In contrast to global research in the Atlantic and Pacific, which has progressed toward predictive modeling, physiological studies, and integrated socio-ecological assessments, southeast Asian climate-fisheries research is still catch-based and descriptive, concentrating on tuna/mackerel fisheries within the Indian Ocean framework, according to the comparison of bibliographic maps (Table 1). This leaves a visible gap: southeast Asia, where reliance on fisheries for food security is high, but data or modeling investment lags, requires SDM-based predictions, mechanistic studies, and socio-economic integration.

Climate change themes identified in the global research

The thematic cluster analysis and keyword co-occurrence mapping revealed four dominant global research themes related to the impacts of climate change on mackerel: 1) Ocean warming and distribution shifts, 2) Migration and spawning changes, 3) Ecosystem-wide trophic responses, and 4) Physiological stress and behavioral impacts. These clusters align with well-established ecological evidence showing that warming, acidification, and deoxygenation are reshaping pelagic ecosystems worldwide. Studies highlight that rising sea temperatures drive poleward species movements (Astthorsson et al. 2012; Wang and Wu 2025), alter spawning grounds (Jansen and Gislason 2013), and cause contractions in traditional habitats (Yang et al. 2022). Emerging evidence of rapid ocean deoxygenation (Lu et al. 2024) and widespread reef hypoxia (Pezner et al. 2023) further reinforces the global research emphasis on environmental stressors affecting mackerel habitat suitability and recruitment.

Table 1. Comparison between the bibliometric analysis of Global and southeast Asian research.

	Global	Southeast Asia
Core keywords	Atlantic Ocean, Pacific Ocean, climate change, pelagic fish, population dynamics, stock assessment, physiology, climate models	Indian Ocean, Scombridae, tuna fishery, SST, ENSO, CPUE, catch statistics.
Research orientation	Mechanistic, predictive, ecosystem-based	Descriptive, monitoring-oriented
Data sources	Multi-source data (survey data, ecological monitoring, physiology, models, remote sensing)	Fishery dependent data (catch, CPUE, abundance, biomass, effort)
Climate drivers studied	Integrated drivers: warming, deoxygenation, acidification, multi-factor climate models	Broad variables: SST, ENSO, climate variability
Analytical approach	Species Distribution Models (SDMs), spatio-temporal models, ensemble climate projections	Statistical correlations, trend analysis
Ecological scope	Ecosystem level focus (food webs, spawning, physiology, ecosystem resilience)	Species/fishery level focus (mainly tunas and mackerels)
Management dimension	Strong: stock assessment, adaptive fisheries management, socio-ecological integration	Limited: mostly linked to catch trends and variability
Research development	Higher data availability and modeling investment, advanced, integrating ecology, modeling, and management scenarios	Often generalized, emerging in methodological sophistication

SST = Sea Surface Temperature; ENSO = El-Niño Southern Oscillation; CPUE = Catch Per Unit Effort.

Distribution shifts and habitat loss as central research themes

Across global publications, distribution shifts associated with sea-surface temperature increases appear consistently in high-frequency keywords and tightly connected network clusters. Multiple studies document northward expansions of Atlantic and Chub mackerel (dos Santos Schmidt et al. 2024; Han et al. 2024) and projected habitat losses of up to 80-90% under high emission scenarios for *Scomberomorus* species (Yang et al. 2022). These findings correspond with the strong 'warming-distribution shift-habitat suitability' cluster in the VOSviewer network, demonstrating that habitat modelling and mechanistic projections dominate global research.

Migration and spawning modifications: a secondary but growing theme

Bibliometric results showed a medium-density cluster associated with migration, spawning, recruitment, and larval dispersal, reflecting a substantial research focus on phenological changes. Article within this cluster reports earlier spawning (Brunel et al. 2018), altered migration timing (Kanamori et al. 2019), and climate-driven mismatches between larvae and plankton blooms (Edwards and Richardson 2004). This articles depict how researchers increasingly integrate biological observations with climate variability, especially ENSO, highlighting a trend toward process-based ecological studies, particularly in the Pacific and North Atlantic.

Ecosystem and trophic interactions: linking climate drivers to food web response

The third major cluster identified dealt with ecosystem and trophic interactions, including prey availability, zooplankton dynamics, and predator overlap. Highly cited global studies showed that warming reduces the abundance of key copepods (*Calanus* sp.) restructured plankton communities (Neven 2024), and intensifies competition among pelagic predators (Ono et al. 2024). The co-occurrence network reflected this through strong associations between terms such as 'plankton', 'trophic', 'productivity', and 'recruitment'. These results demonstrated that much of the global research landscape has moved beyond descriptive assessments toward ecosystem-based and food web-integrated approaches.

Physiological and behavioral responses: a smaller but emerging theme

Although less central in keyword networks, a growing cluster focused on physiological responses such as altered growth, metabolic stress, and behavioral modifications linked to warming and acidification (Munday et al. 2009; Pecl et al. 2017). Studies reporting projected poleward shifts in thermal habitat suitability for *S. commerson* (Wang and Wu 2025) and vulnerability of juveniles to both acidification and hypoxia (Wexler et al. 2023) aligned with this research trend. These emerging studies highlight a transition toward climate-physiology integration in global fisheries science.

Fisheries management and adaptation: policy themes in global versus regional research

The bibliometric mapping also revealed a clear difference between global and southeast Asian articles. Globally, research connects climate impacts to adaptive management, ecosystem-based governance, and transboundary stock agreements. This includes emphasis on climate-resilient MPAs (Marine Protected Areas), quota adjustments, and long-term monitoring (Lehodey et al. 2020; Bagsit et al. 2021). However, southeast Asian publications show limited focus on governance, instead emphasizing catch trends, CPUE, and descriptive stock assessments. Global studies increasingly integrate climate projections into policy frameworks (Pandey and Joseph 2025), whereas regional research points to persistent gaps in funding, monitoring capacity, and institutional support. These findings indicate

that climate-driven risks to mackerel fisheries are well documented at the global scale, but scientific, financial, and governance constraints continue to limit adaptive responses in southeast Asia.

Research prospects in southeast Asia

In order to improve knowledge and management of mackerel fisheries in light of climate change, a number of important research gaps need to be filled. The long term effects of climate variability on the distribution and productivity of mackerel stocks, which are still poorly understood in southeast Asia, need to be studied at the regional level (Breitburg et al. 2018; Dongyu 2024). The physiological and behavioral responses of mackerel to shifting ocean circumstances, such as rising sea temperatures and falling oxygen levels, need further research, especially in relation to migration patterns, predator avoidance, and larval survival (Breitburg et al. 2018; Wexler et al. 2023). Despite growing evidence that coastal populations in the Indo-Pacific region are extremely vulnerable to climatic shocks, there are currently few studies looking at the socioeconomic implications of declining mackerel stocks, particularly the flexibility and resilience of small-scale fishermen (Pecl et al. 2017; Chamsai and Wanchana 2022). To ensure the sustainability of mackerel fisheries, studies on the efficacy of adaptive fisheries management techniques, such as ecosystem-based management and cooperative regional governance, are required (Cheung et al. 2013). Few studies have examined how climate change impacts prey species availability and composition for mackerel, which is important for forecasting population patterns in the future (Doney et al. 2012; Wang and Wu 2025). Developing climate resilient management frameworks for mackerel fisheries, these research gaps need to be filled by integrated ecological, socioeconomic, and governance studies.

These gaps underscore a pressing need for integrated ecological, socioeconomic, and governance research to support the development of climate-resilient fisheries management frameworks for mackerel in southeast Asia. Aligning regional research with global methodological advances, particularly through SDMs, long-term monitoring, and socio-ecological assessments, would significantly improve the scientific basis for sustainable management under accelerating climate change.

CONCLUSIONS

While global studies increasingly employ mechanistic models, ecosystem-based approaches, and integrated climate projections, southeast Asian research remains largely descriptive and catch-based. The keyword structures and thematic clusters confirm a persistent regional gap in modelling capacity, physiological research, and socio-ecological assessment, despite the region's strong dependence on mackerel fisheries for food security. Closing this gap will require strengthening scientific infrastructure, improving data availability, and expanding interdisciplinary work on species distribution modelling, multi-stressor climate analysis, and socioeconomic vulnerability. The findings also highlight the need for adaptive, evidence-driven fisheries governance, including ecosystem-based management and coordinated regional monitoring. Overall, a more integrated research and policy landscape is essential for building climate resilience in southeast Asian mackerel fisheries. Investing in modelling, collaborative networks, and long-term monitoring will support sustainable harvest and help safeguard coastal communities.

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Conflicts of interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Author contributions

Mohammad Ekramul Haque: writing the original manuscript and analyzing the data. Shahadat Hossain: reviewed and analysed the data. Tun Nurul Aimi Mat Jaafar: review and edit the draft. Ying Giat Seah: review and edit the draft. Siti Azizah Mohd Nor: review and edit the draft. Nazia Abdul Kadar: review and edit the draft. Nur Fadli: review and edit the draft. Darlina Md Naim: review and edit the draft. Helena Khatoon: review and edit the draft. Ahasan Habib: conceptualised the topic, reviewed, edited, and supervised.

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