Fishers' Perceptions of the Climate Change Impact on Fishing in Small Islands of Wakatobi

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Abstract

Local ecological knowledge regarding climate change in Wangi-Wangi Island, Wakatobi remains largely unexplored, creating an important research gap concerning how indigenous insights influence community responses to climate change impacts. This is particularly critical for small-scale fisheries communities whose limited resources heighten their vulnerability. Incorporating knowledge from local fishermen is essential for improving the sustainability of these fisheries, which form the foundation of long-term community livelihoods. This study employed methodological triangulation, combining secondary data analysis with primary data collected through in-depth interviews and focus group discussions involving small-scale fishers from five vulnerable villages in Wakatobi, Southeast Sulawesi, Indonesia. The research aimed to identify factors contributing to transformative behavior and adaptive capacities among small island communities facing climate change impacts on their livelihoods. Findings revealed significant anomalies in local weather and climate patterns over the past decade. Participants primarily recognized climate change through seasonal shifts (53%), most notably manifested in unusual wind patterns regarding both direction and speed (64%). The perceived impacts included coral reef ecosystem degradation (61%) and sea level rise (29%), with 55% of participants reporting these changes within the past two years. Additionally, 14% of participants indicated these phenomena had persisted for approximately ten years.

Keywords

climatic change | fisher knowledge | small-scale fisheries | Biosphere Reserve

1. Introduction

The harvesting of marine biodiversity has a substantial influence on small island coastal populations in tropical waters. This is primarily owing to the fact that these communities are dependent on marine resources for their means of subsistence, food security, and coastal protection (Fleming et al., 2024; Maharja et al., 2023b). This impact is further magnified by climate change, which exacerbates the consequences of overfishing and pollution on ecosystems that are already susceptible with regard to their vulnerability (Culhane et al., 2024). Small-scale fishers rely heavily on local ecological knowledge (LEK) of fishing activity to support their daily livelihoods (Stacey et al., 2021). However, the significant challenge of climate change forced them to respond and adapt in order to maintain their future livelihood. Climate change is a global issue that significantly impacts various aspects in human lives, particularly in those reliant on sectors such as agriculture and fisheries, which are vital to the well-being of rural communities in developing nations (Adger et al., 2003). We expect this trend to persist and escalate at rates previously unseen in the next century. Climate change has already altered terrestrial, freshwater, and ocean ecosystems globally, with multiple impacts evident at regional and local scales (Pörtner et al., 2023).

From a geographical perspective, Wangi-Wangi Island, as part of Wakatobi regency, is located in the southern region of the equator, covering a latitude range from 50°14’ to 60°03’ S (with a length of 160 km) and a longitude range from 123°40’ to 124°03’ E (spanning a width of 120 km). Its northern and eastern borders connect to the Banda Sea, while the southern and western boundaries are adjacent to the Flores Sea. The northwestern section includes Button Island within the Southeast Sulawesi Province. Wakatobi Regency comprises four main islands, Wangi-Wangi, Kaledupa, Tomia, and Binongko, which form the acronym Wakatobi. As part of the world’s coral triangle region, the Islands feature a rich array of ecosystems housing numerous marine and coastal species, including seagrasses, coral reefs, edible fish, seabirds, turtles, cetaceans, and mangroves.

In 1995, the Government of the Republic of Indonesia, under the authority of the Minister of Forestry, designated Wakatobi as a Marine Nature Park (WNP as per Decree Number 462/KPTS-II/1995). This decision recognized the Wakatobi Islands as one of the world's regions with the most comprehensive marine biodiversity. Subsequently, in 1996, its status was elevated to that of a conservation area, officially becoming a National Park (Decree Number 393/KPTS-VI/1996). The Minister of Forestry's Decree Number 7651/KPTS-II/2002, dated August 19, 2002 (BPS Wakatobi, 2022).

The sub-district of Wangi-Wangi is home to approximately 61,283 residents who reside in 41 villages. The diverse population comprises ethnic groups such as indigenous Wakatobi, Bugis, Buton, Java, and Bajau. Some of the inhabitants rely on marine resources for their livelihoods, with the fisheries sector being one of the sources of employment, mainly targeted to deep-sea, coral, and coastal fishes. Fishing activity plays a crucial role in sustaining the local economy.

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Meanwhile, the agricultural sector primarily provides for domestic and subsistence needs, cultivating crops like cassava, maize, tubers, and beans (BPS Wakatobi, 2022).

Fishers contribute a small number of 2,135 (<5%) of the Island community's livelihoods (BPS Wakatobi 2022) and are categorized as small-scale fisheries (SSF) and mostly own a fishing boat less than 10 gross tonnage (GT) (Law (UU) no. 7, 2016), operating on a daily scale which rely on harvesting the biodiversity of sedentary and migratory marine species. They play a role in contributing to food security, sustaining livelihoods, and providing and maintaining existing cultural characteristics, including a broad spectrum of traditional local knowledge. The coastal communities of small islands are primarily low-income, relies heavily on marine edible biodiversity and faces socio-economic vulnerability due to the effects of climate change (Macusi et al., 2021) (Maharja et al., 2023a). Many Indigenous communities depend on livelihoods rooted in the sustainable utilization and stewardship of natural resources within their local environments (Ford et al., 2020). These livelihoods encompass subsistence farming, swidden agriculture, animal husbandry, artisanal fishing, hunting, and gathering (UNESCO, 2014). They operate on a small fishing boat and require specialized skills acquired through hands-on experience (N'Souvi et al., 2024).

Traditional livelihoods are diverse and frequently linked to intricate social and land tenure systems (Murken and Gornott, 2022). These arrangements are crucial in resource management and enhance societal resilience during changing conditions (Nakashima et al., 2012). People across cultures, worldwide, are now experiencing the effects of changing climate. The impact of environmental change on culture is most evident at a local scale, particularly in the context of human-biota interactions occurring at various times in various places (Wolverton et al., 2014), which hinders them in performing traditional livelihood practices that are essential in preserving collective identities and strengthening social cohesion (Maharja et al., 2023a). Within this context, this study is aimed (1) to determine to what extent the Wangi-Wangi coastal community, as part of Wakatobi National Park, a small island surrounded by a marine ecosystem, will be affected by several indicators of climate change; (2) Gain knowledge about climate change and mitigation strategies for coastal communities to maintain daily life. Those factors are expected to help explain how they try to transform behavior and adapt when facing challenges with the impacts of climate change on their livelihood. We structured to elicit local knowledge, perceptions, and individual experiences on changing weather and climatic patterns.

2. Methodology

This study employs an ethnobiological methodology, considering both emic and ethical perspectives. We have tailored the examination data on communities dependent on marine and coastal ecosystems, adhering to the guidelines (Albuquerque et al., 2017). This research primarily relied on interviews and secondary data to understand how climate change affects marine living resources. Through semi-structured interviews, fishermen's understanding of weather patterns and their influence on fishing was studied. This knowledge, similar to the ecological insights of fishers serve to reduce uncertainties and improve the relevance and trustworthiness of situations involving poor data analysis. Fishers' knowledge (FK) encompasses a wealth of experiential knowledge, incorporating insights into ecology, resources, ecosystems, fishing practices, fishing communities, livelihoods, governance, and markets, along with the dynamic interconnections among these elements. A specific social, cultural, and geographical context cultivates this knowledge (Cowie et al., 2020).

2.1. Study area

The research was conducted out in the Wangi-Wangi subdistricts, situated in the administrative area of Wakatobi Regency, Southeast Sulawesi. Additionally, we determined that the majority of the ethnic population worked as fishers. This paper employed the data obtained by in-depth interviews and semi-structured questionnaires in focus group discussions with small-scale fishers of five vulnerable coastal villages of the western part of Wangi-Wangi Island: Mola Samaturu, Mola Bahari, Mandati I, Liya one Melangka and Onowe Korowa villages (Fig. 1). Observation was carried out during strong winds and high waves of the southeast monsoon in June and August 2023. The Wakatobi National Park (WNP) is in the heart of the "Coral Triangle", a Southeast Asian region known for its rich marine biodiversity. Within the WNP, coral reefs thrive, and research indicates that the diversity and abundance of scleractinian corals in the park are comparable to other highly diverse areas (Bell et al., 2019).

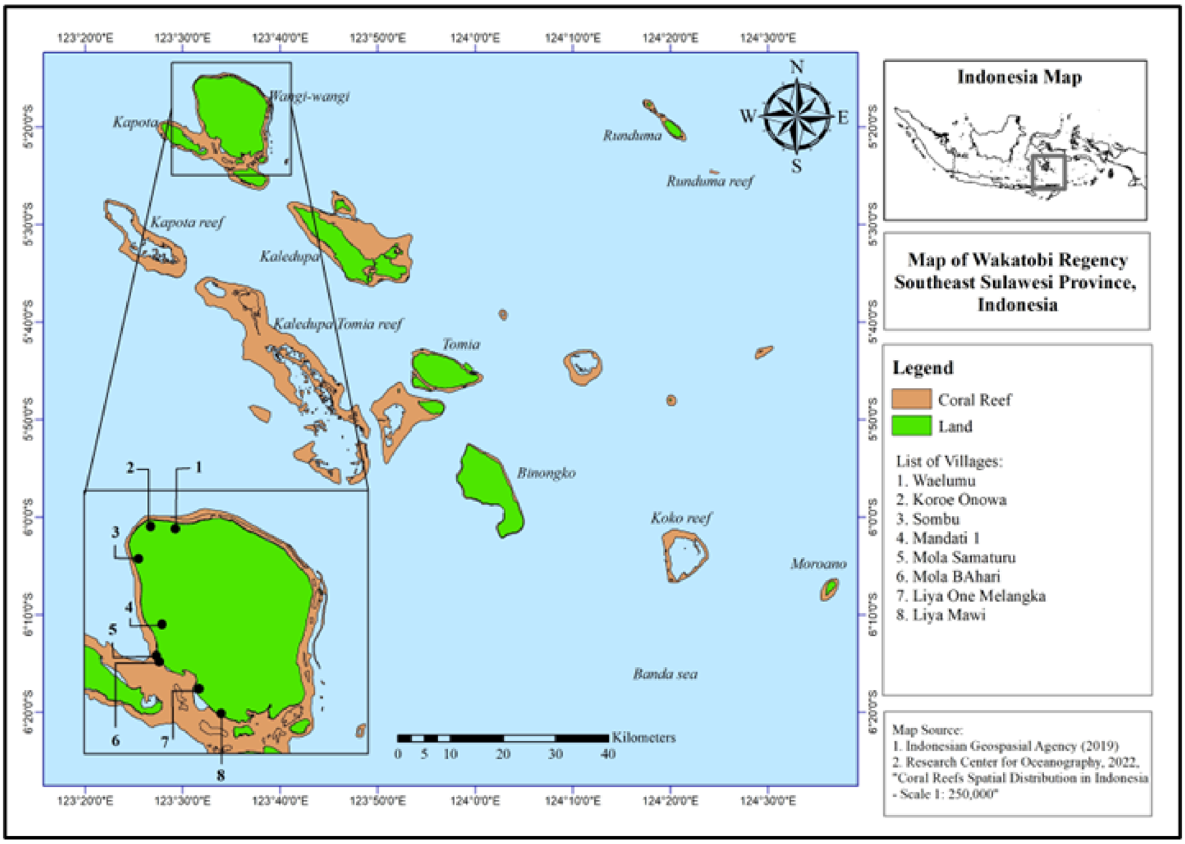

Fig 1. Site location during observation of Wakatobi Regency

The island, surrounded by coral and deep-sea slope reefs (< 1 nmi from the shoreline), dominates coastal waters in the eastern part, while shallow reefs occur in the southwestern part. There are 31 coastal villages and nine non-coastal villages. Most of the population lives in the western and southwestern parts. The villagers in Bajo Mola village (southwestern part) had houses built on coral mined from local reefs (Nelson et al., 2018) (Ariando and Arunotai, 2022) (Ariando, 2023). The topography of the coastal area was a relatively narrow shelf fringed by a coralline island or coral bank, meaning the coastal morphology was dominated by a shelf-slope with a sharply steep coastline.

2.2. Data collection and analysis

We conducted face-to-face, semi-structured interviews with the fishers. We applied a simple random sampling technique to select respondents to participate in the five villages mentioned above. Respondents aged more than 15 years were considered adults in the community and had more than sufficient background experience harvesting marine living resources. We treated the individual respondents as informants, using interviews and Focus Group Discussions FGDs as the primary data sources. We conducted interviews with seven respondents using open questionnaires and 111 respondents using closed questionnaires. The respondents represented various activities to support their livelihoods, including deep-sea tuna fishers, mixed fishers in both deep and shallow coral waters, and seaweed farmers.

The questionnaire inquires about respondents' perceptions regarding the dynamic of climate elements in their daily activities and how they adapt to climate change. We conducted an FGD with 25 key informants, representing all government agencies in Wakatobi Regency, to discuss programs, problems, and government support for coastal communities that utilize natural resources, particularly marine living resources and fisheries. The protocols to conduct research activities involving human participants have received ethical approval from the Research Ethics Committee for Social Sciences and Humanities of the National Research and Innovation Agency (BRIN) Indonesia (No. 135/KE.01/SK/04/2023), approved on 10 April 2023. Informed consents were received from all participants before data collection activities.

In addition to primary qualitative data, the study also utilized secondary data sets to triangulate the findings. The district annual reports significantly illustrate demographics and livelihoods. The climatic data series, specifically temperature and rainfall, were obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG) Beto Ambari weather station to observe the local variations in these parameters. The study used a data-limited, semi-quantitative approach and was shown through graphs and tables to describe the data and find trends, patterns, and relationships that would help summarize the large set of data and effectively share the results.

3. Results and Discussion

The results of our study revealed that the participants perceived that they were generally able to observe more frequent extreme events, such as large waves, intense storms, heavy rainfall, increasing air temperatures, and rising sea levels, are due to climate change phenomena. These changes will likely primarily impact the small-scale fishing communities along the coast (Kifani et al., 2018). People often describe small island systems as self-contained entities that require careful management of limited resources, such as water, plants, and animals. While this somewhat idealized interpretation overlooks the realities of inter-island trade and the seasonal presence of migratory species, numerous instances in small islands showcase sophisticated traditional resource management practices.

These regimes have historically played and continue to play a vital role in governing the social and ecological aspects of resource production, access, harvesting, storage, and distribution. This LEK aspect is evident, for instance, in the small islands of the Pacific, where many remote and geographically isolated communities persist in practicing agriculture and fisheries in adherence to traditional resource management and governance systems (Nakashima et al., 2012).

Communities residing in archipelagic regions and relying on natural resources for their livelihoods are typically susceptible to shifts in climatic conditions. Therefore, it is crucial to understand these communities' knowledge and adaptive capacities regarding climate changes affecting their surroundings (Munawaroh et al., 2018), which can also inform the formulation of strategies for communities’ adaptation to climate change.

3.1 Demographic characteristics

Fishers navigate a complex web of uncertainties that stem from both oceanic conditions and the social fabric of their communities. When they extend their harvesting activities to land-based resources, they encounter similar patterns of unpredictability that characterize their marine operations. The annual series of weather station data for Betoambari were analyzed to illustrate the climatic parameters of the area. Climate change is a global issue that has gained international attention and is one of the themes defined in the United Nations Sustainable Development Goals (SDGs), specifically SDG 13 (Climate Action). Additionally, SDG 14 includes the theme of maintaining marine ecosystems. Wangi-Wangi Island, with an area of 191 km^2, is the largest among the four neighboring subdistrict islands and administratively under the Wakatobi Regency, which 3 has 8 smaller islands (17 of them were occupied). The population is approximately 61,283, with a growth rate of 1.82%. Of these, 66% of the population belongs to the productive group, defined as those aged 15–65 years old, 28% is potentially productive, and 5% is low in productivity level. There is no available data regarding educational background for communities residing in Wangi-Wangi Island. However, in Wakatobi's regency, the majority of the population (44%) had no formal education. Approximately 76,000 individuals within the community have an educational background, with 21% having completed high school or possessing academic/university-level education. The community earns its livelihood from a variety of fields. The majority of these jobs (49%) were in the services sector (both government and private), followed by agriculture (36%) and manufacturing (15%) (BPS Wakatobi, 2022).

There seemed to be positive growth in employment sector within the regency. For example, the ratio of dependence to productive population was relatively high (70%) ten years ago (BPS Wakatobi, 2014). In recent years, a decrease in this ratio to 50% occurred (BPS Wakatobi, 2024), particularly due to the significant development of tourist destinations that provide job opportunities for local residents then the recovery post pandemic were slow. The main livelihoods are agriculture, forestry, and fisheries (28.3%), construction (17%), trade (15%), mining and quarrying (14%), while other business fields contribute < 10%. Agricultural (vegetable, fruit, ornamental, and medical plants) and traditional plantation estates such as coconut, cashew, coffee, and cocoa contribute to their livelihood. A total planted area of 701 ha with 495 tons of crop production was harvested in 2021, with coconut (63%) and cashew (33%) being the primary crop production (BPS Wangi-Wangi, 2022).

The role of harvesting natural resources as a basis for land productivity livelihoods in terrestrial areas over the last ten years has diminished, with wildly fluctuating corn plantations from 18 kg/ha (2012) to 123 kg/ha (2017), then dropping to 27 kg/ha (2022); cassava from 217 kg/ha (2013) to 3,667 kg/ha (2017), then dropping to 204 kg/ha (2022); while sweet potatoes increased from 74 kg/ha to 191 kg/ha. The decline in the plantation area, from the most prominent 3,800 ha in 2017 to 262 ha in 2020, likely contributes to this fluctuation. Utilizing coastal and marine living resources is part of the livelihood of coastal communities. The number of people working in capture fisheries was about 6.2% of the total population in 2013, dropping to 3.2% in 2022. Still, the number of motorized and outboard motorized boats increased from 1,855 units (2013) to 3,633 (2022), with production volume increasing from 7,384 tons (2014) to 21,412 tons (2022). In addition, seaweed cultivation activities carried out by coastal communities have increased in the last five years, with a production volume of 2,800 to 3,900 tons/year.

3.2 Socio-demographic and characteristics of respondent

The majority (34%) of the interviewed fishers were aged between 41 and 50 years old. The range of age of all respondents was betweeb 17 to 70 years, and averaging 42.4 ± 10.8 years. Their average length of stay of the communities in the region was approximately 32 ± 16 years, varying from 2 to 70 years. They had been engaged in fishing for durations ranging from 1 to 47 years, with an average of 16.9 ± 11.4 years. These fishers worked from 2 to 18 hours daily, averaging 9.3 ± 3.8 hours. The number of family members they typically had ranged from 1 to 8, with an average of 3.9 ± 1.6 members. Table 1 describes the respondent profile.

Fisher communities on Wangi-Wangi Island generally divide their production activities into four groups: multi-gear users, speargun users, tuna-targeted fishing gear users, and seaweed farmers. 1) The Butonese Wakatobi ethnic community

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usually carries out mixed fish fishing. Fishermen from this group catch fish in the deep sea and the sea near the coast; therefore, the fish they get usually vary, such as skipjack, small pelagic, demersal, crustaceans, and coral fishes. This group occasionally engages in other occupation, such as farming; 2) Speargun fishers who are ethnic Butonese Wakatobi and capture a variety of reef fish, including cockatoos, emperors, rabbit fish, and groupers; 3) Tuna fishers typically from the Bajo ethnicity, possess a remarkable ability to catch fish in the deeper sea; 4) Seaweed cultivators typically originate from the Buton Wakatobi ethnicity.

Table 1. Respondent profile, age, resident time and years of fishing experiences

Variable (year)	Age (n)	%	Resident time (year)	%	Fishing Experience (years)	%
<10			13	12.1	38	37.3
11–20	1	0.9	14	13.1	30	29.4
21–30	17	16.0	30	28.0	22	21.6
31–40	29	27.4	14	13.1	7	6.9
41–50	36	34.0	19	17.8	5	4.9
51–60	16	15.1	13	12.1		
60+	7	7	4	3.7		

In production activities, the four coastal community groups depend on wind and waves. People in this region understand well the best time for them to fish. For example, tuna fishers in Mola Bahari Village prefer fishing from September to October because the waves are not too high and the sea is shady, whereas from November to February, the sea is dangerous.

3.3. Fishers' perception of the evolution of climatic parameters

Numerous studies emphasize the significance of integrating fishers' knowledge into fisheries and climate sciences, encompassing terms such as "ecological and technological knowledge" (Grant and Berkes, 2007). Utilizing local ecological knowledge (LEK) proves valuable in deducing the ecological interactions of organisms frequently utilized by human populations (Huntington, 2000). The local ecological knowledge of fishers can also provide insights into fish diets and even the trophic levels of fish. Moreover, the LEK of fishers can serve as a wellspring for generating new biological hypotheses and guiding management actions, particularly in situations where financial resources are limited and fisheries are extensive (Pereyra et al., 2021). We identified groups by age, fishing experience, local knowledge, and projected change in their local weather condition. In accordance with (Menon et al., 2016), we prioritized the age and fishing experience of fishers before setting the decadal limit to their traditional knowledge base. Senior fishers with over 30 years of consecutive fishing experience were the primary preference. All the respondents were either small-scale fishers or one-day fishing operations with fleet sizes of less than 10 GT. This approach effectively represented the perspective of those who had dedicated their knowledge to the decision-making process. By valuing their insight, we aimed to implement sustainable practices that would not only protect the fisheries but also honor the traditions that have shaped the local fishing community.

3.3.1 Understanding the climate change

Our study revealed that communities in small islands of Wakatobi perceived that their marine environment is changing, which was experienced through their observation of shifting weather patterns that have occurred over the past few years. In particular, fishers (n = 111 respondents) recognized and perceived different indicators related to climate, such as seasonal changes (52% of respondents) and presumed uncertainties in wind direction and speed (64% of respondents). In addition to climate indicators, the respondents also recognized several changes in the marine ecosystems, including degradation of the coral reef ecosystem (32% of respondents), decline of other marine ecosystem quality (29%), and sea level rise (29% of respondents) that were believed to have occurred especially in the last few years. Some respondents even perceived that these changes have actually occurred even longer, with 14% of respondents stated they had observed these changes since the last decade or more.

The community perceived climate change as a change in air temperature and weather patterns, which indirectly impact the local ecosystem. All these indicated that small island communities in Wakatobi have some knowledge of the impacts of climate change in their localities. Rising seawater temperatures affect coral growth and cause damage, such as coral bleaching in 2016 (Madduppa et al., 2020) and (Haapkylä et al., 2007), which presents challenges for fishers in capturing fish. This decline in coral health not only threatens marine biodiversity but also disrupts the livelihood of local communities that depend on fishing for their sustenance. As fish populations dwindle due to these environmental stressors, the economic stability of these communities is increasingly at risk, prompting urgent calls for sustainable practices and conservation efforts.

Fishers recognized climate change based on indications of seasonal changes (53%). They presumed uncertainty in wind direction and speed (64%) was the primary factor behind climate change. The effects observed include the degradation of coral reef ecosystems (61%) and an increase in sea levels (29%), which took place in the last two years. Moreover, 14% indicated they started experiencing the event more than ten years ago. According to the gathered data, approximately 10% of respondents indicated that they did not recognize any concerns related to climate change (Table 2). Skepticism and perceived self-efficacy influence the perception of low climate change risk (Maltby et al., 2021).

Table 2. The Perception of fishers on Climate changes (CC)

No	Issues	Indicators	% of respondent
1	Knowledge about CC	Increasing Greenhouse gases	7
		Shifting season	53
		Weather changes	29
		Don't know	11
2	The main reason for CC	Air temperature	22
		Rainfall rates	7
		Weather	64
		Sea level rise	7
3	Impact of CC	Sea level rise	29
		Destruction of coral reefs	32
		Decline marine healthiness	29
		Don't know	9
4	Since when (years ago) change in the region	2 years	55
		5 years	31
		10 years	8
		> 10 years	6

3.3.2 The impact on fishing and social vulnerability

In term of the impact of CC to fishing activities identified in their reduce catch (58% of the respondents) (Table 3). The impact on fish cathch was further perceived as the results of uncertainties in the several climatic parameters, such as the wind direction and waves indicate the uncertainty of the seasonal cycle (73% of the respondnent) and weather condition (21% of the respondents). Small number of respondents also perceived other climatic parameters, such as temperature and rainfall rates, to impact production activities. The shifts in those climatic parameters were perceived to have affected the fishing activities only from a few years ago, with the majority of respondents observing the changes since the last 2 to 5 years (from when this study was conducted). Several actions have also been taken by communities in Wakatobi to address the challenges in fishing activities, such as exploring new fishing grounds (55% of respondents), increasing fishing trips (27% of the respondents), and changing or modifying fishing gears (12% of the respondents).

Table 3. Perceived challenge of CC to fishing and social vulnerability

No.	Perceived challenges	Indicators	% Respondent
1.	The impact of CC on the harvesting system	Decreased catches	58
		Shift in time/frequency of activities	15
		Need to explore alternate fishing spots	21
		Don't know	7
2.	Climatic parameters perceived to affect production activities	Wind direction and waves	73
		Temperature	4
		Weather	21
		Rainfall rates	2
3.	When the effect of CC became a challenge in fishing	2 years	60
		5 years	27
		10 years	8
		> 10 years	5
4.	How to address the diminishing of CC	Gear changes/modification	12
		Explore new fishing spots	55
		Increasing fishing trips	24
		Don't know	9

In terms of the direct impact on income and livelihoods, the respondents revealed that the challenges faced in fishing activities contributed to the low income that the fishers get through fishing activities. The majority of respondents (56%) reported that they earned less than IDR 2 million per month during the peak season, which is lower than the provincial minimum wage of Southeast Sulawesi (IDR 2.75 million per month) (Governor decree of South East Sulawesi no. 646/2023); Whereas during the low season, their income were generally reduced with 91% of respondents received income below the minimum wage (Table 4). This variability in income highlights the challenges faced by local communities, particularly during times of economic strain. To supplement their income, many individuals explore diverse livelihood options, such as seasonal fishing or tourism-related activities. However, when these alternative options were not available, small number of community members were forced to migrate or look for work outside their islands (8% of the respondents).

Table 4. The impact of CC to livelihood

No	Perceived challenges	Values/Options	% Respondent
1	Income at peak season (million IDR/month)	< 1	11
		1 - 2	45
		2 – 5	35
		5 – 10	9
2	Income during famine (million IDR/month)	< 1	39
		1 - 2	52
		2 – 5	3
		5 – 10	6
3	How to overcome the lack of income due to CC	Seeking extra income	67
		Switch careers	19
		Migration	8
		Don't know	6

This search for alternative livelihoods often leads to conflicts over resource use, impacting not only the local economy but also community cohesion. As these coastal communities adapt to changing conditions, the need for sustainable practices and support from local governments becomes increasingly crucial to ensure their resilience and long-term sustainability.

3.4. Ecological vulnerability

The reef habitat forms a complex marine ecosystem. Among its many functions, the reef habitat provides environmental services such as shelter and coastal protection (Cesar, 2002), reduces the accumulation of flooding land, supports numerous species with medicinal value, and sustains human life and livelihood, particularly for coastal communities that rely heavily on marine living resources (Miththapala, 2008). Previous studies indicate a wide range of ecological conditions across the coral reef sites in Wakatobi waters, which led to a considerable spread in the composite ecological vulnerability index (Madduppa et al., 2020) (Purwanto et al., 2014). Ocean acidification and rising seawater temperature (SST) occur globally, affecting life history parameters, species distribution, and fishery production (Seggel and Young, 2016).

The coral reef within Wakatobi National Park, situated in the Indonesian Coral Triangle, represents a crucial marine ecosystem with ecological and economic significance. However, the combined impact of human activities, pollutants, and anthropogenic-induced climate change poses a potential threat to the biophysical resilience of this coral reef environment. They used the Maximum Entropy (MaxEnt) method with the Habitat Suitability Model (HSM) algorithm. This methods considers such factors as temperature, salinity, current, chlorophyll, particulate organic carbon, particulate inorganic carbon, nitrate, phosphate, and UV penetration. The model's predictions indicate that anticipated changes in environmental quality due to climate change forecast a decline in conditions conducive to optimal coral reef life (Januar et al., n.d.). Currently, around 578.5 km^2 of water is labelled as "suitable," and 69.7 km^2 is classified as "very suitable" for supporting optimal reef life. However, projections under Representative Concentration Pathways (RCP) 2.6-8.5 suggest a significant reduction in the suitable area. The region categorized as a "very suitable" environment is expected to vanish, and the "suitable" category is estimated to decrease to approximately 487.9 to 550.6 km^2 (Januar, H. I. et al., 2025)

Because the reef conditions are similar to those on Komodo Island, previous report predicted that the coralfish species in the area would be ecologically vulnerable (Oktaviani et al., 2021). This means that snapper and grouper species are highly vulnerable to the changes that happen in the coral reef environment. Studies on the climate change impact on small pelagic and highly migratory species in the area are scarce. However, a series of fisheries data (Puspasari et al., 2019) on the impact of climate variability on sardine fisheries in the Bali Strait revealed that severe climate condition tends to delay the composition of the catch. The alterations in catch composition became evident between 1 and 3 years following the extreme climate events. Specifically, temperature shifts had a direct influence on sardine yields. While sardines continued to be the predominant species in the catch, their relative abundance within the catch diminished, leading to an overall decline in total catch. Diminished sardine yield in their absence, particularly around 2010, altered the overall fish catch composition (Puspasari et al., 2019).

Climate disturbances in the Southern Benguela and Agulhas Bank ecosystems off South Africa (Ramírez et al., 2022) and the Beibu Gulf in the northwestern part of the South China Sea (Zhang et al., 2022) could significantly affect most pelagic fish resources, according to several similar studies in other tropical waters (Kay et al., 2023). These findings underscore the vulnerability of pelagic fish populations to environmental changes, highlighting the need for adaptive management strategies. As climate variability continues to intensify, ongoing research will be crucial for understanding these dynamics and mitigating impact on fisheries and local communities dependent on these resources.

The WNP strictly managed the capture fisheries operation based on limited harvesting activities. The law refers to Law No. 5 of 1990 concerning the Conservation of Biological Natural Resources and their Ecosystems (Clifton, 2013) (Abdullah et al., 2019) and local government Wakatobi regulation No. 62/2020. All destructive fishing systems were prohibited. However, local fishers typically harvest several species of small pelagic fish (scads and mackerel), coral fish (snappers and groupers), and some highly migratory species (tuna and tuna-like species).

The dominant landing volume of capture fisheries is small pelagic fish, contributing 43% of the total volume of marine fish (Fig. 2). Within this category, the most commonly caught species is the mackerel scad. The demersal group taxa, which account for 31% of the overall catch, is characterized by economically valuable species such as snappers, groupers, emperors, and rabbitfish. Reef fish and large pelagic fish contribute 12% to fisheries production. Production from these various groups highlights the importance of marine ecosystems in supporting both local economies, particularly food security. Sustainable management practices are crucial to ensure the health of these fish populations and the longevity of their livelihoods.

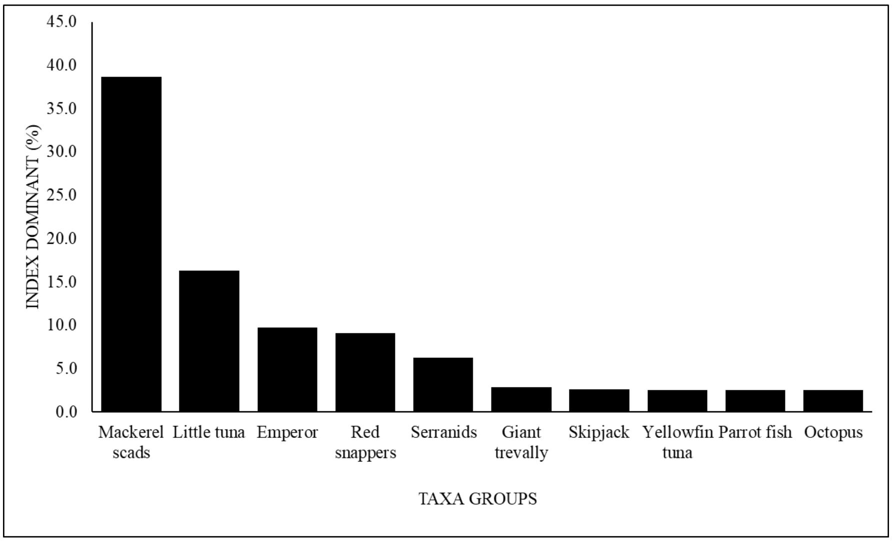

Fig 2. The dominance index of landing volume by taxa groups

We identified eight types of fishing gear, each designed for specific taxa, based on interviews and existing fisheries data. Purse seine fishing gear landed the most fish, followed by troll lines, handlines, and gill nets, primarily targeting pelagic fish in offshore waters. The use of additional fishing gear results in comparatively lower catches, especially at the bottom of the coral waters (Table 5). The diversity in types and configurations of fishing gear contributes to exploring alternative livelihoods, showcasing fishermen's resilience in addressing the challenges posed by climate change. This adaptability not only helps sustain fish populations but also supports local economies dependent on these resources. Consequently, fostering innovative fishing practices and promoting sustainable management strategies are essential for ensuring the long-term viability of both fisheries and coastal communities.

Table 5. The dominance indices by taxonomic group of fish landing and the diversity related gear.

TAXA GROUP	%	GEAR DIVERSITY							
		Purse seine	Hand line	Gill net	Troll line	Spear gun	Bottom long line	Squid jigging	Pots/traps
Mackerel scads	38.6	x							
Little tuna	16.3	x							
Emperor	9.7					x			
Red snappers	9.1					x	x		
Serranids	6.2					x			x
Giant trevally	2.8		x				x		
Skipjack	2.6	x			x				
Yellowfin tuna	2.6	x	x		x				
Parrot fish	2.5					x	x		
Octopus	2.5								x
Rabbitfish	1.8	x	x	x					

This adaptability not only sustains fish populations but also supports local economies that rely on these resources. Consequently, fostering innovative fishing practices and promoting sustainable management strategies are essential for ensuring the long-term viability of both fisheries and coastal communities. By implementing collaborative approaches that involve fishermen, scientists, and policymakers, stakeholders can develop comprehensive plans that balance ecological health with economic growth. This unified effort not only protects marine biodiversity but also enhances the resilience of local communities against environmental changes.

3.5. The climatic parameters

The available data identified rain, wind, and temperature as the three physical variables that have undergone the most significant change over the years. However, fishers' perception of climate change may coincide with their perception of long-term changes in meteorological variabilities in Wangi-Wangi Island and surrounding waters. Plotting the long-term land-based surface temperature analysis could also illustrate the climate drivers (Liu et al., 2021). We derived limited data and information about climatic elements from the BMKG Beto Ambari data. The surface land maximum temperature tends to increase gradually from 1998 to 2022, and the minimum temperature decreases in the same period (Fig. 3). This trend indicates a shift in the island's climate pattern, potentially impacting local ecosystems and communities. Understanding these changes is crucial for developing adaptation strategies.

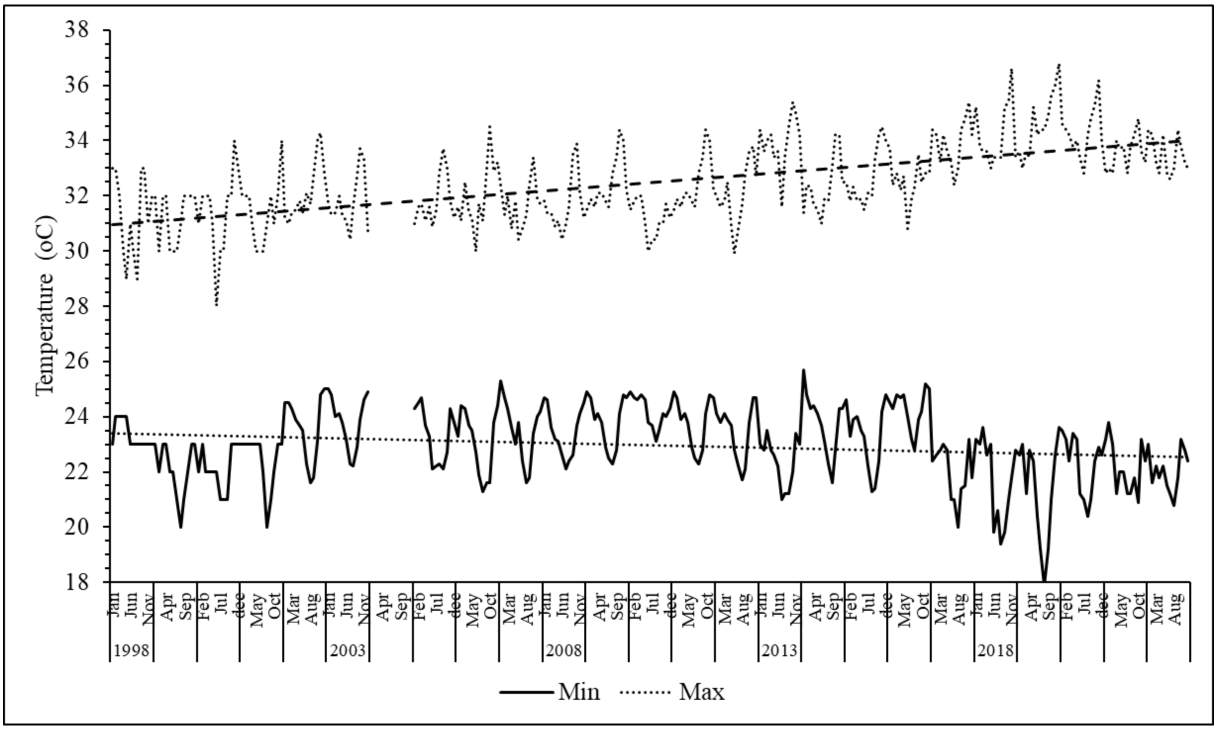

Fig 3. The maximum and minimum trend of land-based temperature (°C) in Betoambari weather station.
Source: BPS South-east Sulawesi province 1998–2010; BPS Wakatobi Regency 2010–2022

Adaptation strategies must consider not only the rising temperatures but also the potential for increased frequency of extreme weather events. By prioritizing sustainable practices and enhancing communities resilience, stakeholders can better prepare for the challenge posed by these evolving climatic conditions

Previous studies show that, over the past three decades, the seas surrounding Indonesia have undergone a warming trend of about 0.18°C per decade, resulting in a total increase of over half a degree Celsius (Kaczan et al., 2023). Projections indicate that, under a low global emissions scenario, sea surface temperatures will rise by 1.39 ± 0.39 °C, and under a high global emissions scenario, the increase will be 3.68 ± 0.86 °C by the end of the century compared to the period 1850-1900. Short-term and localized extremes will intersperse this prolonged warming pattern (Kaczan et al., 2023). By 2050, it can be expected that marine heatwaves, characterized by temporary spikes in ocean temperature, to extend from 1-6 months to 11-12 months, on a global scale, there is information about the impact of climate change on coastal habitats (Kaczan et al., 2023).

2019 was an El Niño year that followed a period of active El Niño from September 2018 to July 2019 in the Central Pacific Ocean. Transitioning into mid-2020, particularly in April, conditions shifted toward La Niña, which gained strength from October to December 2020. La Niña weakened in mid-2021 but re-strengthened to a moderate level from the end of 2021 through 2022 (Fig. 4). The occurrence of La Niña in these consecutive years is an unusual phenomenon known as triple-dip La Niña (Shi et al., 2023). This extended La Niña event has significant implications for aquatic biota due to the prolonged rising sea surface temperatures during La Niña, affecting the life of various aquatic organisms, including fish.

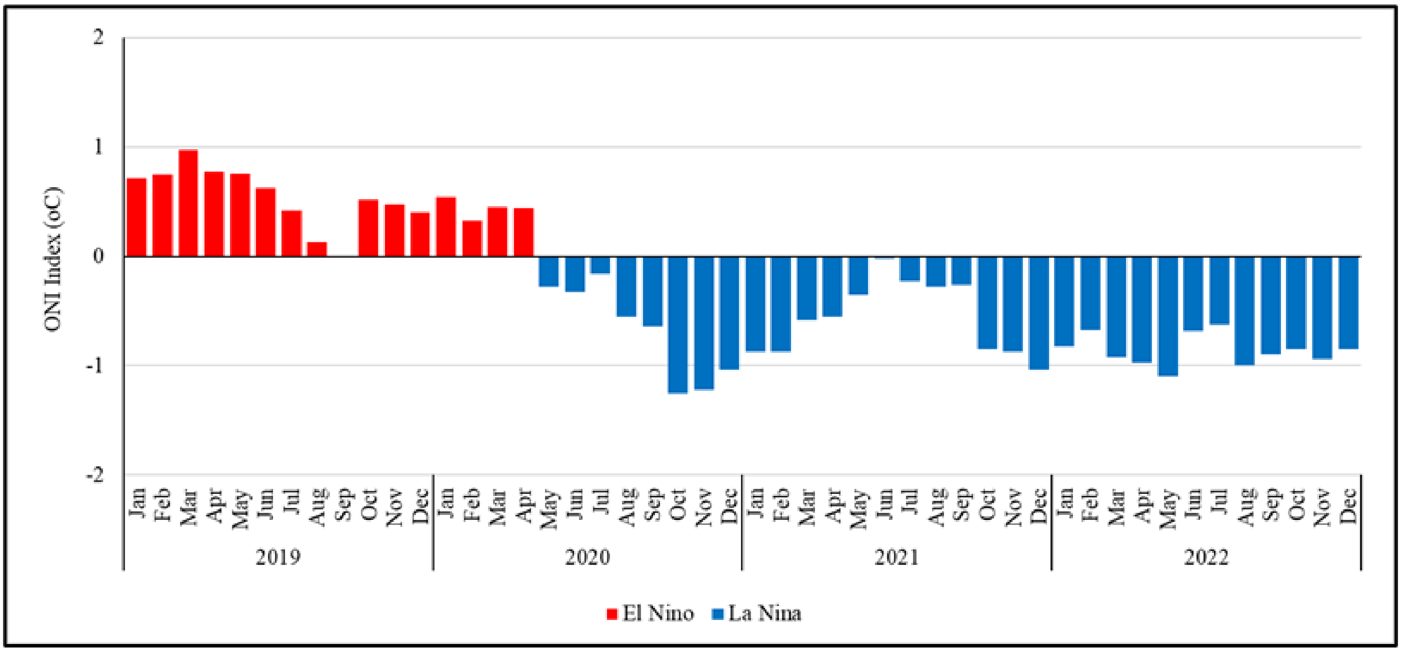

Fig 4. Development of the ENSO index on 2019–2022.
Source: https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/nino34.long.anom.data

Coastal habitats are at risk from direct (temperature, rainfall) and indirect (sea-level rise, coastal erosion) impacts due to a changing climate (Dong et al., 2024). Beyond the environmental impacts and resulting habitat loss, the changing climate will significantly impact coastal communities, affecting everything from health to livelihoods and the loss of essential ecosystem services like coastal defense. This is especially relevant given the predicted increase in storminess (Burden et al., 2020).

Several studies demonstrate small pelagic species' sensitivity to El Niño Southern Oscillation (ENSO) fluctuations, such as sardinella distribution along the northwest African coast (López-Parages et al., 2020). These systems are susceptible to global climate change and variability. Oceanographic factors greatly influenced the brief lifespans of small pelagic fish, such as sardines, herrings, and anchovies. As a result, they are susceptible to shifts in fishing patterns attributed to climate change (Pincinato et al., 2020).

We have observed interseasonal, interannual, and spatial variability in rainfall and wind speed trends in the area, and the success of crop plantation and fishers' harvesting patterns could significantly influence their daily livelihood. The rainfall rates in the area based on weather station Betoambari data from 2005 to 2022 show that four significant peaks occurred in 2007, 2011, 2017, and 2022, and five minor peaks occurred in 2005, 2009, 2019, and 2023 (Fig. 5).

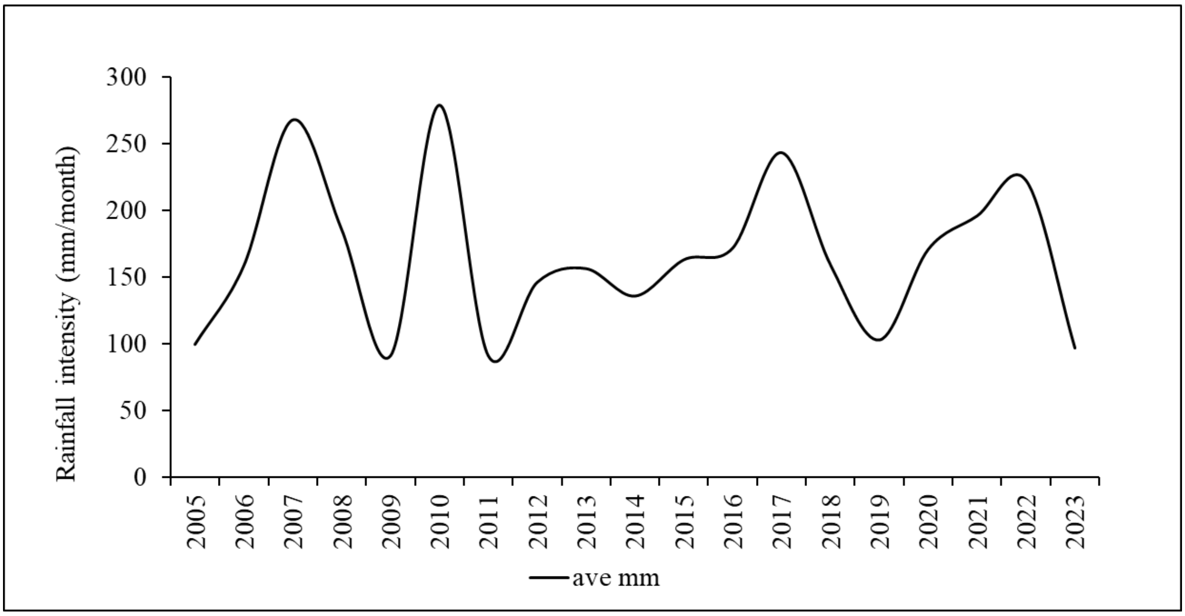

Fig 5. The annual rainfall intensity (mm/year) (2005–2023) in Beto Ambari.
Source: BPS South-east Sulawesi Province (2005–2010) and Wakatobi Regency (2011–2023).

The average monthly rainfall over the previous five years reveals a distinct pattern, particularly from July to October. This observation aligns with the insights of fishermen regarding shifts in rainfall patterns, recognized as one of the indicators of climate change (Fig. 6). As the rainfall increases during these months, it not only affects local ecosystems but also influences fishing practices and the livelihood of those who depend on aquatic resources. Understanding these shifts is crucial for developing adaptive strategies to mitigate the impacts of climate variability on both the environment and the economy.

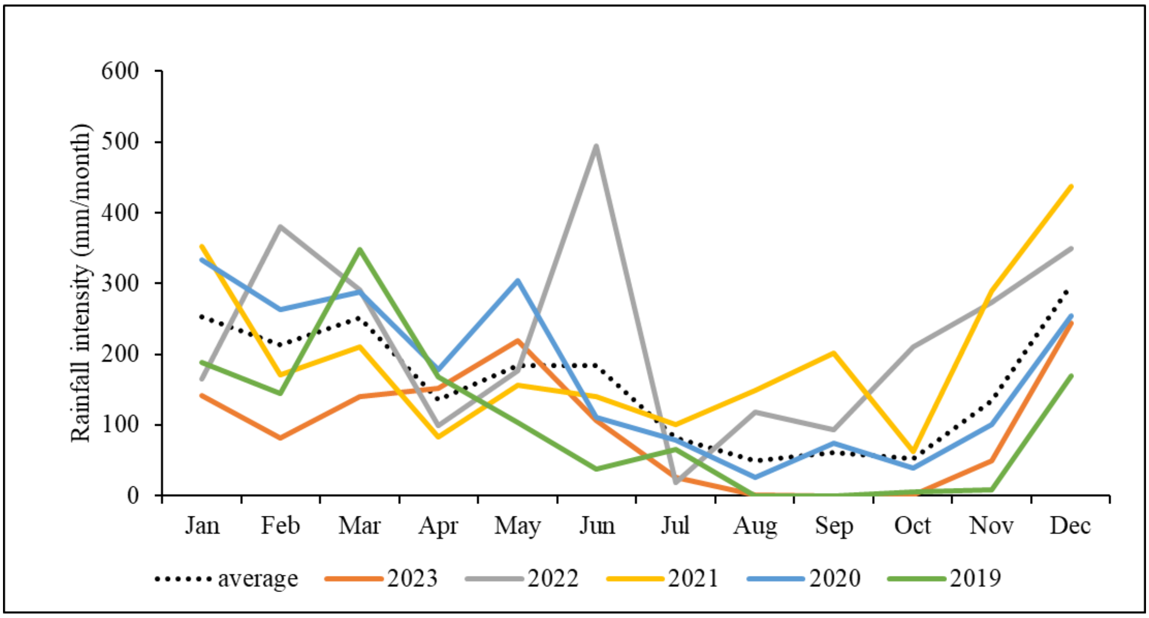

Fig 6. The monthly average of rainfall intensity by year (2019–2023) in Beto Ambari.
Source: BMKG https://dataonline.bmkg.go.id/data-harian

The rainfall graph resembles a wave with alternate cliffs and troughs oscillating irregularly. Surprisingly, there is a time-lapse of 4 to 6 years between significant peaks, probably indicating a pattern of such duration on the island. Over recent decades, variations in rainfall patterns have been evident across Asia, with some regions noting a decline in average yearly precipitation. This includes Northeast and North China coastal areas, dry plains in Pakistan, certain parts of Northeast India, Indonesia, the Philippines, and specific regions in Japan (Sriskanthan and Funge-Smith, 2011). Rainfall patterns influenced the extraction of terrestrial edible biodiversity, which includes crop yield in mountainous regions (Poudel and Shaw, 2016) and the local farming system in Northeast Thailand (Lacombe et al., 2017). Previous research has undertaken various studies on the effects of climate change on Indonesia's coastal environment. Rising sea level in Indonesia could potentially impact climate change in coastal areas due to global warming (Zikra et al., 2015) (Munawaroh et al., 2018). This phenomenon occurs on Wangi-Wangi Island, as informed during the interview. Table 2 lists the general findings of fishers' perceptions of climate change along with related scientific findings.

Comparable situations arise in wind speeds, with August 2023 exhibiting a relatively high level compared to 2020-2022 but aligning closely with the conditions observed in 2019 (Fig. 7). The inconsistency in the rainy season and wind speed disrupts the regularity of their fishing activities, as revealed by the interview results. Coastal communities in the study area profoundly understand natural indicators crucial to their daily livelihoods.

The Beaufort Scale, formally known as the Beaufort wind force scale, is a practical gauge that establishes a correlation between wind speed and the corresponding observed conditions at sea or on land (https://www.rmets.org/metmatters/beaufort-wind-scale). Below is a table featuring the Beaufort Scale, providing speeds in knots, miles per hour, and kilometers per hour. Notably, these speeds represent mean values, typically averaged over 10 minutes by convention, and do not encompass wind gust speeds. Weather and news reports also reference the wind speeds presented in Table 6. Using the fishers' knowledge, we predicted the wind speed and maximum wave height at 1.0-1.5 m, which resulted in a maximum sea state of 3. However, we still tolerated fishing activity and converted the information using the Beaufort scale (Table 6).

Daily operation of small-scale fisheries typically employed fishing boats with an overall length (LOA) of about 10 m. Small fishing vessels navigate the sea under challenging wave conditions, leading to significant motion amplitudes that can impair or restrict the vessel's operational capabilities. Essentially, when a small ship travels through actual sea areas during unfavorable weather, it becomes susceptible to hull damage and heightened risks to human life due to wave impacts and excessive acceleration. Moreover, the response characteristics of the ship are entirely contingent on the nature of the waves (Im and Lee, 2022). Based on weather station records, the average wind speed over a decade ranged from 1.5 to 2.5 knots (Fig. 8), with a maximum of 3.5 knots, or sea state 2. This elevated sea state poses a limitation on the fishing capacity of fishers.

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Table 6. The Beaufort scale, wind speed and sea state.

Wind Force	Description	Wind Speed			Specifications	Probable Wave Height		Sea State
		km/h	mph	knots		metres	Max	
0	Calm	<1	<1	<1	Smoke rises vertically. Sea like a mirror	--	--	0
1	Light Air	1–5	1–3	1–3	Direction is shown by smoke drift but not by wind vanes. Sea rippled	0.1	0.1	1
2	Light Breeze	6–11	4–7	4–6	Wind felt on face; leaves rustle; wind vane moved by wind. Small wavelets on sea	0.2	0.3	2
3	Gentle Breeze	12–19	8–12	7–10	Leaves and small twigs in constant motion; light flags extended. Large wavelets on sea	0.6	1.0	3
4	Moderate Breeze	20–28	13–18	11–16	Raises dust and loose paper; small branches moved. Small waves, reasonably frequent white horses	1.0	1.5	3–4

Source: https://www.rmets.org/metmatters/beaufort-wind-scale

Nevertheless, the uncertainties surrounding monthly wind speed and wave height also impact their understanding of seasonal patterns. Some fishers believe a vessel's flag flying at an angle greater than 45 degrees is a warning for sea safety. Many fishers assert that uncertainties in weather conditions have emerged since two years ago (Fig. 8), leading to unpredictable peak fishing seasons and impacting the knowledge traditionally passed down from generation to generation. This has prompted them to reconsider their traditional fishing systems, highlighting the potential benefits of readily available weather information to enhance their capacity to adapt to natural phenomena.

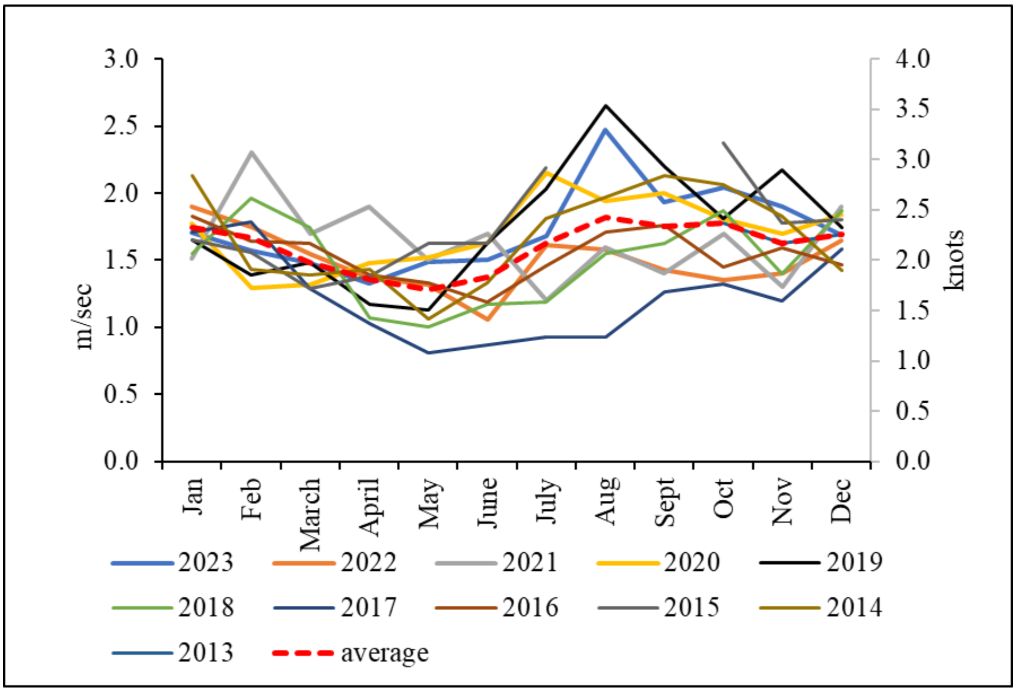

Fig 7. The monthly wind speed from 2013–2023 in Beto Ambari.
Source: BMKG https://dataonline.bmkg.go.id/data-harian

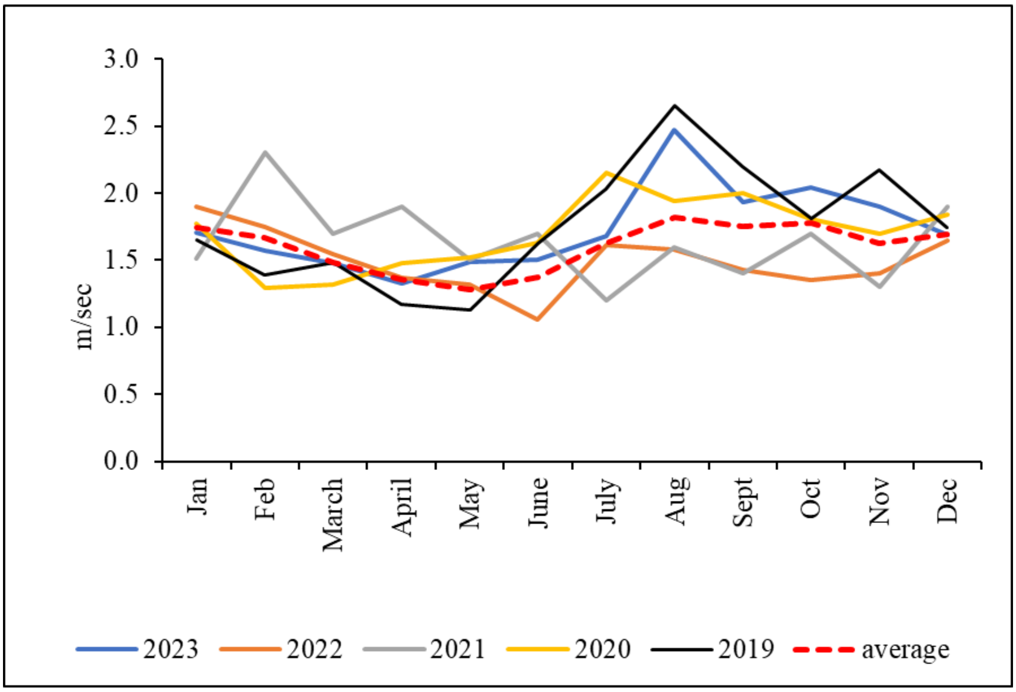

Fig 8. The monthly wind speed for the last five years in Beto Ambari.
Source: BMKG https://dataonline.bmkg.go.id/data-harian

Fishers adapt to discerning winds in relation to cardinal directions North, South, East, and West. Some even associate the winds with specific times or seasons. For instance, the west wind prevailing from September to November is robust and dissuades fishers from venturing into the open sea. If caught mid-sea during an unexpectedly strong westerly wind, fishers seek refuge behind islands until the weather subsides. The transition between cardinal directions West to North, North to South, South to East, and East to North is unpredictable. Continuous rainfall and tumultuous weather prevail during months dominated by North and West winds. The resulting large waves make it challenging for fishermen to embark on sea journeys. The North Wind, prevailing from December to February, brings rain and occasionally cool temperatures. Despite the cooler weather, fishermen still venture to sea during this period, although the fish tend to be unresponsive to bait, possibly due to the cold blowing wind. Table 7 lists the general perception and knowledge indicators of climate change accompanied by scientific findings.

Table 7. Comparison of climate perceptions of fishers (*n* = 111) with the related scientific findings.

Climatic variables	Climate perceptions of senior fishers	National/local indicators on climate impact	Conformity to this study
Sea-level rise	Fishermen possess limited knowledge about the LEK factors, but regular coastal floods occur.	(Zikra et al., 2015), compiling various studies and indicating the sea level rise phenomenon in the coastal waters of Indonesia	Agree
Coastal erosion	Slightly occurred in recent years.	(Solihuddin et al., 2021) stated that two decades of observation indicated shoreline changes in Java's north coast.	Agree
Temperature	Slightly perceived	The weather station Beto Ambari showed that the maximum temperature data for 1998–2022 slightly increased while the minimum decreased. This could potentially impact the likelihood of successful fishing.	Not fully agree
Rainfalls	This trend is becoming uncertain and unpredictable due to the shifts in monsoon patterns.	The weather station of Beto Ambari showed that the trend of rainfall rates and the number of rainy days slightly increased.	Mostly agree
Wind	The shifting monsoonal cycle occurs.	The weather station of Beto Ambari showed the shifting peak of annual wind speed.	Mostly agree

3.6. The adaptation strategy

Since 1997, the WNP has implemented a zoning system, periodically adjusting it to align with current requirements and adhere to ecological and conservation principles. The decree of the Director General of Nature Resources and Ecosystem Conservation defined six categories of national park zoning in 2007. Most of the waters around Wangi-Wangi Island fall under the category of local use areas, allowing traditional development and utilization by the community, albeit with limitations to fulfill their needs. This region boasts abundant marine resources, including coral reefs with diverse marine biodiversity, presenting potential for local communities in terms of capture fisheries (Purwanto et al., 2012). Additionally, (Darman. et al., 2021) identified 30 marine tourism destinations along the coast of Wangi-Wangi Island that can contribute to community and regional income.

To address the adverse effects of climate change, Wakatobi National Park and the Wakatobi Regency Government have implemented various initiatives, including conservation and rehabilitation programs, capacity building, and ecosystem monitoring, as indicated by the findings from FGD. The respondents disclosed that the government's response to climate change included conservation and rehabilitation programs (32%) and technical ecosystem monitoring (55%); they attributed the assistance they received to the impact of climate change. Remarkably, the majority of respondents (57%) were not aware of the government assistance. However, some respondents (43%) reported receiving assistance in the form of GTequipment, financial support, and daily basic needs (43%) (Table 8). This discrepancy in awareness reveals a potential gap in communication between the government and the communities affected by climate change. The government may need to intensify its outreach efforts to tackle this issue, making sure all residents are aware of the resources and programs available for their support.

Table 8. The government initiatives related to climate change mitigation and adaptations

No.	Initiatives	Focus of the Program	% of respondent participated
1	Trainings and engagement in initiatives related to CC	Alternative income source	11
		Conservation and rehabilitation of habitat	32
		Capacity building (skills improvement)	2
		Ecosystem monitoring	55
2	Direct assistance received to support livelihood	Fishing equipment	28
		Direct Funding	8
		Supply basic needs	6
		Don't know / never heard of such programs	58

Among these, coastal communities in the Wakatobi Biosphere Conservation Area have predominantly benefited from capacity-building programs. Additionally, government-provided equipment assistance emerges as the most widely received support. Current climate variability and future expectations presents the primary challenge of enhancing development to adapt to local resource management and national agreements, with the aim of promoting the adaptive capacity of competing sustainable development objectives (Adger et al., 2003; Tomokins and Adger (2004). Human interference, mainly stemming from urban development and agricultural expansion, significantly influences natural processes in coastal areas. This interference modifies the processes and functioning of ecosystems, leading to coast transformations and an increased risk of natural hazards (Capobianco and Stive, 2000) (Silva et al., 2019). The repercussions extend to the lives of people residing in these coastal areas.

Coastal ecosystems play a crucial role in providing various benefits to human communities. These benefits include the providing habitat, support for tourism, scenic beauty, recreational opportunities, sustenance of SSF, climate regulation, carbon storage, coastal water filtration, job creation, and contributions to ocean economies. Additionally, these ecosystems reduce the risk of flooding and, in certain instances, facilitate adaptation to a changing climate (Everard et al., 2010) (Barbier et al., 2011). Recognizing the multifaceted contributions of coastal ecosystems underscores the importance of sustainable practices and management to balance human needs with preserving these vital natural environments.

4. Conclusion

We have captured the experience and fishers' perception of climate change from fishing communities on the west coast of Wangi-Wangi Island within Wakatobi National Park. Most fishers are aware of climate change issues based on the information gathered such as their observation on changing seasonal pattern that eventually affect their fishing activities. This finding challenges the conventional belief that fishermen are progressively finding their LEK irrelevant in the context of climate change. Consequently, enhancing adaptive capacity implies the importance of considering fishers' perceptions and expectations, highlighting a significant necessity for scientific support through appropriate channels to address the impacts of climate change. Fishers convey a sense of uncertainty regarding the sustainability of their profession for future generations. The challenges they encounter in being involved in governance intensify this uncertainty, adversely impacting their job opportunities and income. Encouraging community participation in decision-making serves as a means to foster ownership and offers optimism for potential solutions.

Credit authorship contribution statement

D. Oktaviani: Conceptualization, Formal Analysis, Writing–original draft, Project administration, Supervision & Funding acquisition. D. Nugroho: Conceptualization, Data curation, Writing–review & editing. C. B. Wiati: Conceptualization, Writing–review & editing. H. I. Januar: Conceptualization, Data curation, Writing–review & editing. Y. Purwanto: Conceptualization, Writing–review & editing. R. Puspasari: Conceptualization & Writing–review & editing. R. A. Purnamasari: Providing Map of site location. Radisti Ayu Praptiwi: Writing - Review & Editing.

Data availability

Data will be made available on request.

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