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Interplay of traditional knowledge and adaptive capacity in climate change adaptation of small-scale fishers in central Terengganu, Malaysia

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Introduction: Climate change is a major threat to small-scale fishers and coastal population of Malaysia, especially a significant population relies on the industry. However, records on adaptation capacity of these communities remains limited.

Method: This study investigated the perceived risks of climate change among 136 small-scale fishers in Terengganu, Malaysia and the influence of traditional knowledge on adaptive capacity to climate change. Data were collected from five villages in the coastal area of central Terengganu, Malaysia, using a snowball sampling method.

Results: The respondents identified three primary climate hazards: stronger monsoonal winds and larger waves (noted by 95% of the respondents), more intense weather (91%), and erratic rainfall patterns (91%). The majority of fishers attributed climate change to natural variability (90%) and the anger of God (85%). Of the five dimensions of adaptive capacity, flexibility was identified as the weakest. A structural equation model was employed to analyze the relationship between traditional knowledge and adaptive capacity. The results revealed that spiritual practice was the most significant component of traditional knowledge and subsequently, in general, had a significant impact on the adaptive capacity of fishers.

Discussion: The study highlighted the negative perception by fishers due to the neglect of their concerns by government. To enhance the adaptive capacity of small-scale fishers, national agencies and local fishing associations must actively engage with these effective adaptation strategies.

KEYWORDS

climate change, adaptation, traditional knowledge, small-scale fishers, adaptive capacity, Southeast Asia, perception of climate risk, spiritual practices

Introduction

Climate change is expected to have a significant impact on fisheries worldwide, particularly in developing countries. As highlighted by the Intergovernmental Panel on Climate Change (IPCC, 2019), climate change poses a direct threat to the food security, livelihood, and national development of coastal communities. The anticipated consequences of climate change include more frequent and intense extreme events, reduced fishery yields, and flood- and storm-induced damage to coastal areas (IPCC WGII, 2022). Specifically, coastal communities may experience unusual flooding (Obia et al., 2015; Tuihedur Rahman et al., 2018), declining fisheries catch rates (Macusi et al., 2020), increased social vulnerabilities (Ezcurra and Rivera-Collazo, 2018), warmer days with a more severe monsoon season (Unnikrishnan and Shankar 2007, Southeast Asia Start Regional Centre (START), 2010 in Bennett et al., 2014), and an accelerating sea-level rise (Bagheri et al., 2019).

Furthermore, perceived risks of climate change are subjective judgments made by individuals or communities regarding the potential adverse effects of climate change on their environment, livelihood, health, and overall well-being (Slovic, 1987). These perceptions are shaped by personal experiences, cultural beliefs, social context, and access to information (Weber, 2010). Exposure to direct climate change hazards can heightened risk perceptions. For example, farmers in the Mekong Delta who have observed the impacts of climate change on their livelihood tend to perceive higher climate risks (Le Dang et al., 2014). The strategies people and communities employ to respond to the effects of climate change, including their willingness to adopt adaptation measures and support mitigation strategies, are strongly influenced by their perception of the associated dangers associated with climate change. To effectively address climate change, understanding these perceived risks is essential. By developing more effective communication techniques and policies that align with public perceptions, policymakers can foster greater public engagement and support for climate action.

Similarly, Small-Scale Fisheries (SSFs), also known as artisanal fisheries, are particularly vulnerable to climate change due to their dependence on fishery resources and the coastal environment. Climate change can affect fish abundance, alter fish distribution and migration patterns, (Cisneros-Mata et al., 2019) and damage critical habitats such as coral reefs and mangroves (Kh'ng et al., 2021). Additionally, the rising frequency of extreme weather events poses significant challenges to the infrastructure and operations of small-scale fisheries. As highlighted in the 5th IPCC Assessment Report, SSFs are particularly susceptible to climate change impacts, low adaptive capacity, limited access to data for monitoring catches and climate information, inadequate governance, and limited access to adaptation options and support (financially) (Food and Agriculture Organization, 2016) and due to the shift in marine biodiversity distribution (Brito-Morales et al., 2018). To mitigate these vulnerabilities, strengthening the adaptive capacity of fishers is crucial (Shaffril et al., 2019). Satumanatpan and Pollnac (2020) suggest that increasing resilience involves enhancing adaptive capacity and reducing sensitivity to climate stressors.

Traditional knowledge (TK) is defined as the accumulated knowledge passed down through generations and shaped by adaptive processes (Berkes, 2017). It plays a vital role in effective climate change adaptation in SSF communities and can enhance climate resilience. TK can be categorized into four levels: empirical knowledge, resource management knowledge, institutional of knowledge, and overarching cosmologies (Fikret Berkes 2012 as cited in Savaresi, 2018). Empirical knowledge pertains to the understanding of animals, plants, or landscapes. Resource management knowledge encompasses technical knowledge and practices related to resource utilization. Institutional knowledge refers to the processes of memory, creativity, and learning. Overarching cosmologies represent the perception of the environment based on existing knowledge (Savaresi, 2018). In the context of climate change, as TK can provide real time understanding of change of season and landscape, where fish might migrate and their behavior, it can complement scientific data on how to respond to climate change (Riedlinger and Berkes, 2001; Leon et al., 2015). With empirical data of climate change, it can support fishers' climate resilience and enhance their adaptive capacity (Nakashima et al., 2012).

Adaptive capacity, as defined by the IPCC (2001), refers to the conditions that enable individuals and communities to anticipate, respond to, and recover from climate change as well as seize new opportunities. This concept is relevant to small-scale fishers as they are vulnerable to climate change and relies heavily on fisheries resources. Measuring adaptive capacity involves assessing assets, flexibility, social organization, learning, and agency (Cinner et al., 2018). For fishers, assets holds the technological, financial, and service resources necessary for adaptation, such as investing in larger boats and advanced technologies to extend fishing journeys (Cinner et al., 2018). In the face of environmental shifts, flexibility captures to the ability of fishers to explore diversification of livelihood, explore new fishing grounds, and adopt innovative strategies (Cinner et al., 2018). Social organization reflects the fishers collective efforts to manage climate risks through knowledge exchange and social support (Adger, 2003) while learning pertains to the capacity to acquire and apply new knowledge, such as understanding weather patterns and adopting new fishing gear or alternative livelihoods (Cinner et al., 2018). Finally, agency reflects the belief in fishers having the freedom to make adaptive choices, integrating local knowledge with scientific approaches, and empowering others to undertake change. Understanding an individual's level of assets, flexibility, social organization, learning capacity, and agency can help assess their likelihood of successfully adapting to the climate crisis. Furthermore, identifying the areas in which a community is lacking can inform appropriate policymaking and resource allocation to mitigate climate impacts.

TK may play a major role in shaping fishers' adaptive capacity and choices of adaptation strategies. For example, a case study of the Miriwoong people underscores the importance of understanding overarching cosmologies in shaping a community's perceptions of climate change and, consequently, the flexibility of its adaptation strategies (Leonard et al., 2013). In the Vanuatu community, they highlighted TK as one of the component to respond to climate change (Walshe et al., 2018). The integration of empirical TK with Western scientific knowledge has also been shown to facilitate labor diversification (flexibility in adaptation; Mardero et al., 2023).

Indigenous Australian people have demonstrated a remarkable ability to respond to environmental changes with their cosmological wisdom, which guides their social organization and land resource management to reinforce social cohesion (Rose, 1996). Not all types of TK affect all types of adaptation; these relationships can vary contextually and locally. Empirical knowledge, as suggested by Kolb (1984), can accelerate learning skills. Institutional of knowledge is a key determinant of adaptive capacity and is essential for social organization (Adger, 2003). Shared spiritual practices can foster collective responsibility, shared values, and stronger social bonds, enhancing adaptive capacity (Christian, 2003).

Malaysian SSF makes up to 75.8% of Malaysian registered fishers and are vulnerable to challenges due to climate change impacts (Mohamed Shaffril et al., 2017). Climate change affects fisheries in Malaysia through sea-level rise, extreme wind and waves, rising temperature, unstable rainfall patterns, and change the biology and environmental tolerance of fish, which subsequently change the distribution of the fisheries (Boyborwin and Tuan Soh, 2020; Brito-Morales et al., 2020). The SSF contributes up to 33.7% of the capture fisheries in Malaysia by the gross domestic product (GDP) (Department of Fisheries Malaysia, 2023). SSF in Malaysia are limited to the 0–5 nautical mile zone with traditional vessels below 40 gross register tonnage (GRT) with fishing gears and employ basic communication tools (Lee et al., 2020). SSFs play a vital role in Malaysia's socioeconomic structure, contributing considerably to food security, coastal livelihoods, and the preservation of TK. Given their importance in the context of the economy, society, culture, and environment, the SSF sector requires greater focus. In Sabah, SSFs are undervalued, despite contributing up to 3.5% of its population (Teh et al., 2011). Prior to 2000, SSFs contributed more to food security for human consumption than did industrial fisheries (Teh and Pauly, 2018). In Peninsular Malaysia, SSFs are the primary source of income for many, emphasizing their importance for livelihoods (Raduan et al., 2007). The importance of SSFs in Malaysia underscores the need for their inclusion in fisheries management (Omar et al., 1992).

This study focused on SSF communities in Kuala Nerus and Kuala Terengganu, Terengganu, Malaysia. Terengganu coastal communities, primarily composed of small-scale fishers, are highly susceptible to climate change. Terengganu is one of the five most vulnerable states in Malaysia because it is exposed to various climate change hazards (Yusuf and Francisco, 2010), including sea-level rise. The maximum monthly precipitation is projected to increase by 51%, leading to a 10% increase in annual rainfall because greenhouse gas emissions are high (Alam et al., 2012). During a flooding event in 2021, the Department of Statistics Malaysia (2022) reported substantial losses in residential areas, vehicles, and business premises in Terengganu. Fish are essential to the communities in Terengganu, serving as both a source of food security and an integral part of their intangible cultural heritage. According to the chief of the local fishing association of Northern Terengganu, an estimated 800 fishers (including registered and unregistered fishers) operate in the area. Registered fishers are registered with local fishing agencies (*Persatuan Nelayan Kawasan*, PNK), possess plate numbers attached to their boats, and may receive other benefits and assistance from the fisheries agencies, such as

subsidized petrol. Although marine fish landings in Terengganu account for a relatively small percentage of the total of Malaysia, approximately 2.58% in value (Department of Fisheries, 2022), there were more than 5,023 registered SSF fishers operate within five nautical miles in Terengganu (Department of Fisheries Malaysia, 2019). Various types of fishing gear are used to target different species. For example, line fishing is a low-cost method suitable for catching demersal and pelagic fishes. *Bubu* (fish trap) fishing is used to capture high-value species such as Spanish mackerel. *Pukat kaya* (rich net), a type of gillnet, is considered more expensive, dangerous, and physically demanding but can capture fish further out at sea (Mohd, 2014). Given the diversity of fishing interests, many fishers possess multiple types of gear to diversify their catch and adapt to changing conditions. As Malaysia continues to experience unstable climate conditions, fishers must adopt effective adaptation strategies. Although mitigation efforts have been initiated, research on climate change resilience and adaptation, particularly for SSF communities, remains limited (Shaffril et al., 2022). Despite their contributions, SSFs face obstacles such as undervaluation, climate hazards, and marginalization. Fisher communities' understanding of marine ecosystems and resilience can be enhanced through marine and coastal environmental education which has been increasingly promoted worldwide through the ocean literacy campaign (Mallick et al., 2023; Tsai and Chang, 2024). To ensure the long-term viability and resilience of this sector, greater attention and support are essential.

This study aimed to (1) identify perceived climate threats, traditional knowledge dependency and climate adaptive capacity; and (2) understand how TK may influence fishers' adaptation capacity to climate change in the SSFs of Terengganu, Malaysia. The present study is expected to contribute to a better understanding of the vital role of fisheries in Terengganu, a biodiverse region, and the detrimental effects of climate change on these communities.

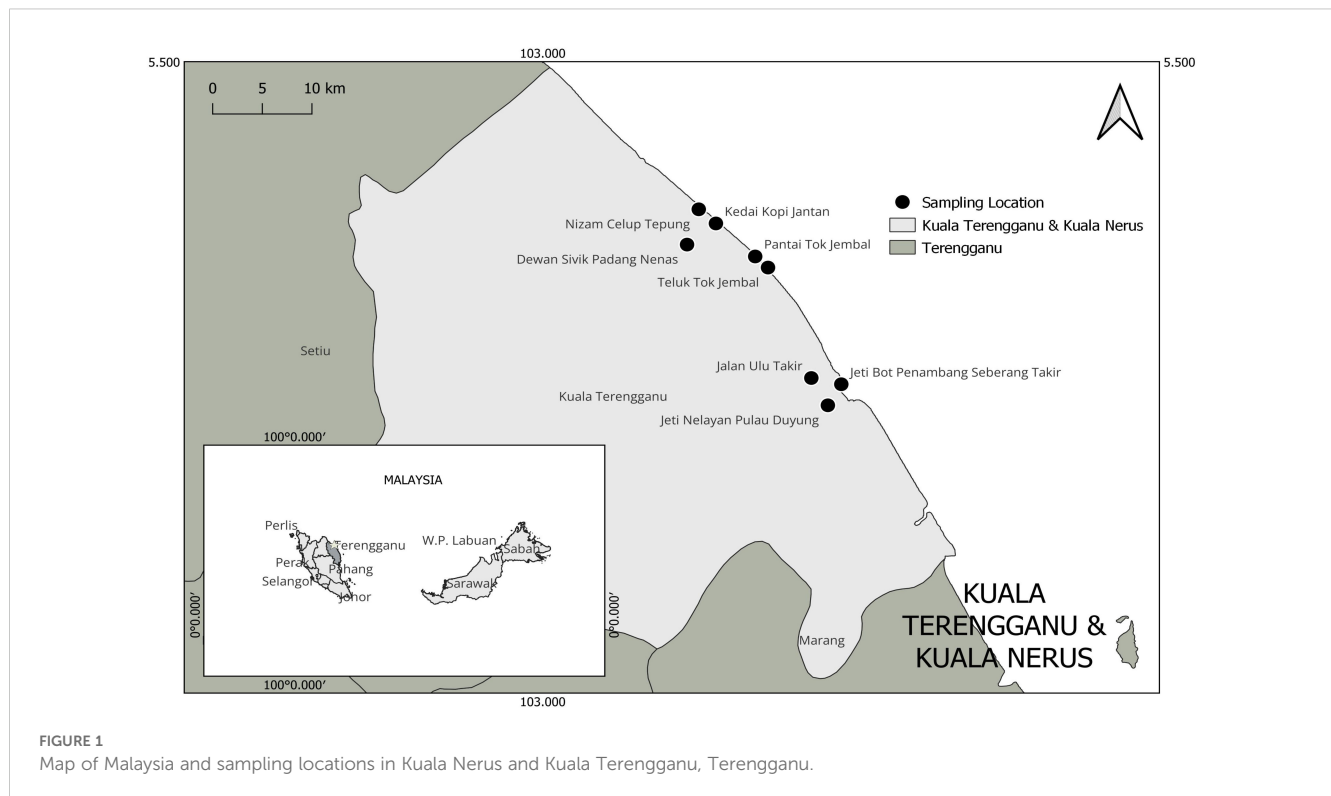
Methodology

Study area

The study areas Kuala Nerus and Kuala Terengganu, Terengganu, Malaysia (Figure 1), are coastal districts vulnerable to erosion and various climate change impacts. Questionnaires were distributed in eight locations in the following five traditional fishing villages (*kampung*): Tok Jembal, Batu Rakit, Mengabang Telipot, Seberang Takir, and Pulau Duyong.

Sampling and questionnaire design

This study was conducted in the Malay Terengganu dialect from February to May 2023 in Kuala Nerus and Kuala Terengganu, Terengganu, Malaysia. Questionnaire copies were administered by six enumerators to 136 respondents among fishers. The structure of questionnaire had a reliable score of Cronbach's $\alpha = 0.914$ as the predefined score is 0.7, hence it was suitable to proceed with the survey (Mallick et al., 2023, 2025). The survey aimed to (1) identify perceived



climate threats, traditional knowledge dependency and climate adaptive capacity; and (2) understand how TK may influence fishers' adaptation capacity to climate change in the SSFs of Terengganu, Malaysia. In addition to the questionnaire survey, a follow-up semi-structured interview were done to clarify emergent themes and provide additional insights that supplemented the questionnaire results (Bryman, 2016). These fishers were selected on the basis of their availability to spend extra time discussing sections C (TK) and D (adaptive capacity) of the questionnaire. This study was conducted in accordance with the National Taiwan University Research Ethics Council (File Number: 202212ES028). Translation of the questionnaire were conducted with our collaborator in Universiti Malaysia Terengganu and accurately represented. All participants provided informed consent prior to participating in the study.

The questionnaire survey was conducted to gather information on the perceptions of risks, perceptions of climate change, TK, and adaptive capacity characteristics of SSF fishers. A total of 136 questionnaires were collected from five villages, representing approximately 17% of the total number of fishers in the region [~800 fishers, including registered (legal) and nonregistered; Yamin pers. comm.]. A snowballing method was employed to recruit

participants. Table 1 presents the number of registered ($n = 95$), and nonregistered ($n = 41$) fishers surveyed. The registered and nonregistered fishers were differentiated by their boats; registered fishers had plate numbers on their fishing vessel, whereas nonregistered fishers lacked such identification. The sample size here may seem relatively small but as noted by Lakens (2022), resource constraints are a valid justification when researchers transparently acknowledge trade-offs between precision and practical limitations. Lakens (2022) emphasized that nonprobability samples of 50–200 participants are common in exploratory social science, provided researchers transparently address resource constraints. In addition, (Zack et al., 2019) validated nonprobability samples in social science, showing that even biased samples yield reliable patterns when stratified.

The measurement items used in this study were adapted from research by Leonard et al. (2013); Le Dang et al. (2014); Mapfumo et al. (2016), and Hasan and Nursey-Bray (2018) and modified to align with the specific objectives of this study. The structured questionnaire comprised four main sections: background information, perceptions of climate change, TK, coping mechanisms, and adaptive capacity (Supplementary Material 1). The background information section

TABLE 1 Number of registered and nonregistered fishers surveyed in each village.

Fisher status	Tok Jembal	Batu Rakit	Mengabang Telipot	Seberang Takir	Pulau Duyong
Registered	17	24	5	34	15
Nonregistered	6	11	2	14	8
Total	23	35	7	48	23

(Section A) addressed demographic details such as age, sex, marital status, education level, household size, monthly income, and religion. It also collected data on fishers' involvement in their local fishing association, fishing income, target species, fishing trip duration and distance, fishing gear, and vessel type. The second section (Section B) included questions about perceptions of climate change and understanding of the consequences. The third section (Section C) explored TK, inquiring about the respondents' reliance on empirical knowledge, resource management knowledge, institutional of knowledge, and overarching cosmologies for their fishing activities. The final section of the questionnaire (Section D) examined coping mechanisms and the five domains of adaptive capacity for climate change: assets, flexibility, social organization, learning, and agency.

Data analysis

Data analysis was conducted in four parts to address the research questions. The first part examined fisheries information and perceptions of risks and climate change. Descriptive statistics for responses to each question in Sections A, B, and C were analyzed using SPSS (version 26) to determine the general patterns in the basic information, observed climate hazards, perceived causes of climate change, consequences of climate change, and types of TK that the fishers relied on for fishing. In the second part, adaptive capacity scores were calculated using mean scores for each of the Subsections D1–D5 (assets, flexibility, social organization, learning, and agency). Each question was rated on a Likert scale from 1 (*strongly agree*) to 5 (*strongly disagree*). An average for each subsection was then used to create a radar plot visualizing the strengths and weaknesses of the fishers and their different adaptive capacities. Structural equation modelling (SEM) (Moreno et al., 2014) was conducted to examine the correlation between the measured TK variables (empirical knowledge, resource management knowledge, institutional of knowledge, and spiritual practices) and the adaptation variables (agency, flexibility, social organization, learning and agency) as the third part of the analysis. SEM is a multivariate statistical technique that allows researchers to assess complex relationships between observed and latent variables. In our study, SEM was used to first explore the correlation structures among observed indicators, and then to test regression paths that represent hypothesized causal relationships between latent constructs, as specified in our conceptual model. As applying the model, we assumed the relationship between variables are linear and no high multicollinearity involved between the variables. TK scores were calculated by determining the mean score for questions C.1 (empirical knowledge), C.2 (resource management knowledge), 8–12 in C.3 (institutional of knowledge), and 2 in C.4 (spiritual practices). All questions in Section D were considered in calculating scores for each adaptation aspect. The analysis was performed using the “lavaan” package in R language (version 4.3.0) (Rosseel, 2012). This study hypothesized that the measured TK variables and adaptation variables can construct the latent variables “traditional knowledge” and “adaptive capacity,” respectively. In the fourth part of the analysis, the relationship between specific TK and adaptive capacity was investigated by testing the following hypotheses: (i) empirical knowledge is correlated with learning skills; (ii) institutional of knowledge is correlated with social

organization; and (iii) individuals with stronger spiritual practices have stronger social organization. The correlation were examined using Kendall's Tau test (Hinkle et al., 2003).

Results

Characteristics of small-scale fisher participants in Terengganu, Malaysia

A total of 136 fishers participated, all of whom were men, reflecting the male-dominated nature of SSFs in the region. All respondents were Muslim (Table 2). The fishers believed that risks are an inherent part of being in the fishing community. The majority of fishers went to sea three to six times a week unless the weather was bad ($n = 80$), and a fishing trip lasted approximately 1 day ($n = 82$). Approximately 52.9% of fishers reported requiring two to six crew members for their fishing operations, whereas 40.4% fished alone. For 67.6% of fishers, fishing was the sole source of household income. The most caught fish species were the skipjack tuna (*ikan Tongkol*; $n = 77$), Indian mackerel (*ikan Kembung*; $n = 69$), squid ($n = 64$), yellowtail scad (*ikan Selar*; $n = 62$), threadfin bream (*ikan Kerisi*; $n = 52$), and narrow-barred Spanish mackerel (*ikan Tenggiri*; $n = 41$). The most used fishing gear was the hook and line (*Pancing*; $n = 113$), followed by the gillnet ($n = 30$), portable trap (*bubu*; $n = 24$), and purse seine net ($n = 23$). The peak fishing season is typically from March to October (after the northeast monsoon season), with July to September being particularly productive months (July: 51.5%; August: 50%; September: 44.1%).

Fishers' perceptions of climate change

The respondents were aware of recent climate change, with 61.7% reporting hearing about climate change more than three times (question B.1). Based on Figure 2, most of the fishers agreed or strongly agreed that the most observed climate hazards were stronger monsoonal wind and larger waves (95%), increased intensity of weather (91%), and erratic rainfall (91%). However, the fishers disagreed that the area was facing more flooding (64.7%) and droughts (31.62%). One fisher noted that the 2022 floods were more severe than those in 2014 but emphasized that flooding may not be a frequent occurrence in this area. The neutral part of graphs made in this paper were removed to streamline the data and better distinct the agreeable/disagreeable perception.

Fishers agreed or strongly agreed that the primary causes of climate change were natural variability in climate (90.4%), the anger of God (85.29%), and industrialization (78.68%) (Figure 3). Conversely, they disagreed and strongly disagreed that population growth, uncontrolled harvest of marine resources, and poor fishing practices were major contributors to climate change (33.09%, 29.41%, and 33.82% respectively).

Climate change has a substantial impact on various aspects of fishers' livelihoods. A large majority of the respondents reported a decline in their fish catch (90.5%), reduced quantity of landed fish

TABLE 2 Demographics of fishers participating in this study.

No	Categories	Frequency	Percentage (%)
1	Location		
	• Tok Jembal	23	16.9
	• Batu Rakit	35	25.7
	• Mengabang Telipot	7	5.1
	• Seberang Takir	48	35.3
	• Pulau Duyong	23	16.9
2	Age		
	• 15-30	8	5.9
	• 31-35	23	16.9
	• 46-60	61	44.9
	• 61 and above	44	32.4
3	Gender		
	• Male	136	100
4	Marriage status		
	• Single	20	14.7
	• Married	107	78.7
	• Divorced/widowed	9	6.6
5	Education level		
	• Never been to school	4	2.9
	• Primary school	39	28.7
	• Secondary school (SRP/PMR/PT3)	38	27.9
	• Secondary school (SPM)	47	34.6
	• Tertiary level	8	5.9
6	Number of households		
	• 1-3	33	24.3
	• 4-5	58	42.6
	• 6 or more	45	33.1
7	Monthly income profile (MYR)		
	• 500 or less	7	5.1
	• 501-750	15	11
	• 751-1000	48	35.3
	• 1000 or more	66	48.5
7	Religion		
	• Islam	136	100

(87.5%), loss and degradation of breeding grounds (86.1%), disappearance of species (84.6%), and decreased fish size (75%) (Figure 4). Although there were strong disagreements regarding the destruction of houses (43.38%) and loss of lives (37.5%) were noted, these impacts highlight the vulnerability of fishing communities to climate change.

Dependency of fishing on traditional knowledge

The findings revealed that the respondents relied on a combination of observation and additional sources to learn about

the weather. Many fishers used mobile apps such as Windy and Windfinder for weather forecasting and shared information with others. Despite this, approximately 60.3% of the fishers continued to observe weather using traditional methods such as checking wave strength and the location of clouds and wind (Figure 5). Although the respondents were concerned about unpredictable weather, increased heat was not a major concern because they were familiar with it (“*biasa doh*”). To mitigate the effects of heat while fishing at sea, some fishers used black canvas covers on their boats to reduce the temperature.

Although the fishers in this study were aware of the rules of sustainable fishing (Figure 6), many continued to engage in unsustainable behaviors, such as taking fish of all sizes and disregarding spawning seasons. This was often attributed to their low-income status and competition with fishers from other zones.

This study revealed that institutional of knowledge—which involves learning, creativity, and collective action—is present within these communities. Fishers collaborate in fishing activities and create a comfortable environment by establishing communal spaces such as *musolla* (Figure 7) and resting places. The division of labor among the fisher community is evident through the delegation of information to acquire more resources and the shared efforts in creating a conducive environment.

Although spirituality can be a determinant in fishers’ perceptions of climate change, the level of religiosity may vary among individuals due to factors such as work schedule. Some fishers may not frequently attend a mosque or participate in their religious community (Figure 8), reflecting different level of participation in religious activities. This may influence their exposure to religious teachings that can be linked to knowledge dissemination, or/and engagement in the community which may affect their social connections. The fishers reported relying more on their religious beliefs when encountering difficulties in fishing (93.4%) rather than practicing specific fishing techniques (e.g., forecasting weather, 80%). A high proportion of the respondents believed that climate change is related to *Qadr* (the divine decree of Allah; 93.4%).

The relationship between traditional knowledge (empirical knowledge, resource management knowledge, institutional knowledge, and spiritual practices) with demographic variables (age, education level, monthly income, and years of fishing) is shown on Table 3. Out of all traditional knowledge, only spiritual practices exhibit a significant relationship with age while other variables like empirical knowledge, resource management knowledge, and institutional knowledge shown a weak relationship and not statistically significant ($p > 0.05$). The correlation between empirical knowledge and education level also shows low correlation. Additionally, resource management knowledge and monthly income does not influence the knowledge of resource management.

Fishers’ adaptation to climate change

Adaptive capacity in five domains

Adaptive capacity has five domains (Cinner et al., 2018), and the fishers were found to have the highest capacity in terms of the

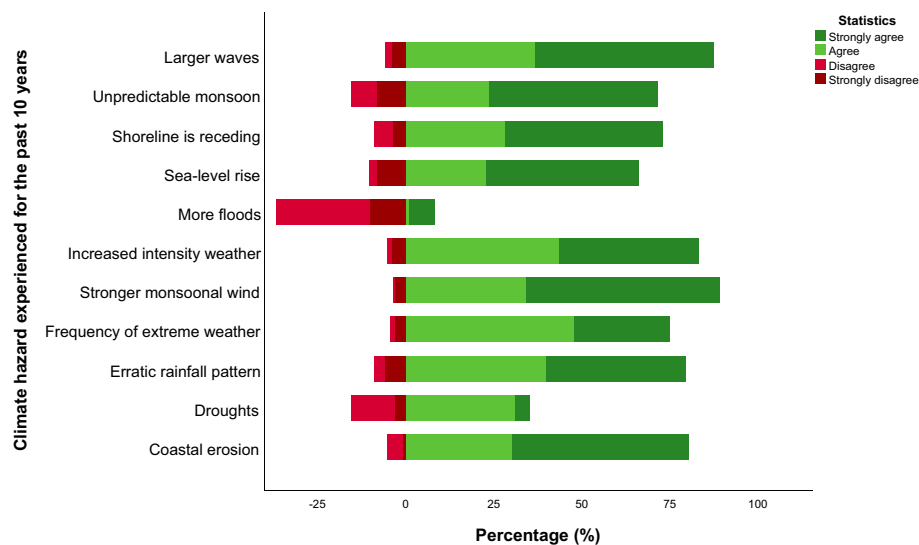


FIGURE 2

Percentages of fisher respondents' agreement on the perceived climate hazard in their communities over the past 10 years.

learning, agency, and assets domains; flexibility was their weakest domain (Figure 9). Regarding learning, 72% of the respondents agreed that they needed to be progressive in learning about new fishing gear and using weather apps to adapt to climate change. They also expressed a desire for access to resources from fishing institutions and governments to support their adaptation. Flexibility was the least developed domain, with only 58% of fishers willing to consider alternative livelihoods such as selling nasi lemak, carpentry, welding, or house construction. Additionally, many fishers were attached to their specific fishing area. In terms of assets, 72% of the respondents had enough savings to invest in higher-quality boats, engines, and fishing gear. Regarding social organization, 76%

expressed their opinions to fisheries agencies on various concerns. However, they noted that they faced challenges in connecting with authorities due to their status as small-scale fishers operating within the 0–5 nautical mile zone, which may be perceived as less profitable compared with offshore fisheries. Regarding agency, 68% of the respondents integrated local knowledge with climate data to adapt to climate change and fishing times. However, they also often felt neglected due to their status as coastal fishers.

Constraints to adaptation

The respondents perceived the Area Fishermen's Association or *Persatuan Nelayan Kawasan* (PNK) and the state government as being

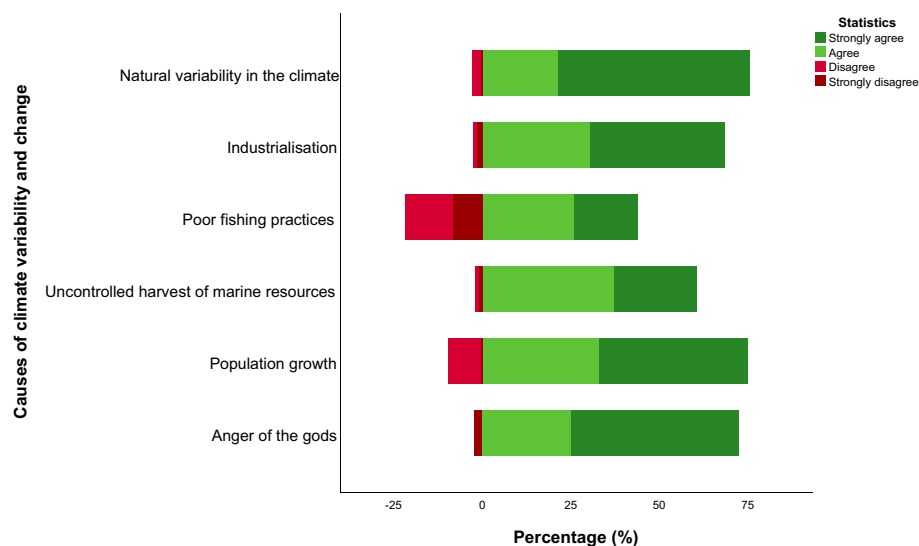


FIGURE 3

Percentages of fisher respondents' agreement on the causes of climate variability and change.

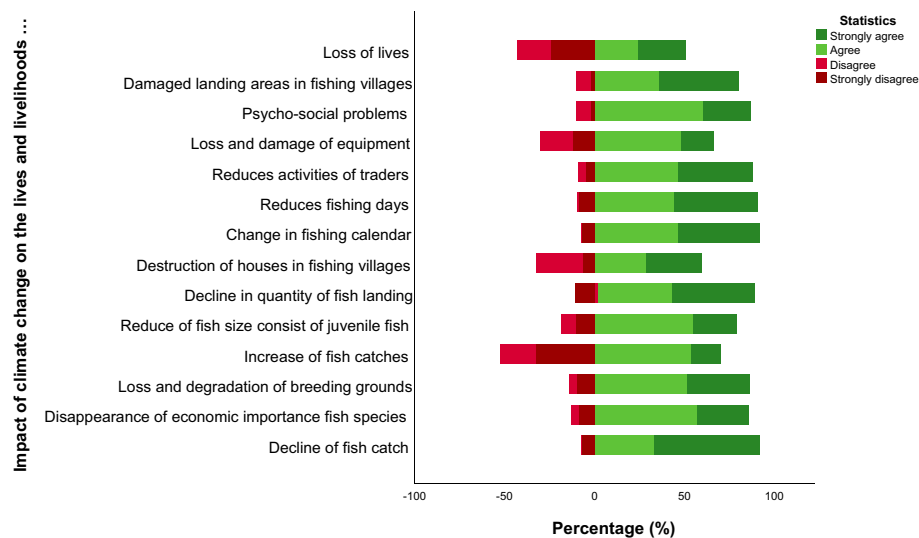


FIGURE 4

Percentages of fisher respondents' agreement on the impact of climate change on the lives and livelihoods of fishing communities.

the agencies primarily responsible for addressing climate change's impacts (Supplementary Figure S1). The current assistance received from the government primarily consists of subsidies (42%), followed by monthly cash benefits (33%; Supplementary Figure S2). Despite the existing support from agencies, the respondents considered this support insufficient and expressed a desire for more assistance (Supplementary Figure S3) through fuel subsidies (24.2%), financial capital (20.90%), training for boat repairs (12.80%), and guidance on identifying potential fishing grounds (12.50%).

Relationship between traditional knowledge and adaptive capacity

The structural equation model depicted in Figure 10 indicates a significant correlation between the latent variable TK and adaptive capacity (0.73). Of the components of TK, spiritual practices had the highest factor loading. Conversely, the five domains of adaptive capacity contributed relatively evenly to overall adaptive capacity.

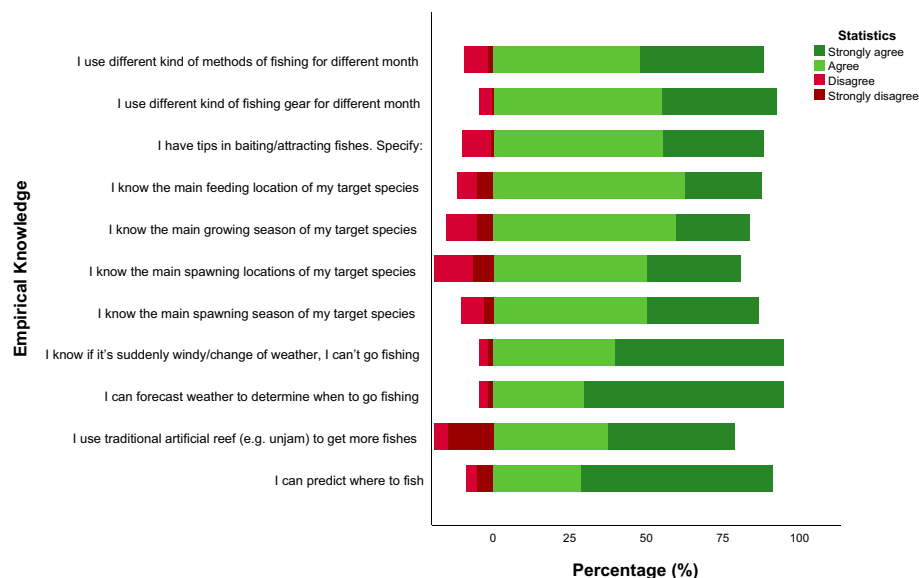


FIGURE 5

Percentages of fisher respondents' agreement on their dependency on empirical knowledge.

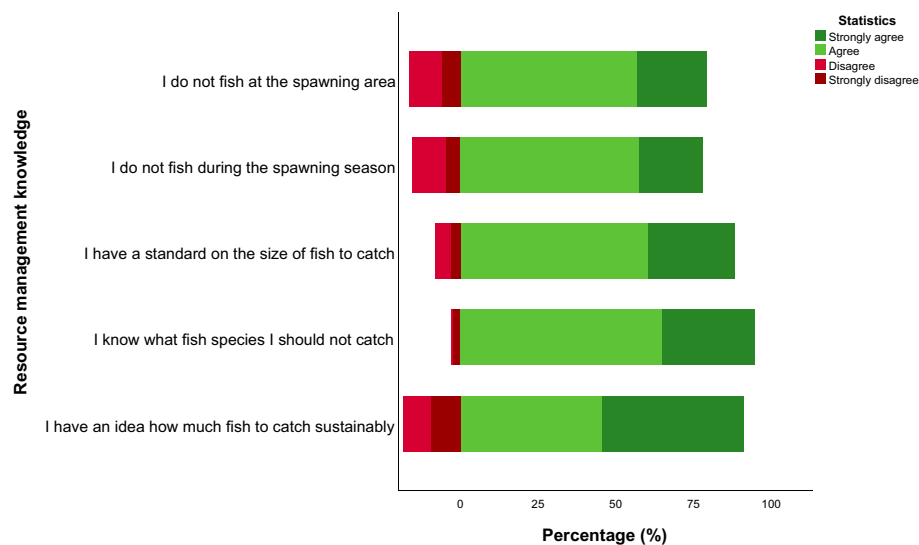


FIGURE 6
Percentages of fisher respondents' agreement on their dependency on resource management knowledge.

In addition, the correlation results indicated that there is weak but statistically significant positive correlation between empirical knowledge and learning skills of fishers (Kendall's tau = 0.176; $p < 0.01$). While there is a weak but statistically significant positive correlation between institutional of knowledge with social organization (Kendall's tau = 0.207; $p < 0.01$).

Discussion

Climate change risks are multifaceted, and understanding fishers' perceptions of climate change is crucial for effective marine fisheries management. As noted by Tang (2019), studies

on climate change implications for fisheries are lacking. Our research aligns with the objectives of Malaysia's Twelfth Malaysian Plan (Economic Planning Unit, 2021), which prioritizes climate change adaptation. This study assessed the small-scale fishing community in Kuala Nerus and Kuala Terengganu by examining key perceived risks, perceptions of climate change, and adaptive capacity characteristics as well as the effect of TK on adaptation to climate change. The primary effects of climate change perceived by the small-scale fishers were found to differ from those emphasized in earlier research and government goals. Moreover, TK for fishing was demonstrated to be dependent on four levels, which can contribute to adaptive management. Furthermore, the five domains of adaptive ability can

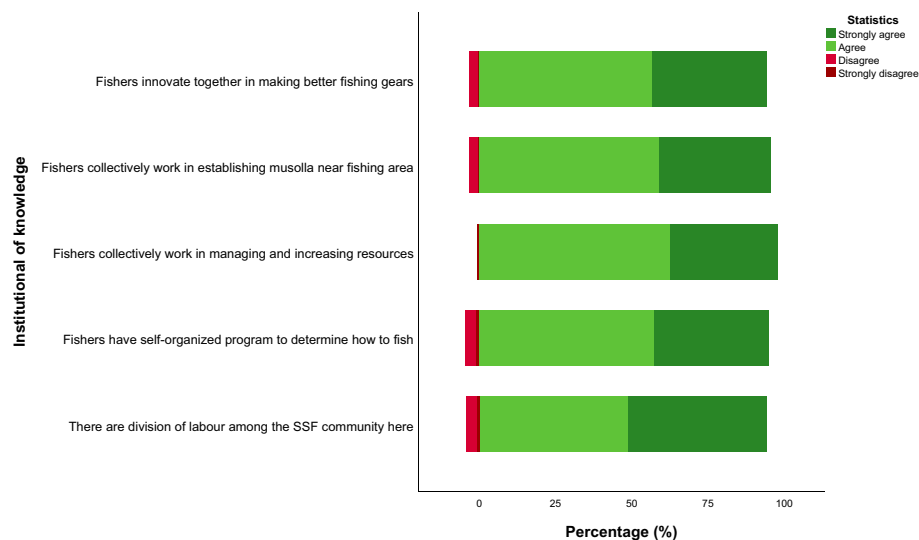
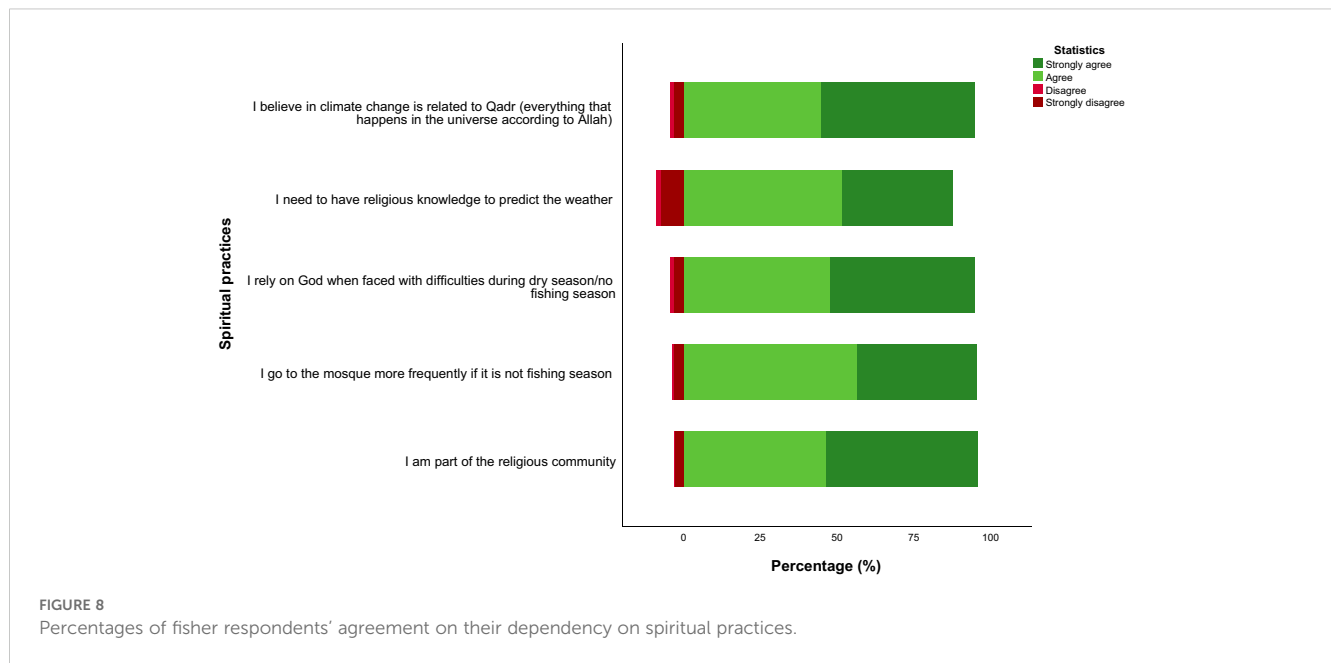


FIGURE 7
Percentages of fisher respondents' agreement on their dependency on institutional of knowledge.



be employed to foster resilience in Terengganu's fishing communities. Understanding and embracing fishers' spiritual practices is essential for achieving environmental sustainability.

Perception of climate change

The primary climate change impacts perceived by the small-scale fisher respondents surveyed in the present study differ from those highlighted in the literature and government priorities. The respondents identified three primary climate hazards: stronger monsoonal winds and larger waves, greater weather variability, and erratic patterns of rainfall. However, studies such as that conducted by Othman et al. (2022) have reported increased flooding in Terengganu due to rising rainfall levels, contradicting the respondents' perception that the area is not experiencing more flooding. Bagheri et al. (2021) noted that Kuala Terengganu's vulnerability to flooding stems from its exposure to coastal erosion. Additionally, Terengganu's rainfall is heavily influenced

by wind direction and temperature (Noor et al., 2023). This discrepancy between the fisher respondents' understanding of climate change risks and expert opinions has also been found in another study, which reported that fishers' perceptions can be contextual and may not fully reflect scientific findings (Hasan and Nurse-Bray, 2018). The discrepancy can hinder timely climate action and adaptation. Furthermore, Mulyasari's (2023) findings support the present result, suggesting that fishers' climate literacy may still be low because their judgments are often based only on personal experience.

Traditional knowledge dependency

This study demonstrated that the four levels of dependency of fishing on TK may assist in adaptive management. Consistent with research by Idris et al. (2018) and Omar et al. (2013), the present respondents expressed mixed feelings regarding the changes in nature; their empirical knowledge is becoming less effective in

TABLE 3 Spearman's Correlation between traditional knowledge components and demographic variables.

TK Component	Demographic Variable	Spearman's ρ	p-value	Significance
Empirical Knowledge	Age	-0.052	0.546	ns
Resource Management Knowledge	Age	0.114	0.186	ns
Institutional Knowledge	Age	0.045	0.606	ns
Spiritual Practices	Age	0.257	0.003	**
Empirical Knowledge	Education Level	0.104	0.229	ns
Resource Management Knowledge	Monthly Income	0.051	0.552	ns

**p < 0.05, ns, not significant.

Adaptative Capacity

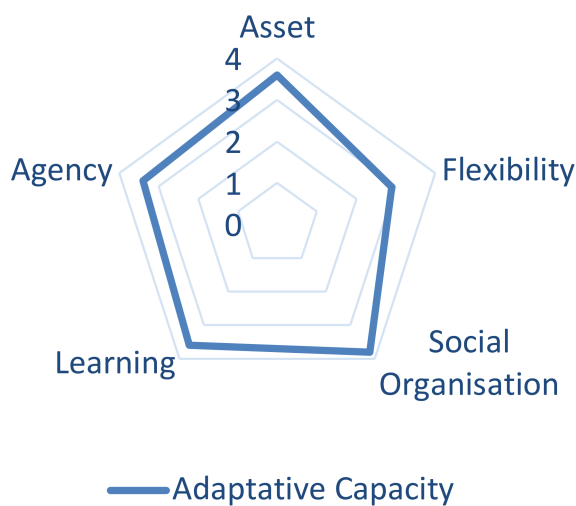


FIGURE 9
Mean adaptive capacity scores in five domains.

predicting weather due to increasingly unpredictable climate patterns. Although approximately 60.3% of the fishers surveyed in this study still used traditional observation methods such as checking cloud locations, wind strength, and waves, they were concerned that their forecasting abilities might diminish with intensifying climate change. Consequently, the fishers are increasingly relying on technologies such as the Windy app, information sharing with other fishers, and social media.

Regarding resource management knowledge, when the fisher respondents were asked about their willingness and ability to engage in sustainable fishing practices, they expressed concerns about the illegal fishing activities of fishers from other countries (e.g., Vietnam and Thailand). These concerns hindered their prioritization of

sustainable fishing because they faced competition and struggled to secure resources from illegal fishers. Illegal fishing is a prevalent concern in Malaysia, as highlighted by several studies that emphasize the country's weak enforcement measures (Kon et al., 2023; Fadzli et al., 2023).

Regarding institutional knowledge, the fishers indicated social cohesion within their community, with fishers collaborating not only in sharing information on the weather and fishing locations but also in creating a comfortable environment through the construction of *musolla* and resting areas. Social cohesion is fostered when TK enables mechanisms for community resilience leading to adaptation (Hosen et al., 2020). Because half of the fishers live below the poverty line, earning <RM1,000 per month (approximately equivalent to 224.60 USD) from fishing, collaborative action by pooling resources and labor is encouraged.

As for, spiritual practices are prevalent among fishers. The finding that the respondents mainly attribute climate change to God's anger, second only to natural variability, may be due to deeply rooted religious beliefs. Although Armah et al. (2017) did not identify religion to be a predictor of climate change perceptions in the homogenous Buddhist community of Cambodia, other studies such as that conducted by Mbaye et al. (2023) in Senegal have reported that some fishers believe that failure to follow religious doctrine can lead to divine punishment through environmental changes (Mbaye et al., 2023). In some cases, religion provides purpose and a framework for navigating life, playing diverse roles in societies (Veldman et al., 2013).

Lastly, the representation of the correlation between different traditional knowledge sectors with demographic variable shown that only spiritual practices with age that has significant positive correlation which indicated the older fishers could be engaged to more spiritual practices. This is influence by the social norm in Terengganu suggesting that older folks are likely to be involved in religious activities as they get older (Zainab et al., 2012). Empirical knowledge, resource management knowledge, and institutional knowledge showed that it is not dependent on fisher's age. This

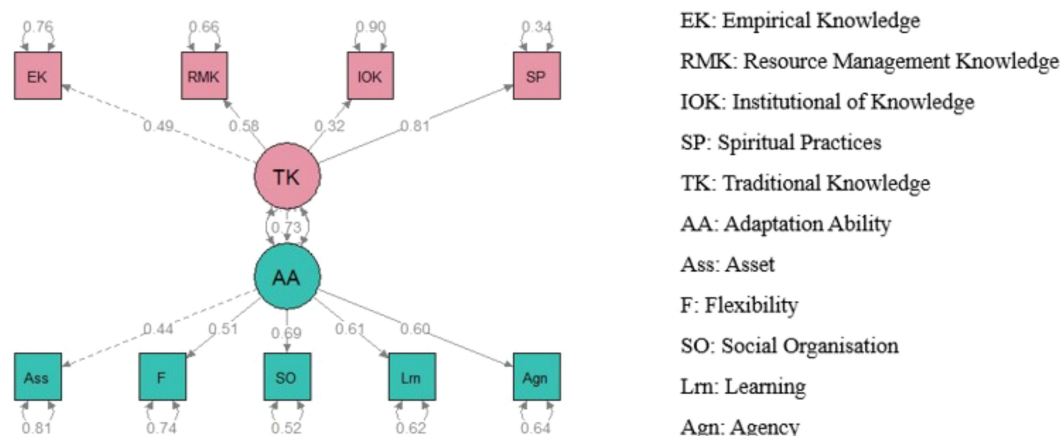


FIGURE 10
Results of structural equation modelling indicating the relationship between TK and adaptation ability. Values indicate the loading of each measured variable (in rectangles) to the latent variables (in circles: TK and AA). The dashed lines represent fixed covariates.

means that experience alone may be gathered through other means like direct learning, community sharing, through NGO initiatives, media interactions or other exposures. In Mexico, external actors like the NGOs help build transfer knowledge to the community (Fernández-Rivera Melo et al., 2024) while in Indonesia, a transformative shift towards digital learning to help with fishers' adaptive capacity (Ayunda Pratiwi et al., 2023). This research implied that fishers' educational level and monthly income do not significantly impact their empirical knowledge and resource management skills. Hence, knowledge acquisition can be beyond formal education hence fishers' with lower educational level should be prioritized in marine environmental education programme to encourage them to be more positive towards embracing any conservation efforts (Braga et al., 2017).

Adaptive capacity to climate change

This study revealed that all five domains of adaptive capacity are instrumental in building resilience within the fishing communities of Terengganu. Adaptation strategies are crucial to reducing vulnerabilities to climate change. Learning was identified as the highest adaptive capacity domain. In response to unpredictable weather, fishers have become more progressive in learning new fishing techniques, acquiring new fishing gear, and seeking access to resources from fishing agencies and the government. As emphasized by Abu Samah et al. (2019), technology plays a vital role in mitigating the risk of extreme weather and enhancing climate adaptation. For instance, GPS guides fishers from their fishing location back to their jetty, and echo sounders assist fishers in determining water depth and detecting fish.

Regarding agency, fishers emphasized that their voices are often overlooked. The majority of fishers expressed frustration with unfair treatment because officials did not take their complaints seriously and prioritized fishers from zones B (5–12 nm) and C (12–30 nm), which have higher revenue. Therefore, co-management between fishers, the Area Fishermen's Association or *Persatuan Nelayan Kawasan* (PNK), and government agencies is essential to fishers' adaptation (Susilo et al., 2021).

Regarding assets, the respondents generally considered it essential to prepare a certain level of assets for future disturbances. As noted in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation by Noble et al. (2015), securing assets for livelihood stability and protection against climate risks is essential for climate adaptation. Fishers in Kuala Nerus and Kuala Terengganu worked diligently to save money to invest in higher-quality boats, engines, and fishing gear for their fishing activities. Access to assets such as financial capital can depend on the size of the community; some have the ability to invest in better gear, whereas others have limited ability to diversify their livelihood (Green et al., 2021).

Regarding social organization, although a large proportion of the respondents had participated in a fishers' association, most of them felt that their voices were unheard by government agencies. A society can efficiently function when social capital, technological advancement, and an open and modular infrastructure are available (Mason et al., 2022). This study revealed that the respondents still struggled to raise issues

with government agencies due to their status as zone A (<5 nm) fishers, which resulted in lower provisions compared with other zones. Despite these challenges, the fishers demonstrated a strong sense of community and supported each other during crises.

Flexibility was the domain of adaptive capacity that the fishers participating in this study considered the least. Given that 67.6% of the respondents rely solely on fishing for their household income and frequently went to sea for extended periods to increase earnings, they are vulnerable to disruptions in fishing activities. Diversifying their livelihoods could help them build financial capacity and mitigate the impacts of climate change (Abu Samah and Shaffril, 2020; Badjeck et al., 2010). Fishermen in Lake Wamala, Uganda, have demonstrated the ability to maintain their livelihood and adapt to climate change by implementing measures such as switching target species and gear (Musunguzi et al., 2016). However, only 58% of the fishers involved in this study were willing to consider alternative livelihoods, such as selling nasi lemak, performing carpentry, welding, and house-building. This limited willingness to diversify their livelihood is attributable to factors such as a lack of financial capital (Islam et al., 2014), limited options for livelihood diversification (Nayak, 2017), lack of opportunities to acquire other skills (Nayak, 2017), and a preference for maintaining the traditional fishing lifestyle (Kadfak, 2020). Some fishers expressed satisfaction with their current subsistence level and a desire to remain in their familiar community for sentimental reasons. Enhancing support for small-scale fishermen to diversify their livelihood is essential to enhancing their overall adaptive capacity and resilience to climate change.

Relationship between traditional knowledge and climate change adaptation

The study findings highlight the complex relationship between fishers' practices and TK in adapting to climate change. Recognizing all aspects of TK is crucial for effective environmental stewardship. TK serves as a foundation of knowledge and resiliency in communities, particularly during times of uncertainty (Berkes et al., 2000; Kupika et al., 2019). Although the use of TK has declined due to the unpredictability of climate change, it remains the foundation of knowledge but is also not sustainable. Integrating new technologies with current TK can be a promising strategy for adaptation. This approach is consistent with that reported by Wongbusarakum et al. (2021), who emphasized the need to rethink coastal resource management by incorporating TK for climate adaptation. Supporting fishing agencies and institutions is essential to facilitating fishers' cognitive processes and enhancing their ability to adapt to climate-induced changes (Gianelli et al., 2021). The present study supports the hypothesis that individuals who engage in more spiritual practices exhibit stronger social organization. This finding aligns with that of a study conducted on Pulicat Lake, which demonstrated that religious duties strengthen social needs at both the individual and community levels (Reddy, 2020). Spiritual practices are also crucial for the healing process when disasters occur. In times of danger or distress, Muslims in Indonesia perform Qunut Nazilah (a prayer to Allah for protection against a specific disaster or tragedy) in

Sayung, Pulo Nasi and Pulo Breuh Islands, and Undango Wanua (a Muslim tradition performed to safeguard communities during difficult times) in Kendahe (Hiwasaki et al., 2014). This study highlights the importance of considering TK, including spiritual practices, when developing policies for improving the climate adaptation of small-scale fishers.

Limitations

The coefficient of correlation between TK and adaptation ability can be affected by several factors including community dynamics and heterogeneity in the fishers' economic conditions, thus the adaption ability may not be fully captured by TK alone. Additionally, the measurements of TK and adaptation ability may have been incomplete because TK and adaptation ability can be quantified in other ways, such as the presence of multilevel governance for adaptive co-management (Pinkerton, 2005) and psychological resilience to cope with various stressors from the environment, social sphere, and politics (Adger, 2000). Other factors that may affect adaptation ability include education level (Paavola and Adger, 2006), access to resources (Allison and Ellis, 2001), and health and well-being (Grafton et al., 2006) could also be considered.

Future research direction

Enhancing fishermen's understanding through marine environmental education and ocean literacy initiatives could increase their adaptive capacity and improve the lives of coastal communities. How to adapt ocean literacy to the requirements of the fishing community could be one possible line of inquiry. Furthermore, studying other learning pathways—like formal training programs and intergenerational knowledge transmission—might provide insight into how they affect fishermen's development of empirical knowledge. The effects of collaborative relationships between local fishermen with other parties, such as non-governmental organizations, in advancing sustainable resource management could also be studied. Finally, investigating how spiritual involvement and religious practices promote sustainable fisheries management may offer important new perspectives on how spiritual understanding enhances adaptive ability.

Conclusion

This study quantitatively analyzed key perceived risks, perceptions of climate change, adaptive capacity characteristics, and the role of TK, including religion, in influencing the adaptation to climate change of small-scale fishers in Terengganu, Malaysia. This study revealed a correlation between TK and adaptive capacity, suggesting that TK can help increase resilience in the face of climate impacts. Despite comparable approaches have been used in other contexts, this case study provides a deeper understanding of the intersection of lived experience and traditional values in climate adaptation by highlighting the cultural-religious layering of TK

within a Muslim-majority coastal Malaysian context. By advancing our knowledge of TK as a dynamic, context-dependent system influenced by local conditions, this study contributes conceptually. The findings of this study offer a valuable foundation for empirical research on various attributes of adaptive capacity, guiding further investigations into the resiliency of livelihood systems dependent on fisheries and advocate for more culturally sensitive, participatory adaptation programs that effectively involve small-scale fishermen and the variety of knowledge they represent.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by National Taiwan University Research Ethics Council (File Number: 202212ES028). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LY: Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft. NA: Resources, Writing – review & editing. T-CK: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2025.1492131/full#supplementary-material>

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