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Abstract

Purpose: The aim of the study was to assess the effects of marine heatwaves on fish population dynamics in coastal ecosystems.

Methodology: This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

Findings: Marine heatwaves (MHWs) have significant and multifaceted impacts on fish population dynamics in coastal ecosystems. These prolonged periods of unusually high sea temperatures can disrupt the delicate balance of marine environments, leading to adverse effects on fish species. One of the primary consequences of MHWs is the alteration of habitat conditions, which can result in shifts in species distribution as fish migrate to cooler waters. This migration often leads to changes in community composition and the displacement of both native and commercially important species. Moreover, MHWs can directly affect the physiological processes of fish, including growth, reproduction, and survival rates. Elevated temperatures can increase metabolic rates, leading to higher energy demands that may not be met if food resources are limited, ultimately affecting fish health and population sustainability. Additionally, MHWs can exacerbate the prevalence of diseases and parasites, further stressing fish populations. The impacts on juvenile fish are particularly concerning, as the survival rates of larvae and juveniles are critical for population replenishment. Warmer waters can disrupt spawning cycles and reduce the availability of suitable nursery habitats, leading to lower recruitment rates. These changes can have cascading effects on the entire marine food web, affecting not only fish populations but also the predators and prey that rely on them.

Implications to Theory, Practice and Policy: Climate change theory, ecosystem resilience theory and biogeography theory may be used to anchor future studies on assessing effects of marine heatwaves on fish population dynamics in coastal ecosystems. Fisheries managers and practitioners should prioritize the implementation of adaptive management strategies that account for the dynamic nature of marine ecosystems influenced by climate change. Policymakers must urgently recognize the implications of marine heatwaves on fish population dynamics within the broader framework of climate change adaptation and mitigation.

Keywords: *Marine Heatwaves, Fish Population, Coastal Ecosystems*

INTRODUCTION

Marine heatwaves (MHWs) are periods of unusually high ocean temperatures that persist for extended durations, often with devastating effects on marine life and ecosystems. Fish population dynamics in developed economies, such as the USA, Japan, and the UK, have shown significant trends in species abundance and diversity due to advanced fisheries management and environmental policies. In the USA, marine fish populations have been recovering due to the implementation of the Magnuson-Stevens Fishery Conservation and Management Act. For instance, the Gulf of Maine cod population has seen fluctuations, with biomass estimates rising from 10,000 metric tons in 2014 to approximately 15,000 metric tons in 2018, reflecting effective management practices (NOAA Fisheries, 2019). In Japan, the population of Pacific bluefin tuna has increased due to stringent catch limits, with spawning stock biomass increasing from 17,000 metric tons in 2014 to over 30,000 metric tons in 2019 (Japan Fisheries Agency, 2020). The UK has also reported an increase in the diversity of fish species in marine protected areas, contributing to overall ecosystem resilience (Marine Management Organisation, 2021).

In Brazil, the introduction of no-take zones in coastal areas has led to a significant rebound in fish populations, with biomass increasing by 25% in protected areas over five years (Brazilian Institute of Environment and Renewable Natural Resources, 2020). Meanwhile, in Bangladesh, improved regulation of fishing practices in the Sundarbans mangrove forest has resulted in a 15% increase in the abundance of key species like the hilsa shad and various prawns (Bangladesh Fisheries Research Institute, 2019). These examples illustrate the potential for recovery and sustainable management of fish populations through concerted efforts and appropriate policy measures in developing

India's hilsa fish population in the Ganges River has faced a 20% decline over the past decade, largely due to overexploitation and habitat loss (Central Inland Fisheries Research Institute, 2020). However, some positive trends have emerged due to improved management practices. In the Philippines, community-based fisheries management initiatives have led to a 10% increase in fish biomass in certain coastal areas, demonstrating the effectiveness of localized management strategies (Bureau of Fisheries and Aquatic Resources, 2018). In Vietnam, the implementation of marine protected areas has contributed to a gradual recovery of certain fish stocks, with an increase in species diversity and abundance noted in monitored regions (Vietnam Fisheries Society, 2021).

Efforts to combat the decline in fish populations in developing economies have included various measures such as catch limits, habitat restoration, and community engagement in conservation efforts. In Brazil, the introduction of no-take zones in coastal areas has led to a significant rebound in fish populations, with biomass increasing by 25% in protected areas over five years (Brazilian Institute of Environment and Renewable Natural Resources, 2020). Meanwhile, in Bangladesh, improved regulation of fishing practices in the Sundarbans mangrove forest has resulted in a 15% increase in the abundance of key species like the hilsa shad and various prawns (Bangladesh Fisheries Research Institute, 2019). These examples illustrate the potential for recovery and sustainable management of fish populations through concerted efforts and appropriate policy measures in developing economies.

In developing economies, fish population dynamics are often influenced by overfishing, habitat degradation, and inadequate fisheries management. For example, in Indonesia, overfishing has led to a significant decline in reef fish populations, with a decrease in biomass from 30 metric tons per square kilometer in 2005 to 20 metric tons per square kilometer in 2018 (Ministry of Marine Affairs and Fisheries, 2019). Similarly, in India, the population of hilsa fish in the

Ganges River has declined by 20% over the past decade due to overexploitation and habitat loss (Central Inland Fisheries Research Institute, 2020). However, some regions have seen improvements; for instance, in the Philippines, the introduction of community-based fisheries management has led to a 10% increase in fish biomass in certain coastal areas (Bureau of Fisheries and Aquatic Resources, 2018). These examples highlight the challenges and progress in managing fish populations in developing economies.

In addition to the countries previously mentioned, several other developing economies are experiencing notable trends in fish population dynamics. In Sri Lanka, marine fisheries have seen mixed outcomes due to varying degrees of regulatory enforcement and habitat protection. The biomass of coastal fish species has declined by 15% over the past decade, primarily due to overfishing and habitat degradation; however, areas with established marine protected areas have recorded a 10% increase in fish biomass, indicating the potential benefits of conservation efforts (Sri Lanka Department of Fisheries, 2020). In Peru, the Humboldt Current system supports a highly productive fishery, but overfishing and environmental variability have led to fluctuations in fish populations. The anchoveta fishery, for example, experienced a significant decrease in biomass from 10 million metric tons in 2014 to 6 million metric tons in 2018, reflecting the impacts of both fishing pressure and El Niño events (Peruvian Ministry of Production, 2019). Efforts to implement stricter catch limits and closed seasons are ongoing to stabilize the population.

In Kenya, the fish populations in Lake Turkana have been under pressure from both environmental changes and overfishing. The tilapia population, a key species for local communities, has declined by 30% over the past two decades due to unsustainable fishing practices and fluctuating water levels (Kenya Marine and Fisheries Research Institute, 2018). Conversely, community-led conservation initiatives have shown promise, with areas under co-management regimes experiencing a gradual increase in fish biomass. In Nigeria, the overexploitation of fish resources in the Niger Delta has resulted in a significant reduction in species diversity and abundance, with some species facing local extinction. However, recent efforts to regulate fishing activities and restore mangrove habitats have started to show positive impacts, with a reported 5% increase in fish biomass in restored areas (Nigerian Institute for Oceanography and Marine Research, 2021).

In sub-Saharan Africa, fish population dynamics are heavily impacted by socio-economic factors, climate change, and limited enforcement of fisheries regulations. In Lake Victoria, shared by Kenya, Tanzania, and Uganda, the Nile perch population has experienced drastic fluctuations, with biomass estimates dropping from 1 million metric tons in the early 2000s to around 300,000 metric tons in 2015, before rising again to 500,000 metric tons in 2019 due to collaborative management efforts (Lake Victoria Fisheries Organization, 2020). In Ghana, overfishing and illegal fishing practices have led to a decline in small pelagic fish populations, with landings decreasing from 200,000 metric tons in 1996 to less than 100,000 metric tons in 2019 (Ghana Fisheries Commission, 2020). Efforts to improve fisheries management, such as the introduction of closed seasons and enforcement of fishing regulations, are beginning to show positive results in some areas, indicating potential for recovery and sustainable management.

Marine heatwaves (MHWs) are prolonged periods of unusually high sea surface temperatures that can drastically impact marine ecosystems. The primary drivers of MHWs include climate change, oceanic and atmospheric circulation anomalies, El Niño-Southern Oscillation (ENSO) events, and localized weather patterns such as persistent high-pressure systems (Smale, Wernberg, Oliver, Thomsen & Harvey, 2019). Climate change has increased the frequency and intensity of MHWs, as rising global temperatures contribute to prolonged warming of ocean waters (Oliver, Benthuysen, Bindoff, Hobday & Pecl, 2021). Oceanic and atmospheric circulation anomalies can cause warm water to accumulate in specific regions, while ENSO events often lead to widespread warming in the Pacific Ocean (Holbrook, Scannell, Sen Gupta, Benthuysen, & Feng, 2020). Localized weather patterns can also induce MHWs by limiting heat dissipation and increasing solar radiation absorption.

MHWs have profound effects on fish population dynamics, particularly in terms of species abundance and diversity. Elevated temperatures can lead to shifts in species distributions, with some species migrating to cooler waters while others face increased mortality rates due to thermal stress (Hobday, Oliver, Sen Gupta, Benthuysen, & Wernberg, 2018). For instance, during the 2013-2016 MHW in the Northeast Pacific, known as "The Blob," there was a significant decline in the abundance of cold-water fish species like Pacific cod, while warm-water species became more prevalent (Cavole, Demko, Diner, Giddings, & Nichols, 2016). Additionally, MHWs can disrupt spawning and recruitment processes, leading to long-term population declines and reduced biodiversity (Caputi, Kangas, Hetzel, Denham, & Pearce, 2019). These impacts highlight the critical need for adaptive management strategies to mitigate the effects of MHWs on marine ecosystems and fish populations.

Problem Statement

Marine heatwaves (MHWs) are emerging as one of the most significant stressors on coastal ecosystems, profoundly affecting fish population dynamics. These prolonged periods of elevated sea surface temperatures disrupt the delicate balance of marine environments, leading to shifts in species distribution, altered community structures, and declines in biodiversity. Fish species that are unable to migrate to cooler waters face increased mortality rates due to thermal stress, resulting in reduced abundance and compromised reproductive success (Caputi, Kangas, Hetzel, Denham & Pearce, 2019). The 2013-2016 MHW in the Northeast Pacific, known as "The Blob," exemplified these impacts by causing a marked decrease in cold-water fish species such as Pacific cod and a concurrent rise in the presence of warm-water species (Cavole, Demko, Diner, Giddings & Nichols, 2016). Additionally, MHWs disrupt spawning and recruitment processes, leading to long-term population declines and threatening the sustainability of fisheries (Holbrook, Scannell, Sen Gupta, Benthuysen & Feng, 2020). Understanding the full extent of MHW impacts on fish populations is critical for developing adaptive management strategies to mitigate these effects and preserve marine biodiversity.

Theoretical Framework

Climate Change Theory

Climate Change Theory postulates that human activities, particularly the emission of greenhouse gases, lead to global warming and significant alterations in climate patterns. This theory emphasizes the cascading effects of increased atmospheric temperatures on various environmental and ecological processes. This theory has been developed and expanded by numerous scientists over decades, with key contributions from climatologists like James Hansen. Understanding the mechanisms of climate change is crucial for studying marine heatwaves, as these events are directly linked to rising ocean temperatures. The theory provides a framework to analyze how global warming exacerbates the frequency and intensity of MHWs and their consequent impacts on fish populations (Hansen, Sato, Ruedy, Lacis & Oinas, 2000).

Ecosystem Resilience Theory

Ecosystem Resilience Theory focuses on the capacity of ecosystems to absorb disturbances, such as extreme temperature events, and still maintain their basic structure and functions. It explores the thresholds beyond which ecosystems can no longer recover, leading to shifts in ecosystem states. C.S. Holling introduced the concept of ecological resilience in the 1970s. This theory is pertinent for examining how fish populations in coastal ecosystems respond to the stress of marine heatwaves. It helps to assess the resilience of different species and the overall ecosystem, providing insights into potential recovery or long-term changes in biodiversity and abundance (Holling, 1973).

Biogeography Theory

Biogeography Theory examines the distribution of species and ecosystems in geographic space and through geological time. It addresses how environmental factors, such as temperature, influence the distribution and abundance of species. Alfred Russel Wallace is considered one of the founders of biogeography. This theory is crucial for understanding shifts in fish species distributions due to marine heatwaves. It provides a framework for predicting which species are likely to migrate, adapt, or face local extinction in response to changing thermal conditions (Wallace, 1876).

Empirical Review

Caputi, Kangas, Hetzel, Denham and Pearce (2019) investigated the impact of the 2016 marine heatwave on the invertebrate fishery in Western Australia. The researchers conducted a comparative analysis of catch data from the fishery before, during, and after the heatwave, utilizing both fishery-dependent data and environmental monitoring. Their findings revealed a significant decline in the abundance of commercially important species, such as the western rock lobster, which experienced reduced catch rates during the heatwave period. The study also noted shifts in the distribution of some species, highlighting the ecological ramifications of increased sea temperatures. To mitigate future impacts, the authors recommended implementing adaptive management strategies that include adjusting fishing quotas and temporary closures during extreme temperature events. They emphasized the necessity for fisheries management to consider climate variability and the increasing frequency of marine heatwaves in their planning. The research provides valuable insights for policymakers aiming to sustain fisheries under changing environmental conditions. Overall, this study underscores the urgency of adaptive strategies in the face of climate change impacts on marine ecosystems.

Hobday, Oliver, Sen Gupta, Benthuysen and Wernberg (2018) explored the categorization of marine heatwaves and their ecological consequences for fish populations across various global regions. The researchers utilized historical temperature data and ecological indicators to identify trends in fish distribution in relation to marine heatwave events. Their analysis revealed that species such as snapper and grouper experienced significant shifts in their range and abundance, with some populations declining sharply due to prolonged exposure to elevated temperatures. The study highlighted the role of marine heatwaves as critical drivers of ecological change, affecting not only individual species but also overall community dynamics. The authors recommended the establishment of monitoring programs to track changes in fish populations as they respond to marine heatwaves. Additionally, they called for flexible management strategies that consider the dynamic nature of marine ecosystems in the face of climate change. This research emphasizes the importance of recognizing and addressing the impacts of marine heatwaves on fisheries and coastal ecosystems. The findings provide a crucial foundation for developing informed management practices aimed at enhancing resilience in fish populations.

Cavole, Demko, Diner, Giddings and Nichols (2016) focused their research on the biological impacts of the 2013-2015 marine heatwave in the Northeast Pacific, known colloquially as

"The Blob." Using a combination of field surveys and remote sensing data, the researchers assessed changes in fish populations throughout the duration of the heatwave. Their findings indicated a notable decline in cold-water species, such as Pacific cod and rockfish, while warm-water species like anchovy increased in abundance during the event. The study underscored the significant ecological consequences of marine heatwaves, revealing how these events can disrupt established community structures. Based on their findings, the authors recommended that fisheries managers incorporate the implications of marine heatwaves into stock assessments to better predict shifts in species composition. They also emphasized the need for strategies that support vulnerable species during periods of extreme temperature. This research highlights the importance of adaptive management practices in the context of climate variability and its effects on marine ecosystems. Overall, this study provides critical insights into the direct biological impacts of marine heatwaves on fish populations.

Holbrook, Scannell, Sen Gupta, Benthuysen and Feng (2020) conducted a comprehensive examination of the drivers and consequences of marine heatwaves on fish populations worldwide. Their research involved analyzing climate models and ecological data to explore the relationship between temperature anomalies and changes in fish community structure across various coastal regions. The study found that marine heatwaves led to significant shifts in community composition, characterized by a decline in biodiversity and an increase in the dominance of thermally tolerant species. These findings underscore the critical implications of marine heatwaves for ecosystem functioning and resilience. The authors recommended implementing ecosystem-based management approaches that integrate climate projections to enhance the resilience of fish populations and ecosystems. By recognizing the impacts of climate change on marine ecosystems, the study emphasizes the need for proactive measures in fisheries management. This research contributes to a broader understanding of how climate change is reshaping marine biodiversity and highlights the necessity for adaptive strategies to safeguard fish populations.

Murray and Le Quesne (2019) investigated the effects of marine heatwaves on the reproductive success of fish species in temperate coastal waters. Through field experiments, the researchers measured spawning success and larval survival rates during periods of elevated sea temperatures. Their results revealed that higher temperatures negatively affected the reproductive output of several key species, including flatfish and herring, leading to decreased recruitment levels. The study highlights the importance of reproductive dynamics in understanding the long-term impacts of marine heatwaves on fish populations. Based on their findings, the authors suggested establishing monitoring programs for spawning periods to identify potential risks associated with marine heatwaves. This approach is critical for developing proactive management strategies to support fish populations during extreme thermal events. Their research emphasizes the interconnectedness of environmental factors and fish reproductive success, underscoring the need for a comprehensive understanding of fish life cycles in the context of climate change. Overall, this study contributes valuable insights into the reproductive implications of marine heatwaves on coastal fish populations.

Siedlecki, Strutton and Zaba (2021) assessed the long-term impacts of marine heatwaves on fish population dynamics in the Southern California Bight. The researchers integrated long-term monitoring data with oceanographic models to analyze the relationship between temperature extremes and trends in fish biomass. Their analysis revealed a significant decline in biomass for several cold-water species, while warm-water species exhibited increases in abundance. The study highlighted the critical implications of marine heatwaves for shifting species distributions and altering community dynamics. Based on their findings, the authors recommended adaptive management strategies that consider both current and projected climate scenarios to enhance the resilience of marine ecosystems. This research underscores the necessity of integrating climate change projections into fishery management practices to better prepare for the challenges posed by marine heatwaves. By recognizing the long-term impacts of thermal extremes on fish populations, this study contributes to a more nuanced understanding of ecosystem dynamics in a changing climate. Overall, this research emphasizes the importance of proactive management in safeguarding the future of coastal fish populations.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

RESULTS

Conceptual Gaps: While existing studies have examined the impacts of marine heatwaves on fish populations, there is a limited understanding of the underlying mechanisms driving these effects. For instance, while some studies have documented shifts in species distributions and biomass changes, there is a need for more comprehensive models that incorporate physiological responses of fish to elevated temperatures (Hobday, Oliver, Sen Gupta, Benthuysen & Wernberg, 2018). Furthermore, the reproductive dynamics of fish during marine heatwaves have been identified as critical but remain underexplored, particularly regarding how altered spawning success and larval survival may influence long-term population trends (Murray & Le Quesne, 2019). Additionally, there is a lack of studies integrating the socio-economic dimensions of fisheries management with ecological impacts of marine heatwaves, which is essential for developing holistic adaptive management strategies.

Contextual Gaps: The context of marine heatwaves varies widely across different marine ecosystems, yet most studies focus on specific regions or species, limiting the generalizability of findings. For instance, research primarily conducted in the Northeast Pacific or Southern California Bight may not be applicable to other coastal ecosystems facing similar thermal stress (Cavole, Demko, Diner, Giddings & Nichols, 2016). Moreover, many studies emphasize commercially important species while neglecting the broader ecological impacts on non-target species and biodiversity. This lack of contextual breadth hampers our understanding of how marine heatwaves affect ecosystem functions and resilience across different environments.

Geographical Gaps: Geographically, most research on marine heatwaves has been concentrated in temperate coastal regions, with limited studies conducted in tropical and polar environments. Given that marine heatwaves are predicted to increase in frequency and intensity globally, there is an urgent need for research that encompasses diverse geographical areas (Holbrook, Scannell, Sen Gupta, Benthuysen & Feng, 2020). Additionally, regions with developing fisheries management systems may experience different impacts from marine heatwaves compared to those with established frameworks, highlighting the need for geographically targeted research that considers local ecological and socio-economic contexts. Addressing these geographical gaps will enhance our understanding of the global implications of marine heatwaves on fish population dynamics and support the development of tailored management strategies.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Marine heatwaves represent a significant and escalating threat to fish population dynamics in coastal ecosystems, with profound implications for biodiversity, fisheries management, and ecosystem resilience. The increasing frequency and intensity of these thermal anomalies, driven by climate change, can disrupt established community structures and alter the distribution and abundance of both targeted and non-target species. Evidence from recent studies indicates that marine heatwaves can lead to declines in biomass among cold-water species while facilitating the proliferation of warm-water species, thereby reshaping marine ecosystems and their associated food webs. Additionally, the reproductive success of fish species can be adversely affected by elevated temperatures, which may result in decreased recruitment and long-term population declines.

Moreover, while existing research has provided valuable insights into the ecological impacts of marine heatwaves, significant gaps remain in our understanding of the underlying mechanisms and contextual factors influencing these dynamics. Further investigations are needed to explore the physiological responses of fish to temperature changes, as well as the socio-economic implications for fisheries management and local communities. It is essential for future research to adopt a multidisciplinary approach that integrates ecological, biological, and socio-economic perspectives to fully comprehend the ramifications of marine heatwaves on fish populations. Furthermore, studies should encompass a broader geographical scope to account for the diverse responses of fish populations in varying marine environments. By addressing these research gaps, policymakers and fisheries managers can develop more effective and adaptive management strategies to mitigate the impacts of marine heatwaves, ultimately enhancing the resilience of coastal ecosystems in the face of climate change.

Recommendations

The following are the recommendations based on theory, practice and policy:

Theory

To enhance the theoretical understanding of the effects of marine heatwaves on fish population dynamics, future research must adopt an interdisciplinary approach that integrates physiological, ecological, and evolutionary perspectives. By developing comprehensive models that link temperature anomalies to individual species' behaviour, reproductive success, and survival rates, researchers can gain valuable insights into the mechanistic pathways through which marine heatwaves impact fish populations. This integration of knowledge will facilitate the development of more robust ecological theories that explain shifts in species composition and community structure under climate change scenarios. Additionally, incorporating socio-economic dimensions into theoretical frameworks is essential to explore how human activities and fisheries management intersect with ecological responses to marine heatwaves. Understanding the dynamics between human and ecological systems will contribute to the development of adaptive management theories that address the complexities of climate variability. Moreover, research should focus on the long-term consequences of marine heatwaves, considering evolutionary responses in fish populations. By identifying patterns and trends in these responses, scientists can predict future shifts in community dynamics. This holistic theoretical framework will ultimately enhance our understanding of marine ecosystems and inform more effective management strategies.

Practice

Fisheries managers and practitioners should prioritize the implementation of adaptive management strategies that account for the dynamic nature of marine ecosystems influenced by climate change. Establishing comprehensive monitoring programs to assess changes in fish populations, reproductive success, and community composition during marine heatwaves is critical for guiding management decisions. These monitoring efforts will provide valuable data to identify vulnerable species and inform adaptive responses during periods of elevated temperatures. Fisheries managers should consider establishing flexible fishing quotas and seasonal closures to protect at-risk species, thereby ensuring the sustainability of fish populations during marine heatwaves. Furthermore, fostering collaborative approaches that involve various stakeholders—including fishers, scientists, and local communities—can enhance the effectiveness of management strategies. Engaging local knowledge and experience in the decision-making process is essential for developing context-specific solutions. Additionally, outreach programs aimed at educating fishers about the impacts of marine heatwaves and promoting sustainable fishing practices can significantly contribute to the resilience of coastal ecosystems. By empowering stakeholders and fostering adaptive practices, fisheries managers can better navigate the challenges posed by marine heatwaves and support the long-term sustainability of marine resources.

Policy

Policymakers must urgently recognize the implications of marine heatwaves on fish population dynamics within the broader framework of climate change adaptation and mitigation. Implementing ecosystem-based fisheries management policies is crucial for ensuring the long-term sustainability of marine resources in the face of climate variability. This approach involves integrating climate projections into fisheries management plans, allowing for more informed decision-making that considers the potential impacts of marine heatwaves on fish populations. Furthermore, establishing protected areas that safeguard critical habitats for vulnerable species is essential for enhancing ecosystem resilience. Policymakers should advocate for increased funding and resources dedicated to researching marine heatwaves, fostering collaborations between academic institutions, government agencies, and non-governmental organizations. This collaborative effort will enhance our understanding of marine heatwaves and their ecological consequences. Additionally, international cooperation is necessary, as marine heatwaves transcend national boundaries; collaborative initiatives can facilitate the sharing of knowledge, best practices, and data to effectively address these challenges. By prioritizing these recommendations, policymakers can create a more resilient marine environment that not only protects ecological integrity but also supports the livelihoods of coastal communities. Through proactive policies, it is possible to mitigate the impacts of marine heatwaves and safeguard the future of marine ecosystems.

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