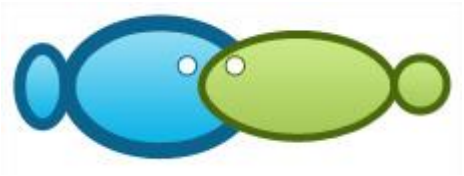

Economic impact of climate change on pelagic fish migration: a systematic review of the literature

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Abstract. Climate change has significantly impacted marine ecosystems, including the migration patterns of pelagic fish in the tropics. This study uses *a* systematic literature review (SLR) approach to examine the economic impact of changes in the spatial distribution of pelagic fish triggered by increased ocean temperatures, changes in currents, and water stratification. The review of 38 selected studies out of 194 screened indicates that changes in fish migration have a significant impact on the capture fisheries sector, particularly through reduced catches, rising operational costs, and growing uncertainty for fishers. In addition, developing countries in the tropics face greater economic risks due to limited adaptation and high dependence on fisheries as a source of livelihood and foreign exchange. This research highlights the importance of ecosystem-based adaptive policies, investment in climate-responsive fisheries information systems, and regional cooperation in managing transboundary fish stocks sustainably. The findings support the establishment of digital skills training programs, community-based adaptation, and support for technology-based maritime entrepreneurs are strategic steps to build coastal communities that are resilient to climate change.

Key Words: climate change, pelagic fish, migration, economic impact, tropical fisheries, Eastern Indonesia.

Introduction. Climate change is a worldwide event receiving more attention in science studies that cross disciplines like fisheries and marine studies. Sea surface temperatures (SST) rise, seawater acidity increases, and ocean current patterns change, factors affecting the spatial and temporal distribution of various marine species, especially pelagic fish living in the open water column. *Thunnus albacares* (Bonnaterre, 1788), *Scomberomorus commerson* (Lacepède, 1800), as well as *Scomber japonicus* Houttuyn, 1782, exhibiting migration patterns towards higher latitudes in addition to different depths (Cheung et al 2010; Poloczanska et al 2013), are susceptible to fluctuations within ocean temperature in conjunction with plankton availability.

In general, this process of migration is carried out in groups. These groups involve people from the same fish species (Pratama et al 2022). Pelagic fish migrate to locate proper habitats supporting their life as pelagic fish (Pratama 2024; Pratama et al 2022). Climate change impacts upon global fisheries productivity by redistributing fish biomass, several studies have identified. This redistribution does have important implications in regard to the availability of fish resources throughout tropical regions, which depend upon the capture fisheries sector (Barange et al 2014; IPCC 2021). Cheung et al (2010) project that tropical countries could see a maximum catch potential decrease of up to 40% by the mid-21st century, while countries at higher latitudes may experience increased stocks. These effects threaten the sustainability of the marine economy and hinder equal access to marine biological resources.

In Indonesia and other developing countries in the Indo-Pacific region, shifts in pelagic fish migration are causing socio-economic vulnerability for small fishing communities. In addition to threats to food security and livelihoods, resource conflicts can

increase due to the cross-border migration of fish stocks previously within national jurisdictions (Havice & Campling 2010; Sumaila et al 2011; Katherine et al 2020).

The implications of this migration are not only ecological but also have far-reaching economic and political impacts, especially for island countries that depend on the fisheries sector as the primary source of income and livelihood for coastal communities. Indonesia, as a maritime country with a large tropical area, is among the groups of countries most vulnerable to this impact.

In particular, the Banda Sea region was of particular concern in this study for several critical reasons. First, this area is a center for marine biodiversity and the main migration route for several species of pelagic fish, especially madding fish (Damora & Baihaqi 2013). The sea temperature at a depth of 10 meters is around 28-29°C, favored by economically important pelagic fish such as skipjack or tuna skipjack (Setyadji et al 2019; Asuhadi et al 2025). At a depth of 100 meters, the sea temperature is around 23-24.5°C, which is preferred by Yellowfin tuna (Tussadiah et al 2018; Liu et al 2023). So, it can be assumed that small pelagic fish and other large pelagic types also have a high probability of living and developing in the exact location (Hilda et al 2018).

Second, the fisheries sector in the Banda Sea has a significant economic contribution to regional income and the welfare of coastal communities. The main areas of tuna capture fisheries are in the Banda Sea and Maluku Sea (Haruna et al 2019; Widjanarko et al 2020). Fishery resources in the Maluku Islands are the largest seafood producers in the Southeast Asian region. The great potential in the Maluku Islands generally comes from capture fisheries. In the Provinces of Maluku and South Sulawesi, Indonesia is the largest producer of tuna fisheries in the Eastern Region. Therefore, Indonesia ranks third in the world as a tuna producer (Ayal 2018).

Third, this region is especially vulnerable to climate events like El Niño-Southern Oscillation (ENSO), which are becoming more frequent. These occurrences lead to abrupt shifts in sea temperature and oceanic conditions, making it more difficult to anticipate the timing and location of pelagic fish presence. Consequently, fishers experience increased uncertainty in finding fish stocks, which directly impacts their catch.

Although the existing literature has extensively discussed the impact of climate change on the spatial and temporal distribution of marine species, particularly pelagic fish (Cheung et al 2010; Poloczanska et al 2013), as well as their implications for global fisheries productivity and resource availability in the tropics (Barange et al, 2014; IPCC 2021), there is a significant gap in comprehensive knowledge synthesis.

Based on these considerations, this study aims to conduct a systematic literature review (SLR) to understand the relationship between climate change, the shift in pelagic fish migration, and its impact on the fisheries economy, with a particular focus on the Banda Sea as a representative case of tropical regions facing ecological and economic stress due to the climate crisis. A structured and comprehensive synthesis of literature is needed to capture the complex interconnections between climate dynamics, pelagic species' behavioral responses, and fisheries economic implications, especially in vulnerable and vital maritime regions such as the Banda Sea. The SLR seeks to fill this research gap by providing a clear picture of these linkages while highlighting the ecological and economic challenges that tropical regions encounter under climate change. Although this study offers deep insights into the Banda Sea as a case study, it also acknowledges the limitations of broad global applicability without further region-specific research.

Material and Method

Description of the study sites. The geographical emphasis on the Banda Sea region strengthens this literature study. This region was chosen as a case study because it is the main migration route of large pelagic fish such as tuna and skipjack. It shows high vulnerability to climate anomalies such as ENSO. Secondary data sources from the MMAF (2023) and the results of local studies (Putri et al 2021; Chan et al 2023) are also used to enrich the empirical context of this study. In selecting studies for this review, research lacking clear economic data or relevance to the fisheries sector was excluded to ensure a consistent analytical focus. While this study emphasizes the Banda Sea region due to its

critical role as a major migration route for large pelagic fish (like tuna and skipjack), its high vulnerability to climate anomalies such as ENSO, and its significant economic contribution to regional fisheries, it is important to acknowledge a potential bias. The majority of the existing literature, including secondary data from the MMAF (2023) and local studies (Putri et al 2021; Chan et al 2023), predominantly covers the Asia-Pacific region. Therefore, applying these findings directly to other tropical regions—such as those in Africa or Latin America—should be approached with caution, as their unique ecological, socio-economic, and governance contexts may vary significantly.

The data collected in this study consisted of secondary data. Secondary data was acquired by tracing literature studies and the results of marine and fisheries studies in Central Maluku Regency reports from the Marine and Fisheries Service of Central Maluku Regency, and other related agencies. In this study, the most extensive data collection was from secondary data. This research focuses on the Banda Sea Waters with 125º-131.5º E and 2º-5ºS positions.

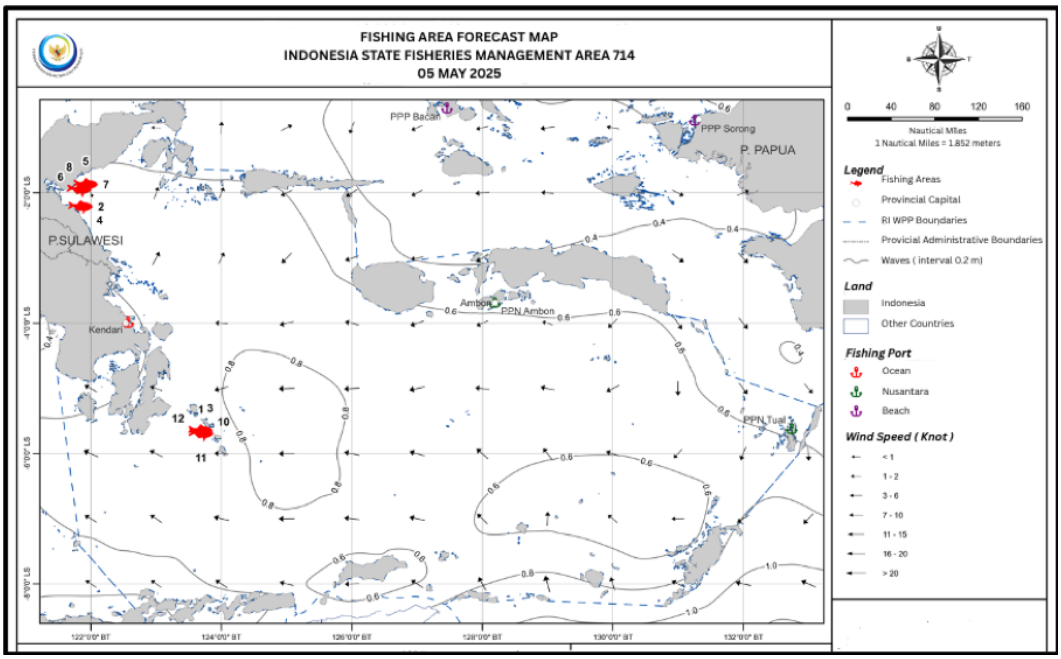

Figure 1. The location of Banda Island, Indonesia.

Statistical analysis. This study uses the SLR method to identify, evaluate, and synthesize research results, referring to the Berrang-Ford et al (2015) approach, which states that an SLR is a collection of various, diverse, and complex literature-based research synthesis approaches. There are nine types of literature review methods (Paré et al 2015). The SLR measures refer to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol.

Many previous studies believe climate change's impact on tropical fisheries does not yet have an agreed-upon conceptualization and measurement (FAO 2018), so it must be enriched with empirical evidence from research that has been conducted. According to Cahyono et al (2019), a literature *review* means the same as carrying out activities such as 1) collecting data/information, 2) evaluating data, theories, information, or research results, and 3) analyzing the results of publications such as books, research articles, or others related to research that has been prepared previously.

The search strategy uses databases such as Scopus, Web of Science, and Google Scholar, with the keywords "climate change" AND "pelagic fish" AND "migration" AND "economic impact". The year range of publication is 2010-2024. In total, we took 194 articles that we browsed. We started a two-step screening process to analyze the paper. Out of 243 articles found, 38 met the inclusion and relevance criteria. It means that the article focuses on the impact of climate change. Selection of criteria to further explore harm and harm in the literature to better understand the context and driving factors (Pascual et al 2022; Pörtner et al 2023).

Results and Discussion. Changes in pelagic fish migration patterns. Climate change is dramatically transforming marine ecosystems, carrying major consequences for global fisheries. One of the most notable effects is the poleward migration of pelagic fish habitats, driven by increasing SST. In the past 50 years, more than 70% of marine species have experienced shifts in their geographic distribution (Poloczanska et al 2013). For example, Yellowfin tuna (Thunnus) are now more commonly found in subtropical waters instead of their usual tropical habitats, while Atlantic mackerel are moving northward toward the Norwegian Sea. These changes present a serious risk to fish stocks and intensify the pressures they already face.

Research by Sarre et al (2024) corroborates that climate change induces spatial shifts in the distribution of small pelagic fish by altering optimal environmental conditions. In Northwest Africa, a region where small pelagic fish are socio-economically and culturally vital, a simultaneous northward shift in their distribution has been linked to long-term warming trends in SST and declining marine productivity in the south. The abundance of Sardinella aurita, a dominant species in the area, has increased in subtropical regions but declined in intertropical zones. Similar spatial shifts in biomass have been observed for other exploited small pelagic species, mirroring changes in surface isotherms. While intensified upwelling in the northern and central regions of the system has been documented without corresponding changes in primary productivity, stable upwelling intensity in the southern region has coincided with declining primary productivity. These environmental disparities, which span national borders, introduce a new threat to fish stocks already facing overexploitation, thereby complicating sustainable management efforts.

The marine environment's alteration due to climate change will have a major impact on marine fish populations (Tanner et al 2019), particularly on species distribution and abundance (Zhu et al 2024). Rising surface temperatures are a key parameter in this context, directly affecting organisms' life cycles and ecosystems (Christopher et al 2019; O'Connor et al 2007). Smaller fish species tend to perform better in warm, oxygen-deprived waters than larger species, suggesting that they may become more abundant compared to their larger counterparts as climate change evolves (Rubalcaba et al 2020; Pauly 2021; Salvatteci et al 2022). Climate change can shorten food webs (i.e., reduce the number of trophic levels) by increasing metabolic costs, reducing energy flow efficiency, and limiting the energy available to top predators (Barneche 2021).

Small-scale fishermen's fishing choices have been greatly impacted by the effects of climate change. When extreme weather strikes, adaptation measures are crucial and a major concern for economic development policy. Furthermore, aquaculture output serves as a substitute for marine fishing and serves as insurance against the unpredictability of capture fisheries' profitability and viability (Rahim & Diah 2023).

Economic impact. The ecological shifts directly translate into significant economic impacts for fishing communities. A study by Cheung et al (2010) projected that tropical countries, including Indonesia, the Philippines, and Ghana, could face a potential decline in catches of up to 40% in the coming decade. It directly threatens the income of fishermen and the welfare of coastal communities. As producers, fishermen rely on diverse species for both income and consumption. Thus, a decrease in fish abundance or diversity impacts their catch in both quantity and quality. Other potential losses, such as damage to vessels or landing sites, compound the economic burden. However, it is crucial to acknowledge that the prevailing market-based framing of "loss and damage" often overlooks more intangible elements of non-economic losses (Boyd et al 2021).

The migration patterns of species like skipjack tuna, which follow changes in aquatic temperatures, further exemplify these challenges. Skipjacks migrate north in late autumn, seeking warm waters, and return south in late spring and summer as cold waters recede before migrating south again in late summer and early autumn (Garbin & Castello 2014; Mugo et al 2011). The spatial distribution of skipjack fishing activities exhibits seasonal patterns closely tied to environmental conditions, with temperature being a primary predictor of their habitat (Mugo et al 2010). Oceanographic factors also have a significant impact on the skipjack tuna's geographic distribution. The catch rises dramatically during

periods of positive ENSO and Indian Ocean Dipole (IOD). On the other side, it drastically drops during a negative La Niña and IOD period. The number of skipjack catches declined between 2010 and 2020 (Suhermat et al 2022). This situation makes it challenging for fishers to accurately pinpoint promising fishing grounds, resulting in a relatively low success rate for their operations and, in turn, decreased income (Nurdin et al 2012).

The socio-economic implications of climate change on fisheries vary regionally, with the most severe effects concentrated in low-income and food-deficient tropical countries, including Small Island Developing States (SIDS) and nations in Africa and Southeast Asia. These developing nations typically depend heavily on fish and fisheries for micronutrients, livelihoods, and employment, yet possess limited adaptive capacities. Consequently, the adverse effects of climate change on catches and total fishery income are proportionally greater in these regions than in countries with high human development indices and diversified economies. Climate change is projected to exert both direct and indirect influences on marine and freshwater fisheries, with broad ramifications for economies reliant on fisheries, coastal communities, and associated ecosystems (Koenigstein et al 2016). Coastal populations in tropical developing nations are considered among the most vulnerable due to several interrelated factors, including a strong economic and dietary dependence on fish and limited resources to enhance their adaptive capacity (Cinner et al 2018; Barange et al 2019).

The fluctuations and effects of climate change have greatly undermined the economic sustainability of fishing-based livelihoods, making households and communities more vulnerable and diminishing their capacity to adapt effectively (Islam et al 2014). Climate change is projected to have far-reaching impacts on fisheries worldwide, threatening the livelihoods and well-being of millions of people (Haas et al 2020). While these effects are global in nature, marine ecosystems and fish populations in tropical regions are particularly vulnerable, emphasizing the critical need for in-depth understanding and tailored climate strategies for these areas (Lam et al 2020).

Age and availability to extension services increase the possibility that fishermen will consider seawater temperature variations, strong winds, rainfall intensity, sea level height, and rising operating costs as high risks, according to research by Dolorosa & Hidayat (2025). The biggest gains come from moving fishing areas and rescheduling fishing activities. In response, fishermen use tactics including modifying fishing schedules, shifting fishing locations, bolstering fishing groups, diversifying their sources of income, and utilizing fish-finding technology. Adoption of numerous solutions is further encouraged by experience, access to extension services, and elevated risk perceptions associated with changes in seawater temperature and operating expenses. These results demonstrate how urgently infrastructure supply, mentoring, counseling, and institutional assistance are needed to increase fishermen's ability to adapt.

This is particularly crucial given broader concerns about how climate change will affect both commercial and small-scale fisheries (Hoegh-Guldberg & Bruno 2010; Lumban-Gaol et al 2012). Small-scale fisheries, which employ 40 million people globally and supply nearly 80% of some countries' fisheries production (FAO 2025), are particularly vulnerable. Many global fishing stocks have been dangerously depleted due to overfishing, leading to a loss of large, high-value top predators that are more sensitive to fishing pressures due to traits like slow growth and late maturity (Pauly et al 1998) - the fish migration to locations farther from the coast forces fishermen to spend more on fuel and logistics.

Potential conflict. The implications extend to international relations and potential conflicts. Countries with a history of recurrent conflicts, such as militarization or failed peaceful negotiations, are prone to perpetual rivalry (Flanders Marine Institute 2019). Some studies warn of increasing conflicts between countries over fishing rights that move jurisdictions, as in the case of tuna shifts in the central Pacific.

A study by Vogel et al (2023) proposed a causal model of fisheries conflict, identifying key factors that can either heighten or reduce the likelihood of disputes over shifting resources. These factors include a legacy of power imbalances, unequal access to resources, and the absence of stable and consistent governance. The study emphasizes that cooperation and fair decision-making processes are crucial components of

internationally shared stock management, promoting sustainable, effective, and conflict-resilient fisheries.

This SLR provides a critical synthesis of existing knowledge on the complex interplay between climate change, pelagic fish migration, and fisheries economics. However, it is important to recognize certain limitations. This SLR does not attempt to measure economic losses for individual countries in monetary terms; instead, it emphasizes identifying patterns and assessing qualitative impacts. While the Banda Sea findings align with broader patterns of tuna migration observed across the Pacific (Havice & Campling 2010; Katherine et al 2020), comparisons with other specific tropical regions, such as the Caribbean, are less direct due to differences in oceanographic conditions and species composition. Additionally, the scope of this review is based on existing published studies, which may contain inherent biases or gaps in data. Future research would benefit from collecting primary data to quantify economic losses and conducting more detailed comparative analyses across various tropical regions.

Conclusions. Climate change has become a significant driver of ecological transformation in tropical marine ecosystems, particularly through its influence on the migration patterns of pelagic fish species. This SLR highlights that changes in sea surface temperature, ocean currents, and unusual oceanographic conditions have significantly altered the spatial and temporal distribution of commercially important species like tuna and skipjack. These ecological shifts have led to major economic repercussions for the capture fisheries sector, particularly in tropical developing nations. In summary, addressing the climate-driven disruption of fish distributions in Indonesia and other tropical regions requires integrating real-time ecological data into adaptive fisheries governance, enhancing regional cooperation, and investing in youth-focused education and innovation to build a more resilient and equitable fisheries sector.

Conflict of interest. The authors declare that there is no conflict of interest.

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