

Article

Climate Change Perceptions and Adaptation Options Among Coastal Small-Scale Fishers in the Asia-Pacific Region: Perspectives from Taiwan and Papua New Guinea

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Abstract

Coastal small-scale fishers in the Asia-Pacific region (APR) face mounting challenges from climate change (CC), with vulnerability shaped by ecological exposure, socio-economic dependence, and limited adaptive capacity. This study reflects on two contrasting cases, Taiwan and Papua New Guinea (PNG), to explore fishers' perceptions and perspectives on CC and practical adaptation strategies. In PNG, 209 respondents from Momase, the Islands, and Southern regions participated. In Taiwan, 45 respondents from the Yunlin and Chiayi coastal regions participated. Significant correlations in coastal communities' vulnerabilities and perceptions towards CC were revealed. Small-scale fishers perceive rising sea temperatures, shifting fish stocks, and intensifying typhoons as disruptive shocks to livelihoods and eroding traditional fishing practices. In Taiwan, despite relatively stronger infrastructure, household income, and access to technology, adaptation remains constrained by market pressures, declining youth participation, and regulatory complexities. In PNG, fishers deeply rely on natural resources and coastal ecosystems for subsistence and income, yet face acute risks from sea-level rise, coral bleaching, and unpredictable weather. With limited financial resources, weak institutional support, and geographic isolation, fishers perceive CC as an amplifying factor to existing vulnerabilities, leaving communities dependent on traditional knowledge and communal coping strategies. Fishers' perceptions of CC are shaped by lived experiences rather than scientific discourse, influencing adaptation choices ranging from livelihood diversification to migration. Perceptions of CC drivers, their distal and proximal impacts on coastal fishing community livelihoods are viewed as siloed; yet, remote sensing data revealed that the impacts are transboundary. The findings underscore the urgent need for context-sensitive policies that integrate local knowledge, science-based data (such as remote sensing CC maps) to strengthen institutional support, and enhance resilience among vulnerable and underserved coastal small-scale fishers.



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Keywords: Asia-Pacific region; climate change vulnerability; coastal communities; mitigation and adaptation perceptions and options; small-scale fishers; Papua New Guinea; Taiwan

1. Introduction

The Asia-Pacific region (APR), encompassing East Asia, Southeast Asia, and Oceania, is a globally recognized biodiversity hotspot with extensive marine ecosystems and resources. APR accounts for 63% of global fish production, thereby contributing to global food security, economies, and the blue transformations [1]. Unfortunately, with global ocean environmental shifts, climate change (CC), exploitative fishing activities, and governance bottlenecks, these benefits are compromised [2,3]. Moreover, as the APR (covering 22% of the global land area) comprises critical ‘climate poverty hotspots’ and includes migratory fish species, achieving sustainable fisheries resources governance and management has remained challenging, partly due to difficulties in identifying which areas are inhabited by fish schools, understanding their migratory patterns, and accounting for shifting dynamics [4]. The 5th Intergovernmental Panel on Climate Change (IPCC) assessment report documented that Southeast Asia (SEA) is one of the world’s most climate-vulnerable regions, facing rising sea levels, extreme weather, and socio-economic risks that threaten millions of lives, notably in rural low-elevation coastal zones (LECZs) [4]. Since the 1980s, SEAs’ CC-induced vulnerability risks have increased, and temperatures have risen by about 0.5 °C [5]. Recent projections reveal that by 2050, SEAs’ temperatures will increase by 1.1 °C (medium emissions) and 3.5 °C (high emissions scenario). Temperature spikes have coincided with extreme weather events, such as floods, tropical cyclones, and sea-level rise, intensifying socioecological systems (SES) vulnerability and livelihood disruptions [6].

As observed by [7], SEAs’ threats are worsened by five existential socio-economic fragilities, including (i) high coastal populations, increasing exposure to sea-level rise and other CC-induced threats, (ii) high dependence on climate-sensitive sectors, e.g., coastal fisheries, agriculture, and nature for livelihood welfare and national gross domestic production (GDP), limited adaptive capacity due to lack of resilient infrastructure, resources, and strong governance mechanisms, (iv) gender and social inequalities in key livelihood sectors, e.g., small-scale fisheries create disproportionate hardships for women and socioeconomically marginalized groups, and (v) environmental-induced displacement and migration, yet legal frameworks and support infrastructure are lacking [8,9]. Without strong adaptation and resilience measures, by 2050, SEA could face triple burdens from environmental change, poverty, and weak or fragmented governance, which could escalate risks to food security, health, resource conflict, and livelihoods [10].

This is because, although SEA has experienced that large global surge in capture fish production, increasing by 7.1 million metric tons between 1993 and 2022, the high dependence on natural stocks makes communities highly sensitive to environmental and market shocks, as localized nearshore overfishing still threatens small-scale fishers who lack access to deeper waters, modern equipment, and adaptation resources. Concerningly, although context-specific vulnerabilities in the Pacific region are recognized in contemporary studies [10], streamlining lived experiences for generating stronger social safety nets, CC adaptation, and sustainable fisheries governance, APRs’ coastal fishing communities are still limited or an emerging scholarly space. This slow trajectory could trap Asia-Pacific’s coastal communities in vicious cycles of poverty, livelihood vulnerability, and ecological decline, which could compromise sustainable development goals (SDGs), e.g., SDG 1 (no poverty), SDG 2 (zero hunger), SDG 5 (gender equality), SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 14 (life below water) [1,11], among

others. Evidence-based studies and innovative adaptation and response mechanisms to help coastal fishing communities prepare for current and future vulnerability are needed. This research attempts to reinvent and co-design CC adaptation and food security strategies by exploring perspectives from two island fishing nations, i.e., Taiwan and Papua New Guinea (PNG).

The overall rationale is to contribute to research directions on blue transformations and sustainable coastal fisheries livelihoods by comparatively linking and comprehending nature-human vulnerability drivers, thereby unraveling feasible and replicable coastal fisheries livelihood empowerment and environmental resilience, and adaptation strategies. Comparing fisher and coastal communities' perceptions of climate change in the Asia-Pacific region, particularly in island states such as Taiwan and Papua New Guinea, is critical because these communities are among the most exposed and dependent on fragile marine ecosystems. Their perspectives can provide insights into both the immediately lived realities of climate impacts and the cultural frameworks through which adaptation must occur.

Additionally, socio-economic and cultural contexts and perceptions differ significantly; empirical studies can help policymakers identify both shared vulnerabilities and context-specific needs. This is because studies in coastal socioecological systems highlight that community perceptions often precede or complement scientific data, making local knowledge an essential component of climate monitoring. Ignoring these perceptions risks overlooking early warning signals that could inform adaptive management [8]. Thus, understanding how communities perceive risks to their food supply helps tailor interventions that safeguard nutrition and livelihoods. For instance, fishers' knowledge about changing migration patterns can guide sustainable fisheries management, while coastal farmers' insights into storm damage can inform infrastructure planning. Critically, in climate resilience and adaptation research, uncovering comparative perspectives and perceptions can help shape trust and cooperation on adaptation policies, as most policies are imposed without community input [9]. Thus, by leveraging a comparative approach and integrating fisher and coastal communities' knowledge, new insights resonating with local communities' realities can be identified, ensuring that adaptation is not only scientifically sound but also socially acceptable and sustainable. To achieve the overall study aim, four objectives will be explored, including:

- (a) Exploring the situational livelihood and SES indicators of coastal fisheries and fishing communities in Taiwan and PNG.
- (b) Comparatively examining coastal fisheries vulnerabilities, including fishers' perceptions on CC, CC-induced vulnerability drivers, and ramifications to SES functioning.
- (c) Assessing the existing resilience strategies and their effectiveness in the context of CC adaptation and food security needs of coastal fishing communities.
- (d) Drawing practical research and policy implications in the context of global and regional sustainability and blue transformation targets across vulnerable fishing regions.

2. Materials and Methods

2.1. Case Studies and Rationale

This study explores small-scale fishers' perspectives from Taiwan and PNG, which are island nations situated in the APR (Figure 1). The rationale for selecting these case studies is based on three valuable research insights related to CC vulnerability among small-scale fisheries. Although Taiwan and PNG rank among the richest biodiversity hotspots, they are highly vulnerable to shifting marine environmental parameters, e.g., CC, sea-level rise, and sea surface temperature (SST). Secondly, coastal megatrends, especially in Taiwan, are compromising coastal livelihoods and indigenous populations, yet citizen

science research is limited [11]. Third, Taiwan's coastal fisheries have developed sustainable resilience actions, due to comparatively higher development indicators than other island nations, implying that documenting these practices could offer innovative and practical examples toward sustainable blue transformations and resilient options in other fishing communities [12].

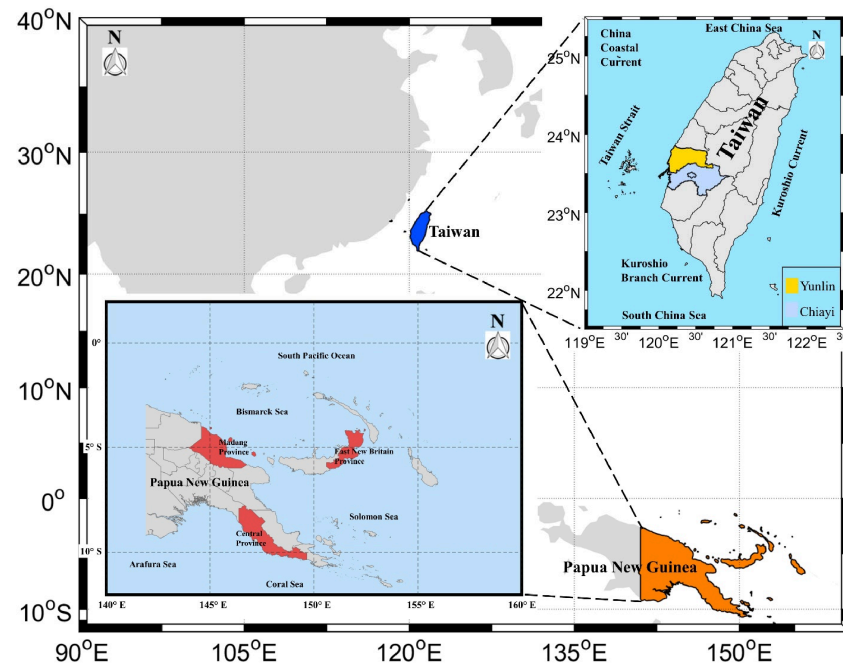


Figure 1. The sampled coastal fishing areas in PNG and Taiwan, where data were collected (source: authors' development).

2.2. Research Design and Rationale

A transdisciplinary (TD) research design that combines qualitative and quantitative data techniques and draws on existing literature to address complex societal concerns is employed. Unlike conventional research approaches, the TD approach integrates pure science, social science, and citizens' knowledge to produce multidisciplinary knowledge that crosses conventional boundaries and places a strong emphasis on collaborations, values, and effects, as a basis for co-creating solutions to real-life problems, thus enhancing comprehensive production of knowledge and actions that foster integrated understanding and responses to societal issues, e.g., CC [13].

2.3. Research Methods

The TD approach encompasses diverse research techniques, thus requiring the identification of feasible, place-based research methods that can capture information related to the study's aim and objectives. As fisheries and fishers operate in complex SES settings, to systematically obtain data that is comparable, a phased process involving qualitative and quantitative research methods is utilized. First, a comprehensive literature review of fisheries-related documents and articles on CC vulnerability, coastal fisheries, and adaptation measures was conducted. To ensure reproducibility, the following systematic criteria were utilized in the literature review strategy and field data collection. The three databases used were searched to ensure coverage of peer-reviewed journals and high-quality gray literature. The search strings involved keywords that combined climate change, small-scale fisheries, adaptation, and Asia-Pacific. Boolean operators (AND/OR) were used to refine results. To align with the remote sensing dataset timeframe and capture contemporary discourse, the literature published between 2000 and 2025 was considered.

The inclusion criteria were based on (i) studies focusing on small-scale or artisanal fisheries in coastal regions of the APR, Taiwan, and PNG's contexts; (ii) research addressing climate change perceptions, adaptation strategies, or vulnerability indicators; and (iii) peer-reviewed articles, book chapters, and high-quality reports in English. Through title and abstract screening, we excluded studies on industrial fisheries, inland freshwater fisheries, or those lacking empirical data. Additionally, a full-text review to confirm relevance to perceptions, adaptation, or governance, and reference snowballing to identify additional relevant works were made. A coding framework was developed to categorize literature into themes: perceptions, adaptation strategies, governance, and vulnerability indicators. Specifically, 45 documents on coastal fisheries, challenges, and governance frameworks in Taiwan and PNG were included and downloaded for data extraction in a Microsoft Excel file. The basis of inclusion was based on (i) the most cited documents, (ii) documents specifying coastal small-scale fisheries, and (iii) articles documenting fisheries governance and adaptation actions highlighted in the FAO small-scale fisheries guidelines and blue transformation roadmap (2021–2030).

Second, data on ocean environmental parameters related to CC and determining marine fish abundance, including SST, sea surface salinity (SSS), sea surface height (SSH), sea surface chlorophyll (SSC), El-Nino Southern Oscillation (ENSO), La-Nina, and ocean wind patterns, were collected and analyzed. The analysis covered the period from 2010 to 2020, a period that experienced massive temperature aberrations as reported by the IPCC. Remote sensing data (RSD) was sourced from the Copernicus Marine Environment Monitoring Service (CMEMS) via the Global Physics Reanalysis product. The ENSO data from the Multivariate ENSO Index (MEI) was sourced from NOAA's Physical Sciences Laboratory.

The RSD helped assess the Ocean Climate Index for the Pacific Ocean region as a critical indicator of large-scale ocean-atmosphere variability, and was utilized to assess how decadal, inter-decadal, annual, seasonal, and monthly fluctuations in oceanic conditions correlate with shifting fisheries and migratory patterns, which directly influence coastal fisheries and livelihoods. To specifically demonstrate comparable environmental trends and align them with field data, monthly mean SST, mean seasonal SST (spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February)), and interdecadal trends in the Asia-Pacific region from 2010 to 2025 were captured. Thus, ocean environmental data illustrated dynamic ocean temperature changes and circulation patterns in Taiwan and Papua New Guinea's coastal fishing zones, offering practical, comparative descriptions for CC and fisheries perception analysis.

Third, participatory field research was conducted among coastal fishers to obtain qualitative findings and perspectives on situational coastal SES and livelihood indicators (vulnerabilities and current mitigation actions), knowledge and perceptions towards CC and its variability, and co-designing better adaptation mechanisms. In Taiwan, participatory interactions were conducted with 45 participants from coastal fishing households in the Yunlin and Chiayi regions, areas that [12] reported to comprise a larger section of small-scale fishers. In PNG, informal participatory interactions were conducted with 209 participants from three coastal regions: Momase, the Islands, and the Southern region, which are historically dominated by small-scale fishers [7]. The integrated and context-specific respondent selection process ensured gender representation across diverse fishing practices. In PNG, the respondents were recruited using community leaders and random sampling at fish landing sites, to ensure inclusivity.

Participatory fieldwork employed semi-structured interviews and focus group discussions, where respondents shared diverse information either individually (in their homes or along fishing sites) or in groups. Protocols emphasized culturally sensitive engagement,

with translation and local facilitators used where necessary. Ethical approval was obtained, and informed consent was secured from all participants before beginning field discussion and interactions, which often lasted for 45 to 60 min or more, depending on the respondents' willingness to offer more information. Field notes, audio recordings, and observational data were triangulated to enhance reliability. To ensure the collection of diverse community perspectives, including on vulnerability and remedial strategies, ten field data collection steps and techniques were utilized, including resource, hazard, or CC vulnerability, livelihood, and infrastructure mapping; actor mapping; seasonal activities calendar; problem analysis; strengths, weaknesses, opportunities, and threats (SWOT) analysis; strategic matrix and priorities development; and co-designing an adaptation pathway.

2.4. Data Reporting and Basis for Comparison

An integrated data reporting and comparison approach is utilized, involving quantitative and qualitative techniques. The basis of data reporting was based on cross-national comparison to represent contrasting perceptions, based on diverse contexts and narratives. Additionally, ocean variables, including sea surface temperature, chlorophyll concentration, and salinity from 2010 to 2025, were analyzed to provide objective environmental baselines. For triangulation, perception data were compared against remote sensing indicators and literature-derived vulnerability frameworks to identify convergences and divergences. To scale up the findings into comparable themes, community-level perceptions were aggregated and contrasted with regional-scale environmental data to highlight mismatches between local experiences and broader climate trends. For field data, specific themes on fisheries, coastal livelihoods, and CC vulnerability and adaptation were developed to support literature and RSD insights. The authors translated the field data to English, followed by manual coding based on dominant study themes, such as livelihoods, vulnerability indicators, and strategies. These were reinforced by descriptive, visual, and inferential techniques to represent and connect diverse fishers' narratives. Additionally, rich field photos and shared or lived experiences were incorporated to serve as practical community photovoice evidence. A concurrent comparative data reporting technique is utilized to correlate, validate, and draw comparative lessons from Taiwan and PNG's coastal fisheries vulnerabilities and adaptation options. By concurrently describing findings from the two case studies, the study offers empirical reflections on how small-scale fishing communities choose to organize themselves to make decisions about important issues, such as CC resilience, fisheries' resource use, and protection of coastal commons (e.g., fishery resources). Additionally, through RSD analysis and literature integration, regional-level evidence for transboundary CC vulnerabilities is reported, which could help inform better fisheries resource governance practices and resilience strategies.

3. Results

3.1. Comparative Coastal Fishers' Livelihood and SES Indicators

Findings from existing literature and coastal communities revealed that coastal and marine zones in Taiwan and PNG possess diverse resources, presenting immense potential for coastal fishers' livelihood empowerment. As indicated in Table 1, the dominant livelihood is either fishing or fisheries-related activities, demonstrating a high degree of dependence on coastal and marine biotic resources. PNG's National Fisheries Authority revealed that coastal fisher livelihoods, including commercial and small-scale tuna fisheries, predominate because PNG has one of the largest tuna stocks globally [14], with a total average catch of 575,000 metric tons reported between 2018 and 2022. According to the 2023 Island Business report, PNG currently contributes 17 percent of the entire tuna catch inside Western and Central Pacific Fisheries Commission (WCPFC) waters (2.6 m

Mt), which translates to about 453,057 metric tons of tuna [15]. Among coastal artisanal fishing communities, unwritten communal rules, elders, and fisher households believed to have supernatural fish-harvesting powers are reportedly vital actors in ensuring better management of fish stocks. With PNG's tuna stocks mostly under-exploited, their value is projected to increase to US\$50 billion in 2028 if sustainable management and harvesting practices are developed. Additionally, with increasing demand for fresh fish products in urban markets, such as in Port Moresby, small-scale aquaculture projects have increased, mostly dominated by rich fishers or fishing companies. Generally, PNG's fisher livelihoods and operations are determined by historical communal resource access rights, which partly account for the predominance of coastal livelihoods that remain artisanal and focused on satisfying micro-level food and household survival needs. Major fish resources, such as tuna, that are major national economic drivers, are mostly managed by commercial dealers or companies that operate deep-sea fishing motorized vessels.

Table 1. Dominant coastal fisher livelihood activities in the sampled coastal areas of PNG and Taiwan (source: field data).

PNG	Taiwan
Artisanal coastal fishing, including reef fish, lobsters, trochus shells, and sea cucumbers (sandfish).	Aquaculture and aquavoltaics, involving oyster farming (especially in Yunlin and Chiayi), and integrated clam and milkfish cultivation with solar energy and seafood tourism projects.
Subsistence fishing (many coastal households rely on fishing for daily food security and income generation).	Nearshore fishing, mostly involving small-scale capture of mullet, squid, and other coastal species.
Tuna fisheries (coastal communities benefit indirectly through employment in processing and small-scale tuna fishing).	Mixed livelihoods, where many households combine fishing with agriculture due to declining fish stocks and aging fisher populations.
Aquaculture (emerging), involving small-scale projects for tilapia and other species, though less dominant than capture fisheries.	Home-based seafood processing (fisher households, including women who process and sell harvested fish to local or regional consumers).

Conversely, Taiwan's coastal fishers' livelihoods and operations vary depending on location, fishers' knowledge, and institutional policy directions on coastal developments. In coastal Taiwan, small-scale fisheries such as oyster farming and clam cultivation dominate nearshore fishing livelihoods. However, at major fishing ports and harbors, such as Dongshi, commercial fishing operations predominate and co-exist with small-scale fishing operations. In such areas, high-value fish products, including oyster shells and mullet roe, are traded by women-led and family-run enterprises, some of which have trading labels, licenses, and exporting contracts. Additionally, among nearshore fisher households, fisher livelihoods are demonstrated and preserved through art, music, and drama, demonstrating strong connections between cultural belief systems and the economy. For instance, as indicated in Figure 2, fisher households are decorated and painted with valuable or culturally significant fish species to help preserve this knowledge among younger generations. In key fish trading towns, such as Kouhu, fishers have formed cooperative organizations and groups, such as the Yunlin Fishery Association (YFA), to increase their bargaining power and socioeconomic benefits from their fish-dependent livelihoods. Through the YFA, for instance, special mandates for conservation of key fishing zones, ensuring regulatory compliance, and advocacy for special rights, including under the Yunlin County exclusive fishing right, where resource owners and holders allocate a 100% access fee for fishing ground management and conservation, have been established. Today, as Taiwan's wild

stocks are dwindling, especially in traditional fish hotspots, such as Chiayi, coastal fisher livelihoods are dramatically transitioning to integrated aquaculture projects. For instance, in Kouhu, nearshore and onshore coastal zones are covered by large, intensive aquaculture farms that are integrated with solar panels and recreational or touristic centers, including seafood restaurants, to generate energy and supplement fisher incomes, respectively.

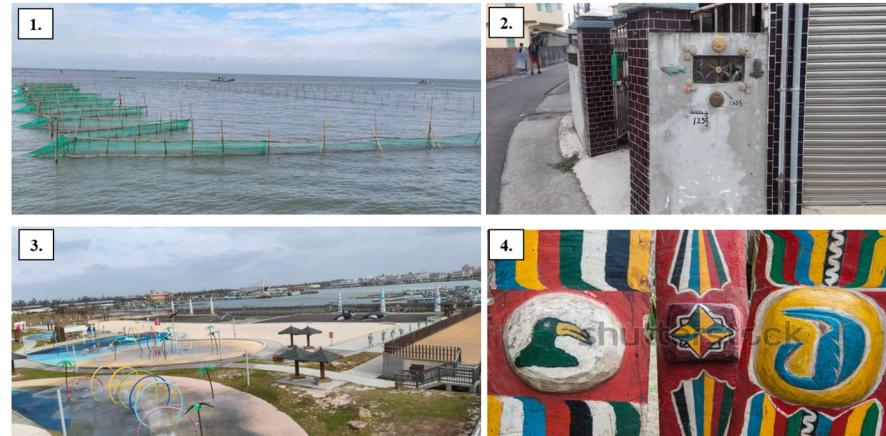


Figure 2. Unique coastal fisher livelihood activities and fisheries knowledge preservation assets (source: field photos). Photo 1 indicates an oyster fishing zone that uses bamboo stems in Kouhu. Photo 2 indicates a house gate and address decorated with indigenous fish species in the Chenglong area. Photo 3 indicates a new coastal recreation park in Dongshi fishing port to boost fishers' livelihood during closed seasons. Photo 4 indicates the decorations of coastal fishing birds and nearshore crocodiles that form a key part of PNG's cultural crocodile festival.

Interestingly, fishers revealed that the transitions are often shaped by changing SES dynamics, including climate change (CC), demographic trends, and coastal developments. In the East New Britain province of PNG, for instance, local fishers reported that fish are becoming variable and pricey, with the most extreme values recorded in urbanizing areas. To sustain their livelihoods, three innovative adaptation and diversification trends have been leveraged, including (a) community-based resource management practices, such as locally managed nearshore fishing areas, to protect reefs and culturally vital fish species, especially during cultural events; (b) diversification into seaweed farming and self-help groups for small-scale aquaculture projects; and (c) cooperation agreements with larger or rich fish dealers to secure long-term benefits, such as daily jobs, markets, and loans. In Taiwan, CC-induced drivers, such as rising sea level, coastal erosion, typhoons, extreme weather, and ocean warming, are reported to be forcing fishers to expand to land-based aquaculture systems to reduce exposure, integrate renewable energy (solar and wind) into coastal aquaculture operations to reduce costs, or lobby for institutional support for climate-resilient aquaculture strategies and capture fisheries diversification. This trend demonstrates that although Taiwan's and PNG's coastal livelihoods have historically relied on fishing, current SES indicators dramatically reduce livelihood empowerment and better welfare outcomes.

3.2. Coastal Fishers' Vulnerabilities and Perceptions of CC-Induced Vulnerability Drivers and Ramifications

Fishers acknowledged that multidimensional human-nature vulnerabilities are dramatically affecting their livelihoods and fishing operations. As indicated in Figure 3, although the percentage of place-based vulnerability challenges varies, practical vulnerability interlinkages are observed across fisheries operations and value chains. Of the eleven reported dominant vulnerability issues, climate and marine environmental changes predominate,

indicating increasing vulnerability among fishers, as most fishers reported correlations between environmental changes and declining ecosystem health, food, and livelihood insecurity. In Yunlin, coastal fishers reported that among the dominant environmental change drivers, rising sea levels and coastal erosion in intertidal zones are increasingly affecting oyster racks and clam farms that are highly vulnerable to flooding and storm surges. In Chiayi, fishers reported that typhoons and extreme weather have become more frequent, damaging nearshore aquaculture infrastructure and reducing harvests. In key fishing villages, such as Iduwan, Badup, and Nulairu in the Momase region of PNG, fishers reported shifts in fish distribution, evidenced by reduced traditional nearshore species, such as sea cucumber, thus making it harder to harvest daily catch and pushing fishers toward unsustainable daily-paying jobs, such as fishnet hauling.

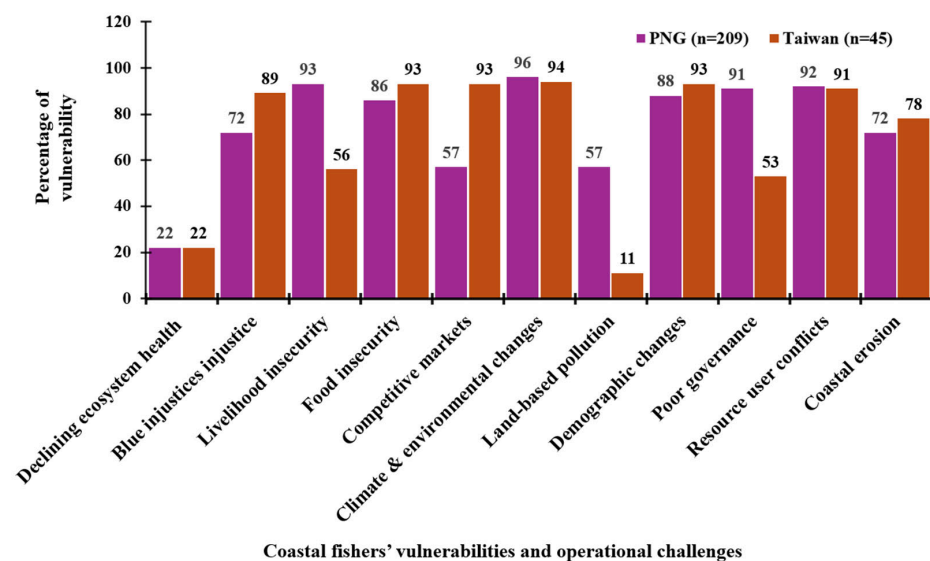


Figure 3. Comparative representation of coastal fishers' vulnerabilities in PNG and Taiwan (source: field data).

Additionally, like Yunlin's coastal fishing regions, in PNG, such as in Kabakaul, Vunamami, and Tokunar fishing villages in ENB, new socioeconomic, demographic, and resource access vulnerabilities are reported. For instance, elderly fishers reported a declining fisher population as most youth prefer better or less tedious jobs in urban centers. Moreover, a declining labor force has coincided with commercialized fishing activities, dominated by rich fishers or external fish dealers who target quick profits in local settings. This trend has led to natural resource user and access contestations, declining capacity or chances to obtain fish for trade, and injustices. Coastal injustices include the displacement of fishers from traditional fishing grounds or landing site operations, such as fair communal fish auctioning practices, notably in Momase and Yunlin. Although Taiwan's coastal fishers reported fair engagement in localized value chain practices, in key fishing areas, such as Beigang and Taixi, fishers reported threats to locally produced oysters and clams by imported fish, such as those from Vietnam.

Within the specific domain of CC vulnerability, drivers and ramifications to SES, fisher perceptions and knowledge varied based on age, fisher knowledge, level of experience, and nature of operations. Studies by [5,7,12] reported that differences in CC perceptions and knowledge can be explained by the distinct socio-cultural and governance contexts of Papua New Guinea and Taiwan. In Papua New Guinea, customary governance systems and subsistence dependence on marine resources mean that older fishers often rely on traditional ecological knowledge accumulated over decades, interpreting climate variability through long-term shifts in fish abundance, coral reef health, and seasonal weather patterns.

By contrast, younger fishers may be more influenced by schooling, NGO interventions, or external narratives, resulting in perceptual divergence across generations. Limited access to modern technology further reinforces reliance on lived experience, making perceptions highly localized and heterogeneous. In Taiwan, small-scale fisheries are more integrated into commercial markets and state-led governance frameworks. Here, perceptions are shaped not only by direct ecological observations but also by technological exposure, government advisories, and market fluctuations. Younger fishers, often more technologically adept, interpret climate risks through data-driven signals such as weather forecasts, mobile applications, and price volatility, while older fishers continue to rely on traditional knowledge of currents and seasonal cycles. The diversity of fishing operations—from nearshore artisanal practices to semi-industrial offshore ventures—also influences perceptions, as vulnerability and adaptive capacity differ across scales of operation. Taken together, these findings underscore that perceptions of climate change are not uniform but are mediated by socio-cultural context, generational knowledge systems, and livelihood structures.

Surprisingly, as indicated in Figure 4, although fishers demonstrated knowledge of seasonal changes in fishing seasons and catch, they have limited practical knowledge and perceptions associated with the reported changes to CC. Many older coastal people are unaware of climate change because they live in remote, rural areas with limited access to formal education, media, and government services. Their daily experiences of environmental change are often interpreted through traditional knowledge systems rather than scientific or global climate narratives. On the other hand, younger generations across case studies are engaging with climate change in very different ways compared to their elders, largely because they have more exposure to education, technology, and global networks. The generational divide affects how communities respond to rising seas, stronger storms, and shifting rainfall, implying that without shared understanding, adaptation strategies can stall, underscoring the need for combining traditional knowledge with scientific insights to build resilience. This observation was common among older fishers, fishers operating in secondary value chain activities, or those living in comparatively more urban settings. Taiwan's older and experienced fishers' knowledge was based on historical tales and fishing zones based on prevailing ocean currents and local wind patterns, including the South China Sea current and the Kuroshio branch current. Fishers, such as those in Yunlin, reported that seasonal ocean circulation patterns determined their fishing seasons, operations, and the type of harvested catch. For instance, it was reported that dominant species, such as mullets, were traditionally caught in autumn and winter, while *Cynoglossidae* are caught between February and March. In other seasons, such as spring, other species, such as *Otoliths ruber*, *Epinephelinae*, and *Sillaginidae*, are caught. In PNG, traditional local knowledge holders and elders, and small-scale fishers' ecological knowledge, especially traditional wisdom about fishing seasons, remain central to how communities adapt and sustain their practices, including fishing days, off-seasons, and special fishing zones, among others. Elderly fishers and women reported that traditionally, key migratory routes existed in the nearshore areas, and these were safely guarded using stick markings.

For generations, environmental changes, including seasonal fishing indicators, were based on local ecological knowledge (LEK), where fishers utilized moon phases, tides, and wind directions to determine optimal fishing times. In Kabakaul, fishers reported that weather patterns are often based on certain bird migrations and the flowering of coastal plants that local communities use to determine areas with abundant fish. In some cases, elderly and experienced fishers are sought to predict or share knowledge on fishing experiences and calendars about when or where specific species, such as tuna and reef fish, were observed or are most plentiful. Moreover, fishers acknowledged observed changes in nearshore and deep-sea fishing areas, including more unpredictable weather, unpredictable

fish migrations (some species appear earlier or later than expected), stronger winds, and rougher seas, making fishing trips riskier and less productive. The seasonal environmental changes have created acute livelihood concerns as unpredictable weather has reduced catches, affecting food security and income. Unfortunately, fishers' attribution of the changes demonstrated limited correlations between changing marine ocean environmental indicators and the fisheries value chain vulnerabilities. For instance, in Yunlin, fishers attributed dramatic changes to the establishment of wind and ocean energy projects and other coastal development projects, which constrain their ability to access fishing grounds. In PNG, dynamic changes were attributed to socio-cultural beliefs, unfortunate events, poor governance, and gender exclusion in value chains. The gradual knowledge erosion is worsening CC unpredictability as traditional ecological knowledge (TEK) relies on stable seasonal cycles, which CC heavily disrupts.

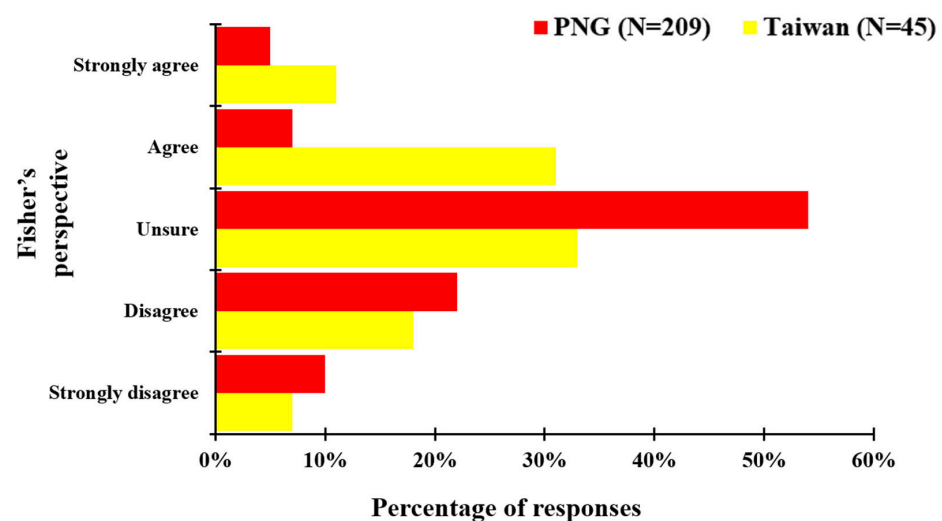


Figure 4. Fishers' perspectives and perceptions on the correlation between CC, environmental, and livelihood vulnerabilities (source: field data).

The limited ability to associate fishing and fisher livelihood vulnerabilities to CC is a concern, as remote sensing findings revealed worsening changes in marine environmental parameters, influencing fish abundance and migration across the Pacific region. First, since 2000, the mean SST in the Pacific Ocean region between Taiwan and PNG has been rising significantly, ranging between 27 and 30 °C. Moreover, in parts of the southwest Pacific, average SST is dotted with significant spikes of 1–4 °C, especially in the western part of PNG, with average temperatures of 30 °C. Moreover, devastating interdecadal indicators are observed, which could have affected the average SST across the Pacific (see Figures 5–7). Across the Pacific, it is observed that seasonal spring, summer, and autumn temperatures are increasing, including in sub-temperate and tropical regions of southern Taiwan, with dense small-scale fishing populations. These changes could account for the fishers' revelation that marine heatwaves, coral bleaching, declining culturally important species, and fish mortality, which directly threaten coastal livelihoods dependent on fisheries and reef ecosystems, have increased recently. For instance, in Kabakaul (PNG), fishers reported that seasonal winds, typhoons, and waves have increased, making it difficult to locate and fish, including in locally managed marine areas (LMMAs), and peak fishing seasons, which last one week per month. Moreover, elevated SST is associated with a reduction in oxygen levels (dissolved oxygen), altering fish migrations, and loss of fish, increasing worries of fisheries collapse, as reported among coastal fishers in Yunlin, that some indigenous species are no longer harvested (Figure 8). Along PNG's west coast, SST is correlated with heat stress, leading to coral bleaching and undermining reef-dependent

livelihoods. Moreover, Figure 8 demonstrates reduced chlorophyll abundance in the Pacific Ocean region, especially in northern PNG, implying that either fish stocks will decline or migrate. To survive, some fishers reportedly harvest in formerly conserved reef zones to obtain some fish for consumption, a trend that could worsen food security threats. As reported by coastal communities, the changing SST along the TS has gradually created warm water anomalies, reducing regional stocks in traditional fishing grounds as they shift eastward, impacting local economies.

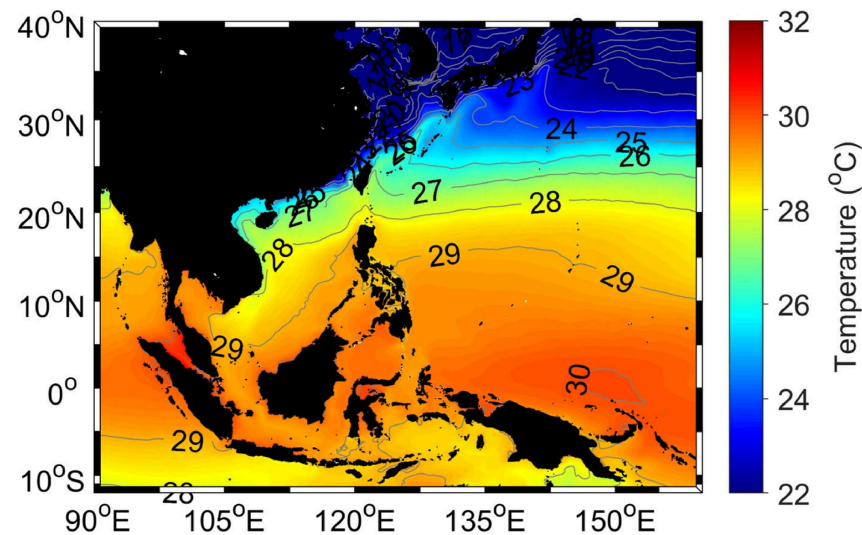


Figure 5. Mean sea surface temperature (SST) in the Asia-Pacific region from 2010 to 2025 (source: authors' analysis of remote sensing data on ocean environmental parameters in the Pacific region).

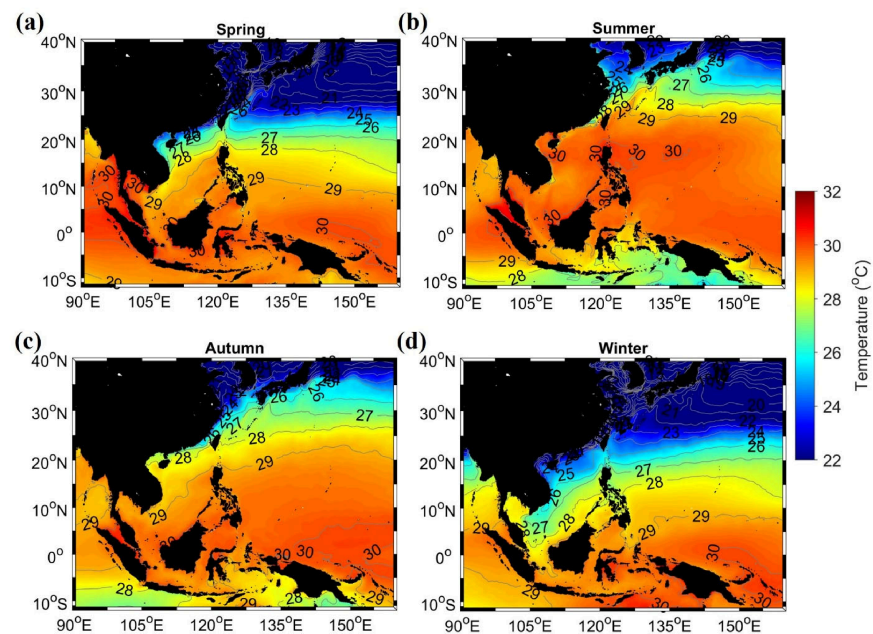


Figure 6. The mean seasonal SST in the Asia-Pacific region from 2010 to 2025: (a) spring (March, April, May), (b) summer (June, July, August), (c) autumn (September, October, November), and (d) winter (December, January, February) (source: authors' analysis of remote sensing data on ocean environmental parameters in the Pacific region).

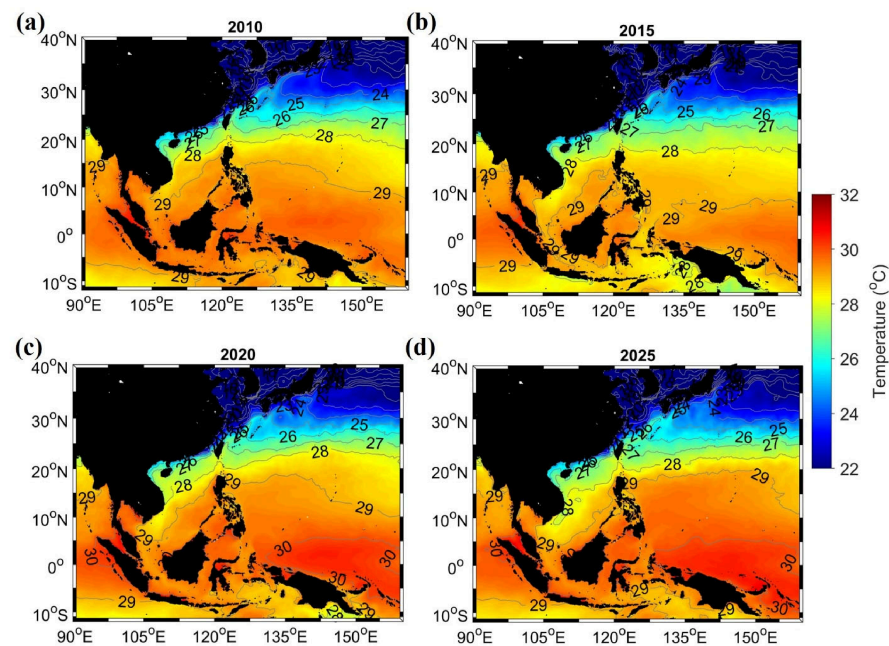


Figure 7. Interdecadal mean SST in the Asia-Pacific region from 2010 to 2025 (source: authors' analysis of remote sensing data on ocean environmental parameters in the Pacific region). (a) shows the mean SST in the APR in 2010, (b) shows the mean SST in the APR in 2015, (c) shows the mean SST in the APR in 2020, and (d) shows the mean SST in the APR in 2020.

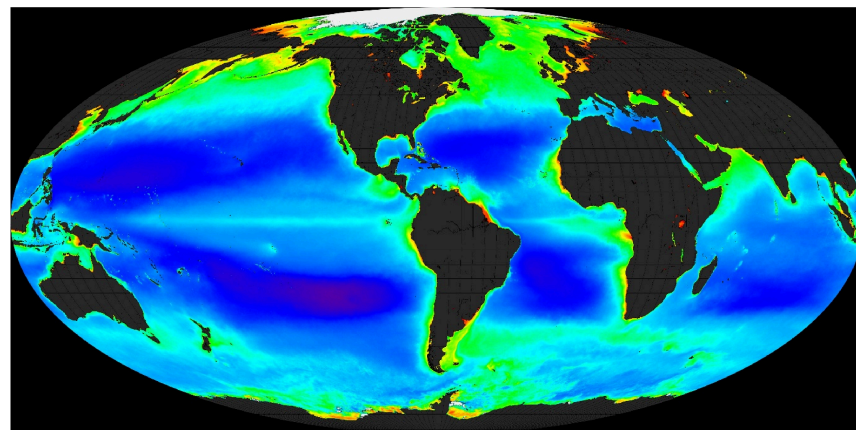


Figure 8. Global distribution of sea surface chlorophyll (source: OceanColor website: <https://oceancolor.gsfc.nasa.gov/>. Blue represents marine areas with declining chlorophyll, and green represents areas with higher chlorophyll concentrations).

Rising sea surface temperatures and fluctuating chlorophyll levels in the Asia-Pacific are already reshaping marine ecosystems, with direct consequences for coastal fishing communities in Taiwan and Papua New Guinea. These changes threaten food security, livelihoods, and cultural traditions tied to the ocean. Within the SES dimension, four observations from the RSD that are correlated with field findings in PNG and Taiwan are synthesized. First, as SST increases, climate feedback loops that balance ecological interactions and Pacific Ocean oscillations emerge, intensifying tropical cyclones and typhoons and compounding coastal fisher livelihood and infrastructure risks. In Taiwan, warmer ocean waters could heighten disease risks in aquaculture, a major sector in Taiwan's seafood supply. In PNG, with marine fish resources that are central to subsistence diets, SST-induced declines in nearshore fish availability directly threaten nutrition. Second, fishers reported ecosystem imbalances as alien species are being affected, reducing biodiversity

richness, changing trophic cycles, and affecting nearshore fish habitats. This dynamic could be attributed to seasonal SST and its ramifications on sea surface chlorophyll abundance, especially in western PNG. As fish abundance heavily relies on chlorophyll abundance, fish migration could heighten socioeconomic stress in coastal fishing villages as fishers migrate or fish offshore to look for declining coastal wild fish resources. Moreover, limited alternative income sources mean coastal communities are highly exposed to ecological shifts. Third, as reported in Yunlin, place-based vulnerabilities have magnified CC-induced threats, such as storm surges in open coastal zones, thus affecting oyster platforms and reducing natural coastal buffers and natural defenses. The association between coastal fisher infrastructure losses and sudden ocean changes and events, such as cyclones and saltwater intrusion, was similarly reported in ENB. Critically, CC-induced threats are increasing forced migrations and displacements, thus cultural disruption. In the Momase region, for instance, fisheries bemoaned the loss of the deep cultural ties to their indigenous and culturally important fishing zones as SST-driven ecological shifts eroded local wisdom and sacred spots for lucrative and culturally significant fish species.

3.3. Resilience Strategies and Their Effectiveness in SES Functioning and Sustainable Livelihood

Small-scale fishers reported that fishing is deeply tied to their coastal livelihoods, and although CC variability is dramatically compromising the socioecological and economic benefits from fishing engagement, they have initiated diverse adaptation and resilience strategies (Table 2). Generally, resilience strategies emphasized strengthening traditional fisheries livelihood empowerment and community-based resilience actions to enhance social cohesion and adaptive fishing practices. To fishers, the existing resilience mechanisms are driven by three practical realities across small-scale fisheries and key coastal fishing regions, including (i) knowledge erosion as younger generations prefer modern knowledge systems, (ii) policy gaps, as national fisheries management often undervalues local knowledge, limiting effective adaptation, and (iii) institutional capacity deficiencies in leveraging capital-intensive adaptation and resilience approaches, such as real-time CC modeling and tracking or integrated fisheries value chain operations. Taiwan's coastal fishers and fisheries strategies are mostly aquaculture-driven and focused on science and technological innovations, with over seventy aquatic species farmed to respond to CC and market pressures. These are further supplemented by tech-driven monitoring, government support, and cooperative models, including women-managed digitalized value-chain demand-supply monitoring systems.

Importantly, coastal fishing communities in both Papua New Guinea and Taiwan demonstrate unexpected resilience through community-driven adaptation and fisher-women's empowerment, showing that practical, fit-for-purpose, and inclusive resilience strategies suitable for specific contexts are essential for coastal survival in the face of climate change. The unexpected resilience strategies, such as micro-level joint funding groups, circular supply-demand systems, and cooperative associations, among others, creatively blend traditional practices with modern adaptation strategies. In PNG, the resilience strategies often emerge through community-based marine tenure systems, where local clans collectively manage fishing grounds. This not only sustains fish stocks but also reinforces cultural stewardship. Faced with protein shortages and climate-driven disruptions, many villages have diversified into small-scale poultry farming and handicrafts, reducing dependence on fragile marine ecosystems. Mangrove restoration and coral reef protection further illustrate how ecological knowledge is mobilized to buffer against rising seas and extreme weather.

Table 2. Comparative summary of coastal fishers’ resilience and adaptation strategies in Papua New Guinea and Taiwan (source: authors’ synthesis of the field data).

Papua New Guinea		Taiwan	
Traditional Ecological Knowledge strategies		Coastal fisheries innovation	
-	Reliance on indigenous ecological knowledge to predict weather and fish dynamics	-	Emphasis on CC-resilient species (e.g., tilapia and milkfish that tolerate temperature fluctuations).
-	Seasonal fishing adjustments based on observed CC patterns.	-	Integrated multi-trophic aquaculture (IMTA) systems that recycle nutrients and reduce waste.
-	Cultural respect and empowerment for key elders and knowledge holders.	-	Aquavoltaics trials to supplement fish catch with onsite solar energy generation and supply.
Community-based resource management		Technological monitoring	
-	Village-level governance system to regulate fishing activities, zones, and species.	-	Use of sensors and data analytics to track water quality, salinity, and SST.
-	Informal fishers’ agreements to avoid overfishing.	-	Early warning systems for disease outbreaks and harmful algal blooms.
-	Marking and voluntary co-governance of historical fish spawning zones.	-	Digitalized fish value chain systems.
Livelihood diversification		Sustainable practices	
-	Integrating fishing with gardening, small-scale farming, and trade to reduce marine fish dependence.	-	Transition to low-carbon coastal fisheries methods, e.g., using bamboo platforms for oysters.
-	Alternative income sources during low or closed fishing seasons, e.g., daily wage labor.	-	Reduced reliance on wild catch and promotion of farmed seafood.
-	Shift to small-scale aquaculture.	-	Women’s empowerment in fish production, harvesting, processing, and trade.
-	Supporting coastal women’s participation in fish trading and marketing to supplement household income.	-	Supporting eco-labels and certification for small-scale fishers and households.
Adaptive fishing techniques		Economic and socio-cultural resilience	
-	Shift to more resilient gear and methods (e.g., nets suited for variable currents and motorized canoes).	-	Holistic empowerment of local fisher associations and cooperatives, e.g., in resource and risk sharing.
-	Adjusting fishing times and locations to cope with unpredictable weather.	-	Connection to <i>Mazu</i> temples and local sustainable fisheries belief systems.
-	Group fishing activities to reduce deep-sea accidents.	-	Institutional subsidies to fisher groups.
-	Use of life jackets in deep-sea expeditions.	-	Disaster recovery and market stabilization initiatives.
-	Advocacy for new fisheries governance regulations.	-	Fisher exhibitions and trade shows.

In Taiwan, resilience takes a different form, rooted in cooperative networks and inclusive fisheries value chains. Fishing families, especially in Yunlin, have responded to saltwater intrusion events and aquaculture disruptions by diversifying production methods, experimenting with adaptive aquaculture, family-run fish value chain enterprises, and strengthening circular supply-demand systems. These innovations ensure that fishing remains both an economic lifeline and a cultural anchor. Across both regions, fisherwomen's empowerment has become a surprising driver of resilience. In PNG, women increasingly lead in alternative livelihoods, microfinance initiatives, and local resource management, while in Taiwan, fisherwomen play pivotal roles in processing, digitalized marketing, and cooperative leadership. Their participation not only diversifies household income but also ensures that adaptation strategies are inclusive and sustainable. Together, these communities show that resilience is not merely about survival; it is about reimagining livelihoods, reinforcing cultural identity, and empowering women to lead in shaping coastal futures.

4. Discussion

4.1. Summary of the Study Findings

This study leverages a TD approach to explore and document the practical realities of CC perceptions and adaptation options among coastal small-scale fishers situated in selected coastal areas of Taiwan and PNG. Overall, the findings highlight that small-scale fishers rely heavily on fisheries and natural ecosystems as their primary sources of livelihood and food security. While this dependence underscores the socio-economic importance of fisheries, it simultaneously exposes fishers to heightened vulnerability under the current CC trajectories across the Asia-Pacific region. The findings reveal that existing resilience and adaptation strategies are either fragmented, localized, or often misaligned with internationally recognized sustainability frameworks, such as the FAO Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries. As reported under the SES framework and theory by [16], when situated within the SES sustainability lens, the diverging CC-resilience strategies demonstrate two practical risks and trade-offs. In PNG, heavy reliance on traditional knowledge may be insufficient against accelerating climate change; infrastructure gaps limit the scaling of modern adaptation. In Taiwan, dependence on aquaculture technology could increase vulnerability to system failures and requires high investment, as small-scale fishers are being marginalized by industrial aquaculture or large-scale capture fisheries operations that predominate the richly endowed fishing zones of the APR [17,18].

4.2. Key Observations and Surprises

The study spotlighted valuable insights around small-scale fisheries, sustainable fisheries policy, governance, and futuristic blue transformation directions. First, findings demonstrate correlations with existing theoretical and conceptual perspectives on sustainability dimensions and requirements among small-scale fishers, especially in island regions. The findings about fishers' dependence on natural resources and their efforts to adapt to CC resonate with resilience theory, which emphasizes the importance of adaptive capacity, social capital, and institutional flexibility. However, the observed fragmentation suggests a deviation from the "transformative adaptation" pathways advocated in sustainability science. The reliance on nature without robust institutional support, as reported in PNG, reflects the "tragedy of vulnerability," where communities most dependent on ecosystems are least equipped to adapt. Within this perspective, two risk scenarios are observed. This observation supports previous studies that reported dramatic increases in complex environmental burdens, particularly in the Pacific Ocean region, disproportionately impacting

Pacific Island Countries and Territories (PICTs) through rising temperatures, sea-level rise, saltwater intrusion of freshwater resources, and coastal erosion, worsening livelihood pressures [18,19]. This implies that although small-scale fishing communities have renowned TEK and social bonds that have been a hallmark for strengthening community-led fisheries management [20], current human-environmental vulnerabilities reported in this study could compromise adaptation potential.

In PNG, for instance, according to [7], fishers face immediate risks, including CC-induced fish kills, coral bleaching, and reduced catch volumes, necessitating urgent adaptation needs, such as strengthened community-based fisheries management, expanded marine protected areas to safeguard biodiversity, investment in early-warning systems for CC-induced threat management, and support for livelihood diversification beyond fisheries. In Taiwan, although institutional safeguards, such as food security, have been established, long-term risks could recur, including cultural erosion and the collapse of fisheries due to intensive aquaculture, thus requiring balanced aquaculture-capture fisheries systems to ensure healthy seafood security and provisioning.

When viewed further from the vulnerability, sustainable food systems, and blue justice lens, unsurprisingly, as all coastal fishers expressed livelihood survival fears due to changing environmental indicators and human-induced drivers and threats, it is plausible to argue that in the future, foundation pillars for coastal livelihood security (i.e., availability, access, and appropriate use of nutritious food) in the Pacific Island states could be compromised [18]. This notable finding is worsened by unsustainable governance mechanisms, including top-down fisheries governance approaches, which often neglect local knowledge and participatory approaches [21,22]. The lack of integration with the FAO small-scale fisheries guidelines and holistic blue transformation roadmap targets further illustrates a disconnect between global sustainability frameworks and local realities in tropical island contexts, as reported by [11]. Thus, as [23,24] observed, despite evidence of adaptive practices across Pacific Island States, such as seasonal diversification, informal community support networks, and emphasis on traditional ecological knowledge, these measures remain insufficient in addressing systemic and dramatically complex CC-induced risks. Thus, guided by the 2021 Declaration for Sustainable Fisheries and Aquaculture and FAO's Strategic Framework 2022–2031, it could be argued that adaptation strategies require expanded focus from siloed strategies to maximizing coastal small-scale fisheries and fishers' contribution to aquatic food systems, through coordinated livelihood empowerment strategies, strategic economic growth, socio-cultural development, and adaptive recovery [8].

Moreover, concurring with [25,26], who argued that as the APR is a diverse geographical arena where existential gaps, such as institutional policy failure to integrate fisheries management with broader CC-adaptation agendas, limited incorporation of blue equity, participatory governance or ecosystem-based precautionary principles, and coastal fishers' resource constraints, such as in financial, technological and institutional support for enhanced adaptive capacity, adaptive strategies require strategic adaptation pathways. This perspective underscores the need for a shift from fragmented, reactive strategies toward integrated, forward-looking adaptation pathways. Embedding resilience within sustainability frameworks, notably in the APR can help coastal small-scale fisheries transition from vulnerability to long-term viability [27,28]. Thus, as concerted efforts towards blue transformations are gaining traction, tropical fisheries and island coastal regions leverage this by balancing ecological stewardship, socio-economic equity, and institutional innovation [25].

4.3. Policy and Research Implications

Drawing on current practical research and policy directions in the context of global and regional sustainability and blue transformation targets across vulnerable fishing regions, the study findings highlight valuable takeaways. It is evident that, irrespective of geospatial location and development levels, coastal fishers and small-scale fisheries are braced for tougher times. Without proactive and sustainable actions, innovations alone, as reported in Yunlin in Taiwan, might not be enough to save coastal fishers and coastal livelihoods from devastating CC impacts that cut across the regions. To enhance coastal fishers' resilience to CC and livelihood empowerment, the following significant implications for policy and practice are emphasized.

- (a) Mainstreaming CC adaptation into fisheries governance: Policies must move beyond fragmented approaches and embed climate resilience within fisheries management plans. In PNG, for instance, government mechanisms can legitimize and recognize customary and traditional communal marine tenure systems as foundational pillars for community-led CC adaptation and resilience practices. In Taiwan, adaptation can be strengthened through buy-back programs for older fishers to sustain their incomes and increase their voluntary participation in CC adaptation and advocacy in fisher groups.
- (b) Blended knowledge spaces on CC adaptation and livelihood empowerment lend traditional seasonal wisdom with modern awareness of climate variability to sustain their livelihoods. Strengthening this integration—through community-led monitoring, education, and policy recognition—can offer the best path to resilience in the face of climate change. For instance, youths in Yunlin and Taiwan can utilize their digital knowledge to design digital platforms for early warning and alert systems for the elderly or fisher households and nearshore fishing sites in CC-prone zones.
- (c) Strengthening participatory governance. Key policymakers and actors should incorporate fishers' voices and traditional ecological knowledge (TEK) into decision-making to enhance legitimacy and effectiveness. TEK can be strengthened by creating biodiversity registers, vulnerability maps, resource maps (based on community and geographic information systems (GIS) mapping), and community seasonal fishing calendars.
- (d) Regional cooperation. Island nations and coastal regions, especially in the APR, should collaborate on shared adaptation strategies, recognizing transboundary CC impacts. This can be through site visits and technology support, e.g., from Taiwan to PNG.
- (e) Capacity building and resource access. Strategic investment in infrastructure, financial mechanisms, and training is critical to empower fishers to adopt sustainable practices.
- (f) Alignment with global sustainability frameworks. National and local policies should explicitly integrate the FAO small-scale fisheries guidelines, ensuring coherence with international sustainability goals. For instance, Article 6.4 calls for participatory decision-making, yet in PNG and Taiwan, national fisheries plans rarely include traditional elders' views. This can be done by embedding culturally rooted and community-based management practices and ecosystem-based approaches, all aligned with FAO's Small-Scale Fisheries Guidelines. Elders' knowledge can be leveraged in understanding seasonal closures and taboos, based on their knowledge of spawning cycles and adaptive fishing bans. This can be vital in local ecological monitoring, where fishers' observations of stock changes complement scientific surveys and inform community-led zoning and voluntary enforcement.

4.4. Study Contributions

This study makes several important contributions to the understanding of climate change perceptions and adaptation among coastal small-scale fishers, especially in the Asia-Pacific region. First, it advances knowledge on climate change perception analysis by documenting how fishers in Taiwan and Papua New Guinea interpret environmental changes and articulate their vulnerabilities. The comparative perspective highlights both shared concerns and culturally specific interpretations, underscoring the importance of perception studies in shaping adaptive responses. Second, the study contributes to the field of adaptation research by identifying locally grounded strategies employed by fishers to cope with climate stressors. For instance, in Papua New Guinea, possibilities for integrating traditional ecological knowledge in understanding environmental shocks to fish species are observed. By linking such community-level survey data with remote sensing indicators, the research demonstrates how diverse adaptation pathways can emerge from the intersection of subjective experiences and objective environmental conditions [22,29]. Third, the study offers insights relevant to governance, showing how hybrid knowledge systems (i.e., combining scientific data with fisher perspectives) can inform policy frameworks that are more responsive to local realities. The transdisciplinary approach employed here illustrates the value of integrating social and ecological data to generate actionable knowledge for resilience-building in coastal communities. Collectively, these contributions enrich the discourse on climate change adaptation in small-scale fisheries and provide a foundation for more inclusive and context-sensitive governance in the Asia-Pacific region.

5. Conclusions

This study examined CC perceptions and adaptation options among coastal small-scale fishers from selected coastal areas of Taiwan and PNG, revealing both the depth of dependence on fisheries and the growing vulnerability to climate impacts. Findings revealed that while long-established local and new adaptive practices exist or are emerging, they remain fragmented and insufficiently aligned with context-specific needs and realities to build sustainable coastal fisher livelihoods and adaptive potential to CC. Comparative multidimensional vulnerability fears and worries underscore the urgency of forward-looking adaptation strategies that bridge local realities with regional and global sustainability frameworks and principles, particularly the FAO Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries. For Taiwan, PNG, and the APR, policy coherence, institutional support, and regional collaboration are critical to strengthening resilience. Moreover, embedding climate adaptation into fisheries governance, enhancing resource access, and recognizing the value of TEK can help transform vulnerability into sustainable pathways. Ultimately, sustainable adaptation in small-scale fisheries requires balancing ecological stewardship, socio-economic equity, and institutional innovation. By aligning local practices with global sustainability frameworks, coastal communities in the Asia-Pacific can move toward resilient futures that safeguard both livelihoods and marine ecosystems.

Study Limitations and Recommendations for Future Research

Although this study provides valuable insights into CC perceptions and adaptation options among coastal small-scale fishers in Taiwan and Papua New Guinea, five practical limitations are acknowledged. First, the geographic scope was restricted to two countries, which, while offering contrasting socio-cultural and ecological contexts, may not fully capture the diversity of experiences across the wider Asia-Pacific region. Second, the uneven sample sizes between Taiwan and Papua New Guinea may have introduced comparative bias, potentially affecting the balance of perspectives, especially on CC vulnerability and resilience actions. Third, the reliance on self-reported perceptions introduces subjectiv-

ity and possible recall bias, as responses may be influenced by recent events or cultural framing. Fourth, while remote sensing data provides valuable regional-scale indicators, it may not adequately reflect fine-scale, localized environmental changes that fishers directly experience. Finally, the integration of transdisciplinary methods, though innovative, posed challenges in reconciling differences in scale and scope between social survey data and oceanographic parameters.

Future research should expand the regional coverage to include additional Asia-Pacific countries, thereby enabling broader comparative analyses of adaptation strategies. Longitudinal studies are recommended to track how perceptions and adaptive responses evolve, particularly in relation to climate shocks such as typhoons, coral bleaching, or El Niño events. Methodologically, combining quantitative surveys with ethnographic approaches and participatory mapping could deepen understanding of cultural and social dimensions of adaptation. Further investigation into the role of governance structures, policy frameworks, and indigenous knowledge systems would enhance insights into resilience-building. Additionally, examining the intersection of climate vulnerability with economic and market factors, such as global seafood trade and livelihood diversification, could provide a more holistic view of adaptation capacity. Finally, future studies should explore the potential of technological innovations, including mobile applications and community-based monitoring tools, to strengthen adaptive capacity among coastal small-scale fishers.

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