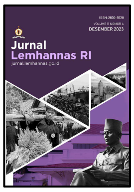

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Climate Change and Fisheries: Meta-Synthesis of Regional Vulnerabilities and Responses

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Abstract

Purpose: This study aims to evaluate the influence of climate change on the viability of the fishing industry across Asia, Oceania, Africa, and the Americas, with particular attention to Indonesia's fisheries sector.

Study Design/Methodology/Approach: The research applies Wavelet Fisher-Z Meta Analysis to 25 peer-reviewed studies published between 2016 and 2024. This method enables the identification of temporal patterns and regional variations in climate impacts on fisheries by stabilising effect size estimates across different environmental and institutional contexts.

Findings: The analysis reveals significant impacts of climate change on fisheries in countries including the United States, Colombia, and Vietnam, while moderate effects are observed in Indonesia. The study confirms that elevated sea surface temperatures, erratic weather patterns, and sea-level rise reduce fisheries' productivity and threaten economic sustainability, particularly in small-scale fishing communities.

Originality/Value: This study highlights the urgency of strengthening policy integration, stakeholder coordination, and adaptive capacity in the fisheries sector. It recommends enhancing sustainable fishing practices, establishing marine conservation areas, and investing in infrastructure resilience to withstand climate variability. These findings contribute to ongoing efforts to align national strategies with the Sustainable Development Goals in securing food systems and economic stability.

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INTRODUCTION

Climate change threatens the global fisheries sector, which contributes significantly to food security, economic development, and protein supply (Zahri et al., 2024). Rising sea surface temperatures have altered ocean acidity, reduced marine productivity, and disrupted fish populations, thereby undermining the sector's long-term viability. Researchers in Indonesia actively investigate climate change impacts on fisheries, recognising the sector's high sensitivity to ecosystem fluctuations. In addition, business management practices and geographical characteristics exert considerable influence on the economic outcomes of fisheries (Putten et al., 2014).

Empirical evidence demonstrates that severe climate-related events have significantly reduced fishery productivity across Asia and other global regions (Abdalah, 2023; Chan et al., 2023). However, scholars have yet to sufficiently incorporate rigorous statistical methodologies that can capture temporal and spatial patterns across diverse regions. Current research often generalises regional vulnerabilities without embedding them within localised socio-ecological systems, particularly in the Indonesian context. To respond to this methodological shortfall, the present study applies the Wavelet Fisher-Z Meta-Analysis to assess cross-regional vulnerabilities and adaptive responses in the fisheries sector. The research introduces a novel analytical approach by focusing on Indonesia, thereby strengthening methodological rigour and improving the practical relevance of climate adaptation strategies within policy-making processes.

The study responds to the identified gap by conducting a meta-synthesis of regional vulnerabilities and adaptive responses within the fisheries sector under climate stress. By integrating empirical findings from Asia, Africa, Oceania, and the Americas, the research develops a comparative perspective on how climate change influences marine fisheries, with a specific emphasis on Indonesia. The synthesis contributes to advancing the discourse on climate adaptation, fisheries governance, and regional economic sustainability. The study examines two central questions. First, how does climate change affect the fisheries industry in Indonesia in comparison with other global regions? Second, how can adaptive and protective strategies reinforce the fisheries sector in Indonesia and other countries experiencing climatic disruptions? The results are expected to inform national policy design and support coordinated stakeholder strategies, thereby strengthening the adaptive capacity and resilience of Indonesia's fisheries sector within the broader framework of climate governance.

LITERATURE REVIEW

Theoretical Studies

Previous studies confirm that the fishing industry faces multiple challenges resulting from climate change. Researchers have shown that climate-induced environmental stress reduces fishing opportunities, thereby weakening the industry's financial performance in affected regions. Although many investigations at global and regional levels have addressed these impacts, scholars have yet to establish a coherent understanding of localised climate vulnerabilities, particularly in regions with limited

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data availability (Suh et al., 2020; Vinh and Nguyen, 2022). A critical synthesis of the literature reveals that scholars have discussed various adaptive strategies, including technological innovation and co-management frameworks. However, their outcomes remain inconsistent due to institutional limitations, infrastructure gaps, and ecological diversity. Rather than viewing prior studies as disconnected contributions, this review integrates them within an adaptive governance continuum that emphasises the need to align policy formulation, ecological dynamics, and economic sustainability (Doktoralina et al., 2025). Moreover, empirical research demonstrates that rising sea surface temperatures alter fish distribution, reduce fishing yields, and diminish industry profitability (Tidd et al., 2023). Climate change continues to disrupt ocean systems and fishing fleet operations, while volatile sea conditions influence production and market responses, often leading to overfishing and declining fisher incomes (Hartanto, 2024).

Recent theoretical contributions demonstrate that rising temperatures and shifting rainfall patterns reduce fisheries and aquaculture productivity across several Latin American regions. Researchers have also found that carbon emissions constrain industry performance by intensifying climate-related stressors (Muniz et al., 2023). Scholars have analysed adaptation strategies focused on climate-sensitive species and proposed practical interventions to sustain profitability under growing environmental pressures (Ojea et al., 2020). Reforming fisheries governance, enhancing international cooperation, and implementing adaptive policies have emerged as effective strategies to reduce systemic risks and strengthen resilience within the sector (Free et al., 2020; Gaines et al., 2018). Strategic responses consistent with these measures support the achievement of the Sustainable Development Goals by minimising climate-related threats to food security, economic stability, and poverty reduction (Muhala et al., 2021; Townhill et al., 2019).

Empirical Studies

Findings indicate that global fisheries revenue may decline by up to 35 per cent by the 2050s due to rising carbon emissions (Sumaila et al., 2011). Although high-latitude regions may experience increased yields, the catches consist largely of low-value species, offering only marginal income gains (Daw et al., 2009). In contrast, coastal tropical nations may suffer a 40 per cent decline in maximum catch potential, thereby threatening food security and weakening regional economies (Erauskin-Extramiana et al., 2023; Lotze et al., 2021). Developing countries that rely heavily on fisheries, including those in Africa, South America, and Southeast Asia, are likely to incur substantial economic losses due to depleted stocks and limited adaptive capacity (Anwar et al., 2023; Boyce et al., 2023)

In Indonesia, climate change has increased sea temperatures, introduced weather unpredictability, and raised sea levels, all of which reduce the resilience of fishing communities (Savo et al., 2017). Emissions from aquaculture activities have accelerated mangrove degradation along coastal regions (Arifanti et al., 2021), while acidification has disrupted fish population dynamics and decreased biodiversity (Britten et al., 2016; Daufresne and Boet, 2007). These environmental pressures, along with overfishing and

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declining productivity, have diminished fish biomass and reduced profitability by between 20 and 80 per cent. Small-scale fisheries face particularly high vulnerability, marked by declining operational efficiency and unstable income streams (Franco et al., 2020; Osman et al., 2021). Case studies from Atlantic Canada also illustrate how climate-induced disruptions affect socio-economic stability in fishing communities (Greenan et al., 2019). Nevertheless, mitigation strategies have demonstrated potential in improving productivity and income, particularly when integrated into adaptive fisheries management frameworks (Boyce et al., 2023; Pinsky and Fogarty, 2012).

This study examines the impact of climate change on fisheries performance across Asia, Oceania, the Americas, and Africa, with a primary emphasis on Indonesia. The evidence affirms the importance of adaptation in ensuring long-term sustainability. Accordingly, the following hypotheses are proposed:

H_1: Climate change has affected the fishery sector in countries across Asia, Oceania, the Americas, and Africa.

H_2: Implementing adaptation and protection strategies against climate change strengthens the resilience of the fishing industry in Indonesia and in other countries across the Asia-Pacific region, including those in Asia, Oceania, the Americas, and Africa.

METHODS

A comprehensive literature search was conducted across Scopus and Web of Science by applying the PRISMA-based protocol (Page et al., 2021) to ensure methodological transparency and replicability. The inclusion criteria required peer-reviewed empirical studies that employed quantitative analyses using correlational effect sizes and were published between 2016 and 2024. A total of 25 studies met these criteria, encompassing various ecological zones. The analysis adopted the Wavelet Fisher-Z method (Borenstein et al., 2009), for its capacity to capture temporal variability and address cross-study heterogeneity. Meta-analytic computations were carried out using JASP 0.19.1, which included heterogeneity tests (τ^2, I^2), publication bias diagnostics (Egger's, Kendall's τ), and clustering validation to strengthen analytical rigour.

The systematic review incorporated a critical assessment of both theoretical and methodological dimensions of each selected study, following the PRISMA workflow illustrated in Figure 1 (Page et al. 2021;Haddaway et al., 2022). The process involved six stages: identifying and retrieving relevant literature, screening studies based on inclusion and exclusion criteria, extracting key data, evaluating potential bias and study integrity, synthesising findings for detailed reporting, and applying PRISMA standards to ensure full disclosure and consistency. The inclusion criteria required peer-reviewed empirical studies that applied quantitative analyses using correlational effect sizes and were published between 2016 and 2024.

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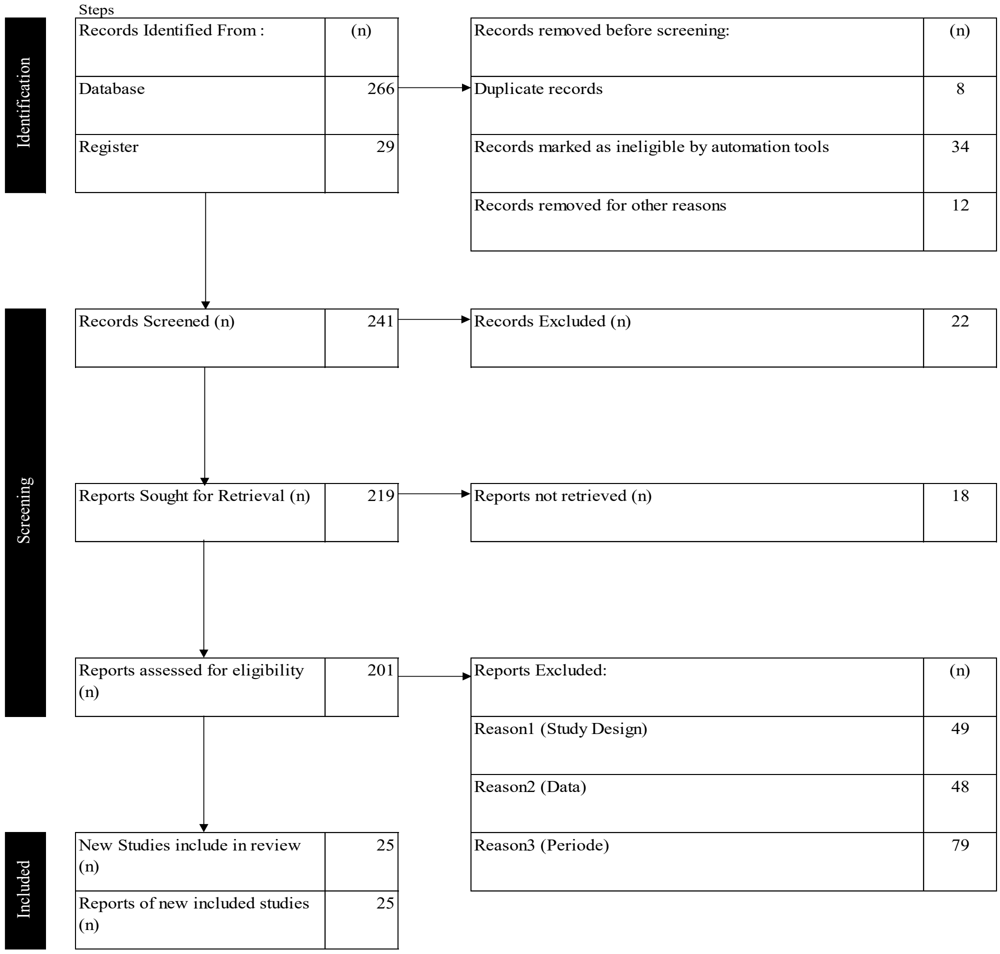

Source: based on (Haddaway et al., 2022).

Figure 1. The Process of Data Filtering Using Systematic Literature Review

The data clustering is presented in Table 1. The correlation parameter is the estimated sample correlation coefficient (r). The variance of r is roughly formulated as follows: $V_r = \frac{(1-r^2)^2}{n-1}$ (1) where *n* is the sample size.

Traditional meta-analyses rarely synthesise correlation coefficients due to the dependence of variance on the correlation function. In contrast, this study applies the Wavelet Fisher Z Meta-Analysis method to assess the effects of climate change on fisheries across various geographic regions. This method offers significant advantages over conventional approaches, particularly in handling non-stationary data. It enables the identification of temporal patterns and emerging trends in the relationship between climatic variability and fisheries productivity (Torrence and Compo, 1998). Its ability to localise time and frequency supports multi-scale analysis, while the Fisher Z transformation improves statistical robustness by stabilising correlation coefficient variance and mitigating outlier influence (Borenstein et al., 2009). Furthermore, it facilitates comparative evaluation of effect magnitudes across regions, offering critical insights for evidence-based policymaking. The method also facilitates the comparative

E-ISSN: 2830-5728

assessment of effect sizes across regions, thereby informing evidence-based policymaking. Equation 2 illustrates the analytical process involving natural logarithmic transformation and reconversion to the original scale, thus providing a robust foundation for examining the dynamic interactions between climate variables and fisheries performance.

The correlation transformation to Fisher z values is formulated as follows: (2) $z=0.5 \times \ln\left(\frac{1+r}{1-r}\right)$ (3) The variance of *z* (to an excellent approximation) is: $V_r=\frac{1}{n-3}$ (4) And the standard error is: $SE_Z=\sqrt{V_Z}$ The analysis applied Fisher's Z-test by transforming raw correlation coefficients into z-scores, thereby avoiding the direct use of raw variance. It calculated the corresponding variances of these z-scores to generate summary effect sizes and confidence intervals within the Fisher Z-metric. (5) The final step involved converting these values back into correlation coefficients through a standard mathematical transformation: $r=\frac{e^{2z}-1}{e^{2z}+1}$.

The meta-analysis applied JASP 0.19.1 to systematically process the data, as outlined in Figure 1. The process began by calculating the effect size for each study to quantify the strength of relationships. It continued with a heterogeneity test to evaluate variability among studies and concluded with a publication bias assessment. The analysis then synthesised the combined effect sizes into a summary estimate. All results were interpreted using Cohen's classification presented in Table 1, where 0.2 represents a small effect, 0.5 a medium effect, and 0.8 a large effect. These standardised thresholds enabled consistent interpretation and facilitated comparison across regions, particularly in studies assessing environmental and economic impacts.

Table 1. Effect Size Categorisation

No	Classification	Interval of Effect Size
1	No Effect	$0.00<ES\leq0.19$
2	Small Effect	$0.19<ES\leq0.49$
3	Moderate Effect	$0.49<ES\leq0.79$
4	Large Effect	$0.79<ES\leq1.29$
5	Very Large Effect	$ES\leq1.29$

Source: based on Cohen (2013).

The findings further emphasise the susceptibility of tropical fishing sectors to climate change and underscore the urgent need for adaptive management strategies and enhanced international climate policies. These include broader adoption of Climate Change Performance Index (CCPI) measures. Table 2 outlines the Climate Change Protection Initiative (CCPI) management practices. This study positions the strengthening of the CCPI as a foundational element, providing an explanation for government decisions to integrate adaptation into international climate protection frameworks.

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Table 2. Climate Change Protection Index Level

Countries	CCPI Score (out of 100)	CCPI Category
USA	42.36	Medium
China	41.88	Medium
Colombia	66.86	High
Zimbabwe	-	N/A
Uganda	-	N/A
Indochina	-	N/A
Indonesia	57.84	Low
Vietnam	58.23	Medium
Saudi Arabia	22.67	Very Low
Turkey	46.37	Low
Thailand	54.31	Medium
Polynesia	-	N/A
Chile	68.72	High
Clipperton	-	N/A
Costa Rica	73.83	High
Ecuador	55.42	Medium
El Salvador	-	N/A
French Polynesia	-	N/A
Guatemala	-	N/A
Kiribati	-	N/A
Mexico	53.73	Medium
Nicaragua	-	N/A
Panama	-	N/A
Peru	49.37	Low
North America	-	N/A

Source: based on Burck et al (2023)

RESULT AND DISCUSSION

Result

Table 3 presents the influence of climate change on the fishing industry across the Asia-Pacific region and the United States, based on the Wavelet Fisher Z Meta-Analysis. The analysis confirms that climate change affects fisheries through diverse regional mechanisms, resulting in varying effect sizes across different study locations. Kolstad and Moore, (2020) examined the United States and Turkey, while Tayyar (2024) identified significant impacts in both countries, with effect sizes of 1.29 and 2.09, primarily driven by sea level rise and altered ocean currents. In contrast Linsenmeier (2023) recorded negligible effects in Ecuador and North America, with effect sizes of 0.09 and 0.11, suggesting that moderate environmental pressures and effective planning have supported resilience in those areas. Alnafissa et al. (2021) reported moderate to high effects in China and Saudi Arabia, reflected in effect sizes of 0.59 and 0.95. These variations demonstrate the necessity of region-specific conservation measures and reinforce the broader conclusion that climate impacts on fisheries depend not only on ecological exposure but also on strategic governance and institutional adaptability.

E-ISSN: 2830-5728

Table 3. Effect of Climate Change on the Fisheries Industry

Nr. Study	Data Source	Countries	Effect Size	Effect of Climate Change on the Fisheries Industry
1	Kolstad and Moore (2020)	USA	1.29	Very Large Effect
2	Li et al. (2016)	China	0.59	Medium Effect
3	Selvaraj et al. (2022)	Colombia	1.66	Very Large Effect
4	Muringai et al. (2022)	Zimbabwe	1.19	Large Effect
5	Oyebola et al. (2021)	Uganda	1.19	Large Effect
6	Lebel et al. (2020)	Indochina	1.42	Very Large Effect
7	Rahman et al. (2021)	Indonesia	0.57	Medium Effect
8	Vinh and Nguyen (2022)	Vietnam	1.83	Very Large Effect
9	Alnafissa et al. (2021)	Saudi Arabia	0.95	Large Effect
10	Tayyar, 2024)	Turkey	2.09	Very Large Effect
11	Lebel and Lebel (2018)	Thailand	0.23	Small Effect
12	Linsenmeier (2023)	Polynesia	0.76	Medium Effect
13	Linsenmeier (2023)	Chile	0.24	Small Effect
14	Linsenmeier (2023)	Clipperton	0.42	Small Effect
15	Linsenmeier (2023)	Costarica	0.25	Small Effect
16	Linsenmeier (2023)	Ecuador	0.09	No Effect
17	Linsenmeier (2023)	Elsalvador	0.36	Small Effect
18	Linsenmeier (2023)	Polynesia	0.76	Medium Effect
19	Linsenmeier (2023)	Guatemala	0.54	Medium Effect
20	Linsenmeier (2023)	Kiribati	0.17	No Effect
21	Linsenmeier (2023)	Mexico	0.34	Small Effect
22	Linsenmeier (2023)	Nicaragua	0.34	Small Effect
23	Linsenmeier (2023)	Panama	0.41	Small Effect
24	Linsenmeier (2023)	Peru	0.05	No Effect
25	Linsenmeier (2023)	North America	0.11	No Effect

Source: based on Comprehensive Meta-Analysis (CMA), 2024

Table 4 reports a Q value of 39.465 ($p < 0.01$, $df = 23$), indicating that climate change significantly influences the fishing industries across multiple regions. The residual heterogeneity test confirmed notable variation among the studies, implying that the differences in effect sizes stem from specific moderating variables rather than random chance. The analysis assessed the research model considering these variations. The heterogeneity statistics revealed moderate variability across studies, with a τ^2 value of 0.325 and an I^2 value of 99.284 per cent, indicating that most of the variance arises from random effects rather than systematic inconsistencies.

DOI: 10.55960/jlri.v13i1.1096

E-ISSN: 2830-5728

Table 4. Heterogeneity Test

Evaluation	Q	df	p
Omnibus test of Model Coefficients	39.465	1	< .001
Test of Residual Heterogeneity	3212.206	23	< .001

Note. *p* -values are approximate.
Note. The model was estimated using the DerSimonian-Laird method

Table 5 presents the evaluation of publication bias based on the Asymmetric Correlation Rating Test and Egger's test. The Kendall coefficient from the Asymmetric Correlation Rating Test reached 0.017 (p > 0.05), suggesting no statistical evidence of asymmetry and, consequently, no indication of publication bias. Egger's test generated a z-value of 2.762 and a p-value of 0.060 (p > 0.05), reinforcing the interpretation that, although the funnel plot may appear visually asymmetric, it does not provide statistical confirmation of publication bias.

Table 5. Test of Publication Bias

Rank Test of Asymmetric Correlation	Kendall's τ	p-value
	0.017	0.913
Regression test for Funnel plot asymmetry ("Egger's test")	z	p-value
	-2.762	0.060

Scientifically robust meta-analytic studies that aim to maintain objectivity must include an assessment of publication bias. The File-Safe N (FSN) approach was applied in the present study to evaluate the extent of potential bias. As reported in Table 6, the FSN value reached 64,844, which substantially exceeded the critical threshold of 5k + 10 (135). The findings of the meta-analysis, therefore, can be regarded as statistically reliable and unaffected by publication bias.

Table 6. File Drawer Analysis

	Fail-safe N	Target Significance	Observed Significance
Rosenthal	64844.000	0.050	< .001

Note. *p-value>0.10, **p-value>0.05, ***p-value>0.01.

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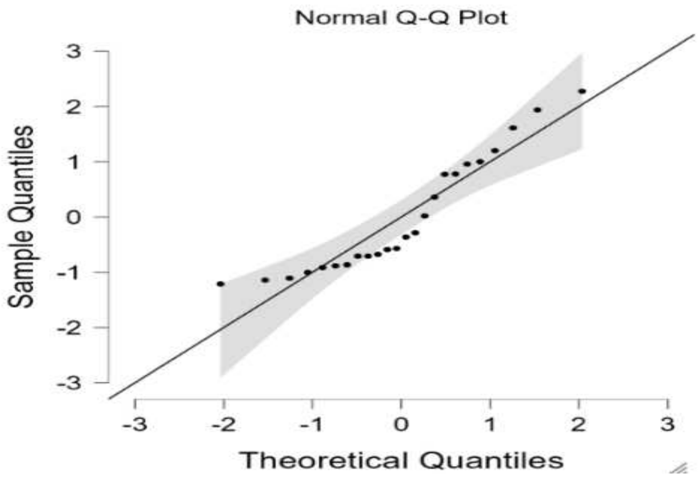

Figure 2. Data Normal Test

Visual outputs confirm the statistical robustness of the analysis. Figure 2 illustrates that the sample data closely follow a normal distribution, with most points aligning along the reference line, particularly in the central quantiles. The analysis indicates that actual effect sizes and their respective confidence intervals vary across the included studies. The pooled effect size was calculated at rRE = 0.75, reflecting a statistically significant relationship at $p < 0.05$, with a confidence interval ranging from 0.52 to 0.98.

Discussion

The Fisheries Industry and the Impact of Climate Change.

A meta-analysis of studies conducted across various regions demonstrates that climate change affects the fisheries industry through a combination of environmental characteristics, governance capacity, and structural features of fishing systems. Countries in Southeast Asia, including Indonesia, Vietnam, and Thailand, are confronting rising sea surface temperatures and altered oceanic currents, which disrupt marine ecosystems and modify fish distribution patterns. The United States and Europe have also experienced the consequences of ocean acidification and shifting fish populations. In Indonesia, moderate impacts have been observed; however, policy responses involving marine conservation programmes and community-based fisheries management have contributed to enhancing adaptive capacity. In contrast, Vietnam and Colombia exhibit higher levels of exposure to climate-related risks due to weak regulatory enforcement, insufficient infrastructure, and reliance on traditional fishing methods. Indonesia’s participation in large-scale commercial fisheries has enabled a more effective response to climate pressures, yet small-scale fishers remain acutely vulnerable. These findings are consistent with the assessment by Tidd et al. (2023), who argue that diminishing fish stocks directly reduce catch volumes and threaten the long-term sustainability of the fisheries sector.

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Climate Change Protection and Adaptation Strategies.

Countries that maintain robust climate governance, including Chile and Costa Rica, illustrate how effective adaptation and mitigation measures reduce the severity of climate change impacts on the fisheries sector. Although notable effects remain, the intensity is lower than that observed in the United States, Colombia, Vietnam, and Turkey. Indonesia, with its extensive aquatic ecosystems, has exhibited moderate policy performance; however, advancing regulatory implementation and enhancing local adaptive measures remain essential to address escalating risks. In Asia, China continues to encounter water quality issues and sustainability challenges in aquaculture, despite displaying moderate policy efficiency. The results indicate statistically significant differences in climate change impacts, influenced by governance standards, ecosystem responsiveness, and regional socio-economic structures. Indonesia's moderate effect size suggests institutional adaptation to some extent, yet discrepancies between large-scale and small-scale fisheries point to persistent governance imbalances. These observations support the differential vulnerability framework developed by Lam et al. (2020), , which emphasises the role of institutional strength in shaping exposure and sensitivity to climatic stressors. The findings also reinforce the conclusions of Free et al. (2019), who highlight that adaptive fisheries management minimises economic losses, as confirmed by regional differences involving Colombia, Vietnam, and Indonesia. The analysis emphasises the importance of multilevel governance and coordinated transboundary policy frameworks to counteract climate-related threats to fisheries. Saudi Arabia, despite achieving relatively strong climate policy ratings, confronts geographic limitations due to its reliance on the Red Sea and Arabian Gulf, both highly susceptible to environmental fluctuations. Recent developments in Turkey and Saudi Arabia reveal emerging disruptions in fish stock dynamics and fishing practices, resulting from elevated sea surface temperatures and unpredictable climatic conditions.

Regional comparisons underscore varying degrees of climate vulnerability and the effectiveness of policy responses across continents. In Oceania, Clipperton Island and Polynesia experience moderate impacts, which may reflect either successful adaptation measures or relatively low exposure. In the Americas, the United States demonstrates moderate policy capability yet continues to encounter significant challenges in addressing ocean warming (Putten et al., 2014), acidification, and shifting species distributions, with the Gulf of Mexico and Pacific Northwest facing more severe effects. Colombia remains highly exposed due to limited policy capacity and geographical susceptibility along its Pacific coastline. Central and South American countries present a spectrum of conditions: Ecuador exhibits stronger adaptation practices than Indonesia, while El Salvador, Guatemala, Mexico, Nicaragua, Panama, and Peru report comparatively lower climate impacts, suggesting reduced vulnerability despite irregular policy advancement. In Africa, countries such as Zimbabwe and Uganda lack comprehensive climate governance, exposing inland fisheries to risks arising from fluctuating river systems and increased flooding. Indonesia’s primary challenges originate from marine-related threats, which highlights the influence of geographical and ecological features in shaping fisheries' sensitivity to climate change.

E-ISSN: 2830-5728

CONCLUSION

This study concludes that climate change significantly affects the performance and sustainability of fisheries in various global regions, including Indonesia. The findings respond to the two research questions by demonstrating that the impact of climate change on the fisheries industry is shaped by ecological sensitivity, institutional capacity, and economic structure. Some regions have developed adaptive responses supported by robust governance and infrastructure, while others remain exposed to climatic risks. In Indonesia, adaptation efforts such as community participation and ecosystem-based approaches show promising outcomes, yet disparities between large-scale and small-scale fisheries remain. The use of the Wavelet Fisher Z Meta Analysis has provided strong methodological support, allowing deeper understanding of region-specific vulnerabilities and responses.

To enhance Indonesia's national resilience in the face of climate-related threats to the fisheries sector, this research recommends an integrated approach involving policymakers, researchers, and practitioners. Policymakers must improve regulatory implementation, invest in decentralised and adaptive infrastructure, and ensure long-term support for scientific monitoring. Researchers are encouraged to expand localised and ecosystem-oriented studies that inform evidence-based governance. Practitioners should adopt sustainable aquaculture techniques, diversify income sources, and reinforce community-based management to reduce dependence on vulnerable ecosystems. Strengthening collaboration across these stakeholders will contribute to building an adaptive, inclusive, and sustainable fisheries system that aligns with national development objectives and fortifies Indonesia's resilience.

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