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Assessing the Impact of Climate Change on Ocean Governance and Coastal Adaptation

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Abstract

This study examines expert perceptions of the impacts of climate change on ocean ecosystems and the associated challenges for ocean governance and coastal adaptation. Drawing on a mixed-methods expert-elicitation approach combining a survey of 70 experts with qualitative interviews, the research identifies ocean warming, ocean acidification, and biodiversity loss as the most critical climate-related threats to marine systems. Rather than conducting a policy-by-policy evaluation, the study explores how experts assess the perceived effectiveness, limitations, and adaptive capacity of existing international and national ocean governance frameworks, based on their professional experience. The findings indicate a strong consensus on the urgency of strengthening governance arrangements, enhancing international collaboration, and improving adaptive and flexible policy responses. Barriers to community engagement—particularly limited awareness and financial constraints—are highlighted as persistent challenges for coastal adaptation. By integrating quantitative patterns with qualitative insights, this study contributes to the scholarship on ocean governance by clarifying expert-identified governance gaps and priority areas for climate-resilient ocean governance.

Keywords

climate change; coastal adaptation; impact; mitigation; ocean ecosystems; ocean governance

1. Introduction

Climate change, driven primarily by anthropogenic activities, has emerged as one of the most pressing global challenges of the 21st century (Berrang-Ford et al., 2011; Lee et al., 2023). Rising temperatures, melting ice

caps, and altered precipitation patterns have triggered widespread ecosystem change worldwide (Dutton et al., 2015; Grimm et al., 2013; Williams et al., 2021). One of the most vulnerable and ecologically diverse ecosystems facing the brunt of these changes is the world's oceans (Bijma et al., 2013). Oceans cover more than 70% of the Earth's surface, regulating climate, supporting biodiversity, and providing livelihoods for millions of people across the globe (Alverson, 2012; Halpern et al., 2015). However, these vital marine ecosystems are under threat due to climate change-induced phenomena such as ocean acidification, sea-level rise, and altered marine currents (Feely & Doney, 2011; V. Gray, 2007).

In the face of these challenges, effective ocean governance has become imperative (Haas et al., 2022). Ocean governance encompasses a range of activities, from policy formulation to international agreements, aimed at conserving and sustainably managing marine resources (Winther et al., 2020). Addressing climate change impacts on oceans requires comprehensive governance frameworks that transcend national boundaries and integrate scientific knowledge with policy-making (Jaeckel et al., 2017). Moreover, coastal communities—often the most directly affected by climate change-induced hazards such as storm surges and coastal erosion—require adaptive strategies that are socially, economically, and ecologically viable (Adger, 2015; Eisenack et al., 2014; Reed et al., 2009). Recent scholarship further suggests that achieving climate-resilient ocean governance depends on strengthened international collaboration and adaptive polycentric governance arrangements that complement existing institutional frameworks (Kim, 2024; Yadav & Gjerde, 2020). Over the past two decades, ocean governance has evolved through a combination of international legal instruments, regional agreements, and national policy frameworks aimed at conserving marine ecosystems and promoting sustainable use (Bennett et al., 2025; Haas et al., 2022; Haward & Vince, 2009; Rudolph et al., 2020; Shih, 2024). Notable achievements include the establishment of global norms under instruments such as UNCLOS, the expansion of marine protected areas, and growing recognition of integrated and ecosystem-based management approaches. These efforts have improved scientific cooperation, data sharing, and policy coordination across jurisdictions. However, substantial governance challenges persist. Implementation remains uneven across regions, enforcement capacity is often weak, and many governance arrangements struggle to respond adaptively to accelerating climate-driven risks such as sea-level rise, ocean warming, and ecosystem degradation. Fragmented institutional responsibilities and mismatches between ecological processes and administrative boundaries further limit governance effectiveness. Against this backdrop, understanding how experts perceive the strengths, limitations, and priorities of existing ocean governance frameworks is essential for informing future climate-resilient governance pathways.

2. Methods

2.1. Research Design and Methodological Approach

This study adopts a mixed-methods expert-elicitation design, combining semi-structured interviews with a structured expert survey to examine perceptions of climate change impacts on ocean ecosystems, ocean governance frameworks, and coastal adaptation strategies. Expert elicitation is widely used in climate governance and adaptation research to capture informed judgments in contexts characterized by uncertainty, complexity, and limited empirical observability (Parmesan et al., 2013; Spalding & de Ycaza, 2020; Tvinnereim & Fløttum, 2015).

Expert elicitation is widely used in climate governance and adaptation research to capture informed judgments where policy effectiveness, governance capacity, and emerging risks cannot be fully assessed through quantitative indicators alone. Semi-structured interviews were employed to generate in-depth qualitative insights into perceived governance gaps, adaptation challenges, and institutional constraints, while the structured survey enabled the systematic comparison of expert assessments across key dimensions such as perceived severity of impacts, governance effectiveness, urgency, and collaboration needs.

The integration of qualitative thematic analysis with quantitative descriptive and inferential statistics allows for methodological triangulation, strengthening the robustness of the findings. Importantly, this design aligns with the study's objective, which is not to evaluate specific policies or institutions, but rather to identify expert-informed priorities, perceived governance limitations, and strategic directions relevant to climate-resilient ocean governance.

2.2. Participant Selection and Ethical Considerations

Participants were selected using purposive sampling, targeting individuals with demonstrated professional expertise in marine science, climate policy, ocean governance, coastal management, or related fields. Inclusion criteria required participants to have: a minimum of five years of professional or research experience related to oceans or coastal systems; and active involvement in research, policy analysis, governance, or management related to climate change, marine ecosystems, or coastal adaptation.

A total of 70 experts participated in both the survey and interview components of the study. Participants represented diverse professional backgrounds, including academia, government agencies, policy advisory bodies, and applied coastal management organizations.

All participants received an information sheet outlining the study objectives, data usage, and confidentiality provisions. Informed consent was obtained prior to participation. Responses were anonymized, and no personally identifiable information was retained. The study received approval from the relevant institutional ethics review board.

2.3. Semi-Structured Interviews: Design and Themes

Semi-structured interviews were conducted to elicit in-depth qualitative insights into expert assessments of climate change impacts and governance challenges. The interview guide was informed by prior studies on climate impacts, adaptation, and ocean governance (Kim, 2024; Oliver & Morecroft, 2014; Spalding & de Ycaza, 2020). In this study, a "precisely planned interview" refers to a semi-structured interview design based on a predefined interview guide, in which the core questions, thematic domains, and analytical objectives were established in advance. The interview guide was developed directly from the study's research questions and relevant literature on climate change impacts, ocean governance, and coastal adaptation.

Four overarching thematic domains guided the interviews:

1. Perceived climate change impacts on ocean ecosystems (e.g., ocean warming, acidification, and biodiversity change).

2. Effectiveness and limitations of existing ocean governance frameworks, including international and national arrangements.
3. Assessment of coastal adaptation strategies, including engineered, policy-based, and community-based approaches.
4. Governance and societal challenges, including institutional fragmentation, enforcement capacity, and community engagement.

The semi-structured format ensured thematic consistency across interviews, while allowing flexibility for participants to introduce context-specific examples and emergent issues.

2.4. Survey Design and Variables

A structured online survey was administered to the same group of experts to quantitatively assess perceptions identified in the qualitative phase. The survey design was informed by previous expert perception studies in climate and environmental governance (Ding et al., 2017; Tvinnereim & Fløttum, 2015).

Key variables included: (a) perceived severity of climate change impacts (e.g., ocean warming, acidification, and biodiversity loss); (b) perceived effectiveness of ocean governance frameworks; (c) perceived urgency of strengthening ocean governance; (d) perceived importance of international collaboration; (e) confidence in different coastal adaptation strategies; and (f) perceived barriers to community engagement.

Most variables were measured using Likert-scale items, complemented by selected open-ended questions to contextualize responses.

2.5. Data Analysis

2.5.1. Qualitative Analysis

Interview transcripts and open-ended survey responses were analyzed using thematic analysis. An initial coding framework was developed deductively based on the interview themes and research questions, followed by inductive refinement to capture emergent patterns. Codes were grouped into higher-order categories corresponding to climate impacts, governance effectiveness, adaptation strategies, and societal challenges.

This qualitative analysis directly addressed research questions 1–4 by identifying recurring expert narratives, areas of convergence and divergence, and perceived governance gaps.

2.5.2. Quantitative Analysis

Quantitative survey data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics (means, medians, and standard deviations) were used to summarize overall expert perceptions.

To examine relationships between key variables, the following analyses were conducted:

- Spearman's rank correlation and Pearson's correlation to assess associations between perceived government proactivity and urgency of ocean governance.
- Chi-square tests to examine associations between expertise level and frequency of encountering climate change impacts.
- Crosstabulation analyses to explore relationships between collaboration essentiality and perceived governance effectiveness.

Each statistical analysis was explicitly aligned with the relevant research question to ensure analytical coherence and methodological appropriateness.

3. Results

3.1. Expert Perceptions of Climate Change Impacts and Ocean Governance

Among the 70 experts surveyed, rising sea temperatures were identified as the most significant climate change-induced threat to ocean ecosystems, with 64.3% of respondents (n = 45) ranking this factor as their primary concern. Ocean acidification was identified as the most critical threat by 21.4% of experts (n = 15), while 14.3% (n = 10) highlighted biodiversity loss as their main concern.

Regarding the frequency of encountering climate change-related impacts in their professional activities, 40% of respondents (n = 28) reported occasional encounters, 28.6% (n = 20) reported rare encounters, and 21.4% (n = 15) reported frequent encounters. Only 10% (n = 7) indicated that they had never encountered such impacts in their work.

In terms of awareness of existing ocean governance policies and frameworks, 55% of experts (n = 39) considered themselves well informed, while 30% (n = 21) reported moderate awareness and 15% (n = 10) indicated limited awareness.

Assessments of current ocean governance frameworks indicated mixed perceptions of effectiveness. Half of the respondents (50%, n = 35) perceived existing frameworks as moderately effective, whereas 32% (n = 22) viewed them as ineffective. Only 18% (n = 13) considered current governance arrangements to be highly effective.

Despite these mixed evaluations, there was a strong consensus on the urgency of strengthening ocean governance. A total of 91% of experts (n = 64) rated the urgency of enhancing ocean governance as high or extremely high. Similarly, international collaboration was viewed as essential, with 88% of respondents (n = 62) assigning scores of 6 or 7 on a 7-point Likert scale, underscoring widespread agreement on the need for coordinated global responses to climate change impacts on ocean systems.

3.2. Qualitative Insights From Expert Interviews

Qualitative analysis of semi-structured interviews and open-ended survey responses provided deeper insights into expert perceptions of climate change impacts, governance challenges, and adaptation barriers.

As summarized in Table 1, experts consistently identified ocean warming as a systemic driver of ecological change, intensifying coral bleaching, altering species distributions, and amplifying other stressors such as ocean acidification. Biodiversity loss was frequently discussed in relation to cascading effects across marine food webs and ecosystem stability.

Table 1. Guiding questions, emergent themes, and illustrative expert quotations.

Guiding question	Emergent theme	Illustrative expert quote
What do you perceive as the primary climate change-induced threats to ocean ecosystems?	Ocean warming as a systemic driver	Rising sea temperatures are not just an isolated stressor—they intensify coral bleaching, alter species distributions, and amplify other pressures such as acidification
	Ocean acidification and ecosystem fragility	Acidification fundamentally changes ocean chemistry and threatens shell-forming species and ecosystem stability
	Biodiversity loss and food-web disruption	Cascading effects across marine food chains are becoming increasingly evident as key species decline or migrate
How effectively do you think existing policies and governance frameworks address climate change impacts on ocean ecosystems?	Governance ambition, but implementation gap	There are strong international agreements on paper, but enforcement and coordination remain weak at the national level
	Fragmented institutional responsibilities	Ocean governance is divided across agencies that often lack effective coordination, slowing adaptive responses
	Need for adaptive and flexible governance	Governance frameworks were not designed for rapid climate change and must become more adaptive and forward-looking
What are the primary barriers to community engagement in coastal adaptation efforts?	Limited awareness and risk perception	Many coastal communities do not perceive climate change as an immediate risk, which limits proactive adaptation
	Financial and resource constraints	Even when awareness exists, the costs of adaptation measures often exceed local financial capacity
	Cultural resistance and institutional exclusion	Top–down planning frequently overlooks local knowledge, reducing community ownership and engagement
How urgent is it to enhance ocean governance and coastal adaptation efforts in response to climate change impacts?	High urgency and time sensitivity	Environmental change is occurring faster than governance systems can respond, creating serious risks
	Need for targeted, place-based interventions	Vulnerable regions require tailored and immediate governance responses rather than generic solutions

Note: The guiding questions shown represent core prompts used across semi-structured interviews and open-ended survey items. Interviews were thematic and included follow-up and probing questions depending on participants' expertise.

Experts highlighted a persistent gap between governance ambition and implementation. While international agreements were often described as well-designed in principle, interviewees emphasized weak enforcement, fragmented institutional responsibilities, and limited adaptive capacity at the national and sub-national levels. Many experts noted that existing governance frameworks were not designed to respond to the pace

and uncertainty associated with climate change, reinforcing calls for more flexible and forward-looking governance arrangements.

Barriers to community engagement in coastal adaptation were also emphasized. Limited awareness and risk perception were commonly cited, alongside financial constraints that restrict the ability of local communities to implement adaptation measures. Several experts further highlighted cultural resistance and top–down planning approaches that marginalize local knowledge and reduce community ownership of adaptation initiatives.

Across interviews, there was near-unanimous agreement on the urgency of enhancing ocean governance and coastal adaptation. Experts stressed that climate-driven changes are occurring faster than governance systems can respond, increasing risks for vulnerable ecosystems and coastal communities and underscoring the need for timely, place-based governance interventions.

3.3. Quantitative Analysis

Most respondents, comprising 45% of the participants, were moderately knowledgeable, signifying a substantial understanding of the subject matter. This diverse range of expertise among the respondents allowed for comprehensive insights into the perceptions and attitudes concerning climate change impacts on ocean ecosystems and coastal adaptation strategies.

3.3.1. Primary Threat to Ocean Ecosystems

Upon delving into the primary climate change-induced factors threatening ocean ecosystems, rising sea temperatures emerged as the most significant concern among experts. This consensus was robust, with 64.3% of participants ranking it the top threat. Ocean acidification and loss of marine biodiversity followed closely, with 21.4% and 14.3% of respondents, respectively, highlighting these factors. These findings underscore the gravity of rising sea temperatures as a critical issue demanding immediate attention and comprehensive solutions.

3.3.2. Frequency of Climate Change-Related Impacts

Experts reported sporadically encountering climate change-related impacts on ocean ecosystems in their professional work. The intermittent nature of these events was noted, with 40% of respondents indicating occasional encounters and 28% reporting rare incidents. While not daily occurrences, these events remained significant, emphasizing the sporadic yet impactful nature of climate-driven changes in ocean ecosystems.

3.3.3. Awareness of Policies and Governance Effectiveness

Regarding awareness of international agreements and national policies related to ocean governance and climate change mitigation/adaptation, 55% of participants considered themselves well-informed. However, a notable portion, constituting 30% of respondents, revealed a need for more awareness in this area. This discrepancy highlights existing gaps in knowledge dissemination, indicating a need for more targeted efforts in education and information sharing within the expert community.

3.3.4. Effectiveness of Current Ocean Governance Frameworks

Participants generally perceived current ocean governance frameworks as moderately effective. This moderate rating, provided by 50% of the experts, indicated the need for continuous improvements to effectively address challenges arising from climate change impacts on oceans. This feedback emphasizes the importance of refining existing governance structures to enhance their efficacy in the face of evolving climate-related challenges.

3.3.5. Essentiality of Collaboration and Adaptability of Frameworks

The survey revealed a unanimous consensus among experts on the essentiality of international collaboration to address climate change impacts on ocean governance. On a scale from 1 to 7, where 7 signifies *extreme essentiality*, the average rating for the importance of international collaboration was 6.5, indicating a high degree of consensus on the necessity for global cooperation. Additionally, the adaptability of current ocean governance frameworks was rated moderately high, averaging at 5.8. While indicating a certain degree of flexibility, these responses also suggested room for enhancements to address emerging climate-related issues effectively.

3.3.6. Preferred Coastal Adaptation Measures and Barriers to Community Engagement

Engineered solutions were resoundingly considered the most viable and sustainable coastal adaptation measure, with 68% of respondents expressing this preference. This preference for technological interventions highlighted experts' faith in engineered solutions to mitigate climate change impacts on coastal areas. Simultaneously, lack of awareness and education emerged as the primary barriers to community engagement in coastal adaptation efforts, as indicated by 42% of the respondents. This finding underscores the importance of public education initiatives in fostering community participation and overcoming barriers to engagement.

3.3.7. Confidence in Engineering Solutions and Support for Policy-Based Measures

Experts expressed moderate to high confidence in the effectiveness of current coastal engineering solutions. With 48% of participants indicating high confidence and 32% expressing moderate confidence, there exists a substantial level of trust in these measures. Additionally, 60% of the experts reported a likelihood to professionally support policy-based coastal adaptation measures, highlighting their openness to engage with regulatory and policy initiatives.

3.3.8. Government Proactivity, Urgency, and Optimism and Public Awareness Significance

Perceptions of government proactivity in implementing policies that address climate change impacts on coastal areas varied among respondents. While 35% perceived government efforts as moderately proactive, indicating a moderate confidence level, there is room for improvement to enhance governmental initiatives further. There was unanimous agreement among experts on the urgency to enhance ocean governance and coastal adaptation efforts in response to climate change impacts. On a scale from 1 to 7, the average urgency rating was 6.8, emphasizing the pressing nature of this issue and the need for immediate

action and comprehensive strategies. However, optimism about the future effectiveness of ocean governance and coastal adaptation measures varied among experts, ranging from low optimism to high optimism. These diverse viewpoints underscore the complexity of the challenge and the need for nuanced, context-specific approaches.

3.4. Qualitative Analysis

In-depth qualitative exploration provided nuanced insights into experts' perspectives on climate change impacts on ocean ecosystems. Interviews were instrumental in capturing the complexities of their views. Table 1 showcases critical questions posed to the experts, unveiling their nuanced responses, thereby enriching the qualitative dimension of the study.

3.4.1. Open-Ended Questions

Regarding the primary climate change-induced threats, a variety of concerns were raised. Rising sea temperatures emerged as a significant worry, emphasizing their adverse effects on marine species and ecosystems. Ocean acidification was underscored for its detrimental impact on shell-forming organisms, while the loss of marine biodiversity was highlighted, raising concerns about disruptions in food chains and ecosystems. Some experts also linked the increased frequency of extreme weather events to coastal erosion and habitat destruction, further emphasizing the complexity of climate-driven challenges.

Opinions on the effectiveness of existing policies and governance frameworks varied widely. While certain international agreements received praise, criticism was directed at their enforcement. Gaps in national policies were noted, raising concerns about insufficient regulations to curb overfishing and pollution. The need for more stringent enforcement mechanisms and increased international cooperation was emphasized to effectively address policy shortcomings.

Barriers to community engagement in coastal adaptation efforts were identified, highlighting obstacles faced during implementation. Lack of awareness was a common issue, with communities often underestimating the urgency of climate change impacts. Financial constraints created significant challenges due to the high costs of implementing adaptive measures. Cultural factors, including resistance to change in traditional coastal communities, emphasized the need for culturally sensitive approaches. Additionally, bureaucratic hurdles and limited community involvement in policy-making processes were major obstacles that hindered effective engagement.

Experts unanimously emphasized the need for immediate action to improve ocean governance and coastal adaptation efforts. They highlighted the rapid pace of climate change and its serious impacts on coastal communities and ecosystems. Rising sea levels and more frequent extreme weather events were identified as urgent threats that demand quick responses. Vulnerable regions were specifically pointed out, emphasizing the importance of targeted, timely measures to avoid irreversible damage.

3.4.2. Interviews

In-depth interviews with experts provided valuable insights into observed changes in ocean ecosystems due to climate change. During these interviews, experts noted coral reef bleaching caused by rising sea

temperatures, highlighting the loss of vibrant marine life. They attributed shifts in fish species' migration patterns to changing ocean conditions, thus illustrating the dynamic nature of marine ecosystems. Discussions on coastal erosion affecting local communities emphasized the need for immediate protective measures. These real-life examples illuminated the tangible impact of climate change on ocean ecosystems, reinforcing the urgency for comprehensive strategies.

Experts viewed international collaborations from different perspectives. They shared successful joint research projects and information exchanges, showing the positive results of global cooperation. However, they also expressed frustrations about bureaucratic delays and a lack of funding that hinder collaborative efforts. The need for a unified global approach and the diversity of national priorities were recognized. Despite these challenges, experts stressed the importance of ongoing international efforts, highlighting the interconnectedness of ocean ecosystems and the necessity for coordinated responses.

The critical role of local communities in shaping effective coastal adaptation strategies was emphasized throughout the interviews. Experts recognized residents as repositories of valuable traditional knowledge about coastal ecosystems and adaptation practices. They stressed the essentiality of involving local communities in decision-making processes to ensure the sustainability and cultural appropriateness of adaptation measures. Community engagement catalyzes behavioral change, underscoring the importance of education and awareness initiatives tailored to specific local contexts (Galappaththi et al., 2024; Hügel & Davies, 2020). The interviews highlighted the necessity of empowering local communities to actively participate in adaptation planning and implementation processes, reflecting the holistic approach needed for practical coastal adaptation efforts.

4. Statistical Analysis

Table 2 illustrates a detailed crosstabulation between respondents' perceptions of government proactivity (categorized as "not proactive at all," "moderately proactive," and "very proactive") and the corresponding levels of urgency attributed to ocean governance (ranging from "not urgent at all" to "extremely urgent").

Table 2. Crosstabulation between government proactivity and urgency of ocean governance.

Government Proactivity—Urgency Ocean Governance Crosstabulation									
Count									
		Urgency ocean governance							Total
		Not urgent at all	Very low urgency	Low urgency	Moderate urgency	High urgency	Very high urgency	Extremely urgent	
Government proactivity	Not proactive at all	19	15	15	11	11	5	6	82
	Moderately proactive	15	25	9	8	12	3	11	83
	Very proactive	9	7	7	7	4	4	3	41

Pearson's R and Spearman correlation coefficients were calculated to explore the correlation between government proactivity and the urgency attributed to ocean governance. These coefficients, hovering close to zero, indicate exceptionally weak correlations. This signifies virtually no linear relationship between respondents' perceptions of government proactivity and the urgency they associate with ocean governance.

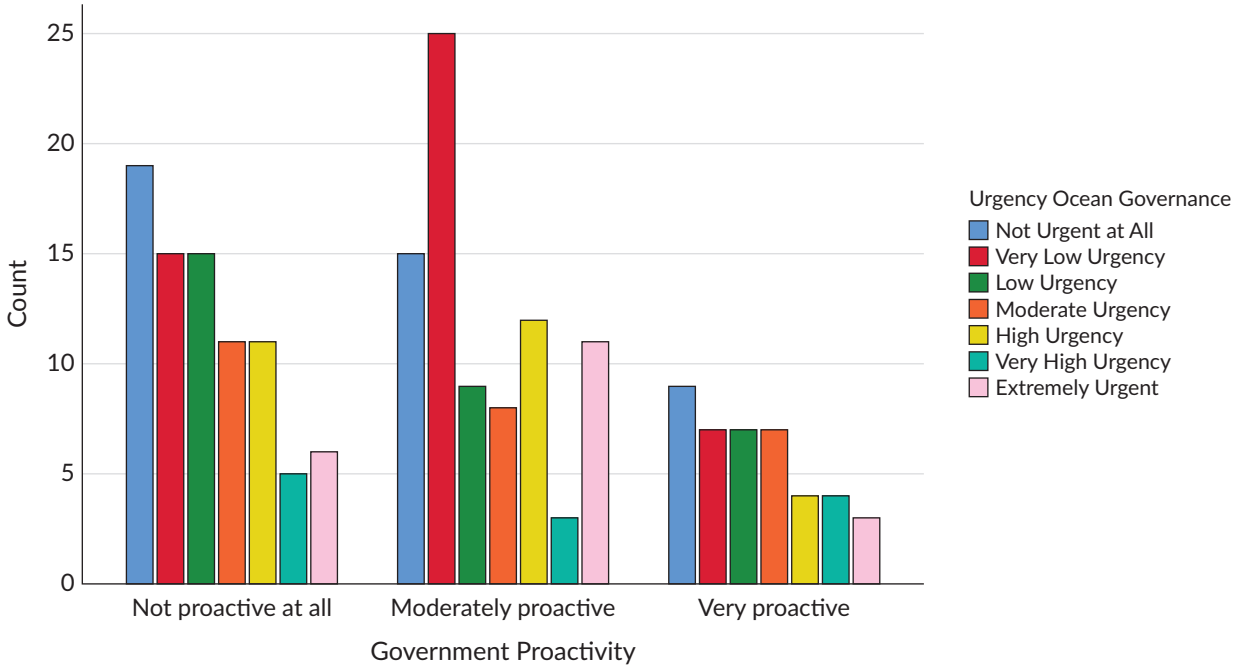

Figure 1. Perceived government proactivity vs. urgency of ocean governance.

The bar chart illustrates the relationship between respondents' perceptions of government proactivity (categorized as "not proactive at all," "moderately proactive," and "very proactive") and the corresponding levels of urgency attributed to ocean governance (ranging from "not urgent at all" to "extremely urgent"). While there are slight fluctuations in perceived urgency across different levels of government proactivity, the lack of a significant trend indicates a complex and nuanced understanding among respondents regarding the urgency of addressing climate change impacts on ocean governance.

Table 3 presents the relationship between respondents' self-assessed familiarity with ocean ecosystems (categorized as "very knowledgeable," "moderately knowledgeable," "slightly knowledgeable," and "not knowledgeable") and the frequency of encountering climate change-related impacts (ranging from "frequently" to "never"). Chi-square tests indicated a significant association ($p < 0.001$) between familiarity with ocean ecosystems and the frequency of encountering climate change-related impacts. Pearson's R and Spearman correlation coefficients further confirmed a strong positive correlation, emphasizing the influence of expertise on the occurrence of these impacts.

Table 3. Crosstabulation and correlation analysis between familiarity with ocean ecosystems and frequency of climate change-related impacts.

Familiarity Ocean Eco—Encounter Frequency Crosstabulation						
Count						
	Encounter frequency					Total
	Frequently	Occasionally	Sometimes	Rarely	Never	
Very knowledgeable	50	27	2	0	0	79
Moderately knowledgeable	23	46	18	1	0	88
Slightly knowledgeable	0	5	9	8	1	23
Not knowledgeable	0	1	5	7	3	16

Figure 2 visually represents the relationship between respondents' familiarity with ocean ecosystems and the frequency of encountering climate change-related impacts. The bar chart demonstrates a clear trend of higher encounter frequencies as familiarity levels increase.

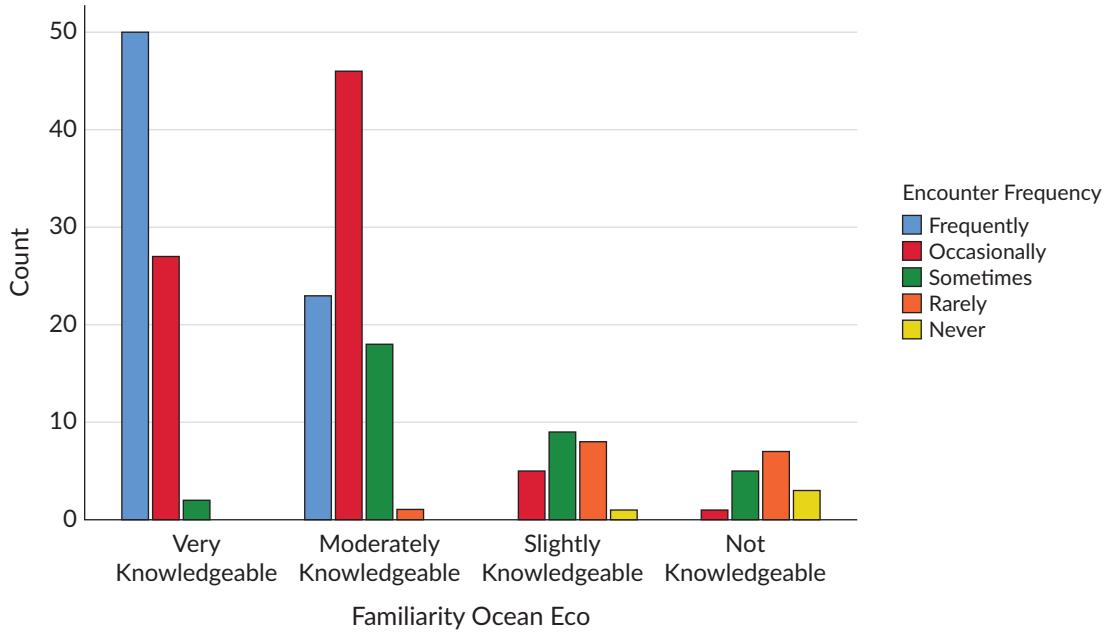

Figure 2. Relationship between familiarity with ocean ecosystems and frequency of climate change-related impacts.

Table 4 presents the relationship between respondents' perceptions of collaboration essentiality (categorized from "extremely essential" to "not essential at all") and their evaluation of governance effectiveness (classified as "very effective," "moderately effective," and "ineffective"). Despite various levels of collaboration essentiality, the distribution of effectiveness perceptions among respondents shows no significant association, as indicated by the chi-square tests ($p > 0.05$). The symmetric measures support this finding, demonstrating negligible correlations between collaboration essentiality and governance effectiveness.

Table 4. Crosstabulation between collaboration essentiality and governance effectiveness.

Collaboration Essentiality—Governance Effectiveness Crosstabulation					
Count					
		Governance effectiveness			Total
		Very effective	Moderately effective	Ineffective	
Collaboration Essentiality	Extremely essential	13	22	4	39
	Highly essential	19	28	9	56
	Essential	19	11	4	34
	Fairly essential	7	11	3	21
	Moderately essential	9	10	3	22
	Slightly essential	8	10	5	23
	Not essential at all	3	6	2	11

Figure 3 illustrates respondents' perceptions of collaboration concerning the effectiveness of governance (denoted as "very effective," "moderately effective," and "ineffective"). The varying shades represent different levels of collaboration essentiality. While the chart displays diverse opinions on collaboration's importance, there is no discernible pattern in the effectiveness ratings, indicating a lack of direct correlation between the perceived essentiality of collaboration and the effectiveness of governance measures.

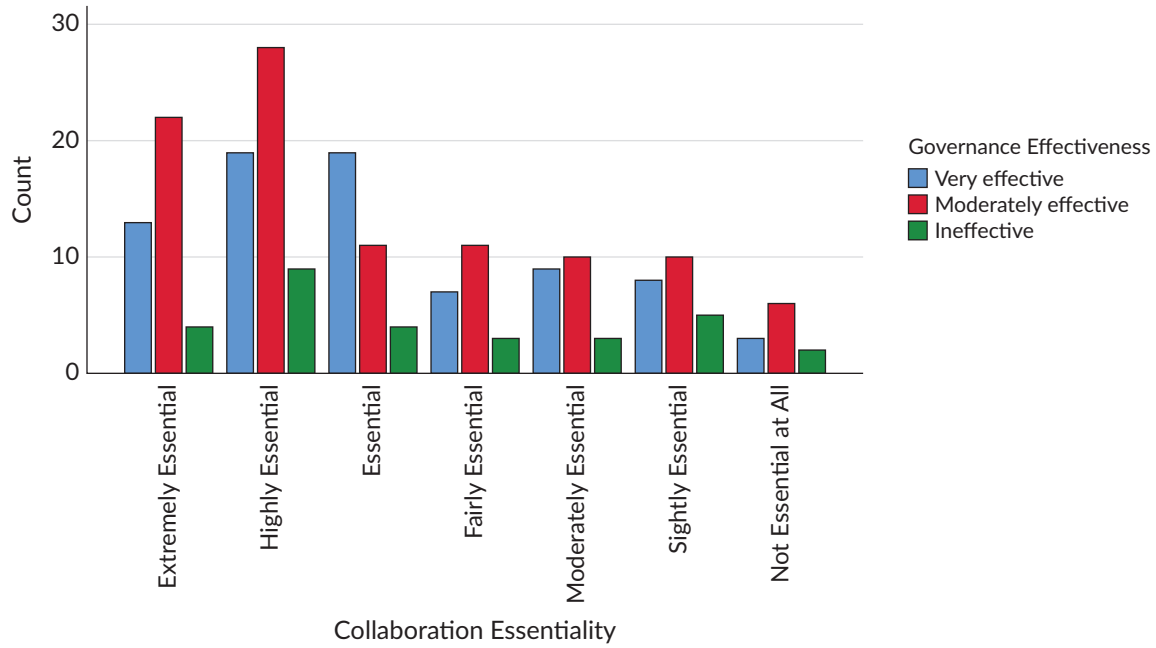

Figure 3. Perceived collaboration essentiality vs. governance effectiveness.

5. Discussion

The comprehensive analysis of experts' perspectives on climate change impacts on ocean ecosystems offers valuable insights into the multifaceted challenges coastal communities and marine environments face. Rising sea temperatures, ocean acidification, and loss of marine biodiversity are the primary climate change-induced

threats. These findings align with previous research, emphasizing the urgent need for targeted interventions to mitigate the adverse effects on marine ecosystems and the communities reliant on them (Doney et al., 2009; Halpern et al., 2008; Hoegh-Guldberg et al., 2008; Pinsky et al., 2013).

The multifaceted nature of climate change impacts on ocean ecosystems underscores the urgency of addressing these issues through integrated approaches (Lin et al., 2021; Suprayitno et al., 2024). Rising sea temperatures and ocean acidification are two interrelated challenges. Ocean warming directly affects marine species and ecosystems and amplifies ocean acidification. The latter, driven by increased CO_2 absorption, severely threatens shell-forming organisms and disrupts marine food chains (Connell et al., 2013; Gattuso et al., 2015). It is crucial to recognize these interconnected impacts to develop comprehensive mitigation and adaptation strategies. The loss of marine biodiversity is another pressing concern (Virtanen et al., 2024; Worm et al., 2006). The disruption of ecosystems due to climate change affects the availability of resources and services that coastal communities depend on (Doney et al., 2012; J. S. Gray, 1997; Halpern et al., 2009). It also has far-reaching implications for global fisheries and food security (Ding et al., 2017). Implementing effective policies and governance frameworks to preserve marine biodiversity is critical (Shih, 2025).

Assessing the effectiveness of existing policies and governance frameworks revealed a diverse range of opinions among experts. While certain international agreements received accolades, concerns were raised about their enforcement mechanisms. Gaps in national policies, particularly in curbing overfishing and pollution, emerged as significant hurdles. The findings emphasize the need for enhanced global cooperation and more stringent enforcement strategies to bridge policy gaps and ensure the sustainable management of ocean ecosystems (Folke et al., 2005). The effectiveness of governance frameworks is pivotal in adapting to climate change impacts and safeguarding marine ecosystems.

Community engagement in coastal adaptation efforts presents a complex landscape marked by challenges such as a lack of awareness, financial constraints, and cultural resistance to change. Traditional knowledge, deeply rooted in local communities, emerges as a valuable asset in shaping effective adaptation strategies. Empowering these communities and integrating their insights into decision-making processes are pivotal to fostering resilience and promoting culturally sensitive approaches (Berkes et al., 2000; Ford et al., 2013). Community involvement in adaptation planning is essential, as it enhances the relevance and effectiveness of adaptation measures (Adger et al., 2003). International collaboration surfaced as a consensus point among experts, underscoring its pivotal role in addressing climate change impacts on ocean governance. The need for coordinated, transnational efforts is vital to tackling the cross-border challenges marine ecosystems face. The findings align with global initiatives such as the Paris Agreement, emphasizing the importance of shared responsibilities and collective action to combat climate change (UN, 2015; UN Framework Convention on Climate Change, n.d.).

It is essential to recognize that the impacts of climate change on ocean ecosystems are experienced differently across regions, and understanding these variations is crucial for developing effective policies and adaptation strategies.

Longitudinal studies assessing the efficacy of adaptation measures over time are imperative for refining policies and strategies. The evolving nature of climate change and its impacts necessitate ongoing assessments and adjustments to adaptation and governance frameworks.

Despite its contributions, this study has several limitations that should be acknowledged. First, the analysis is based on expert perceptions rather than direct evaluation of policy outcomes or governance performance. While expert elicitation is well-suited to contexts characterized by complexity, uncertainty, and limited empirical observability, perceptions may reflect professional experiences, disciplinary backgrounds, and institutional positions rather than objective measures of effectiveness.

Second, although the study draws on a diverse group of 70 experts from academia, government, and applied coastal management, the sample size and composition limit the generalizability of the findings. The perspectives captured may not fully represent regional, sectoral, or cultural variations in ocean governance and coastal adaptation, particularly those of local communities, Indigenous groups, or private-sector actors.

Third, the study adopts a cross-sectional design, capturing expert views at a single point in time. Given the rapidly evolving nature of climate change impacts and governance responses, expert assessments may change as policies, technologies, and institutional arrangements develop. Longitudinal research would be valuable for examining how perceptions of governance effectiveness and adaptation priorities evolve over time.

Finally, the study does not assess the effectiveness of specific governance instruments or adaptation measures. Instead, it focuses on identifying perceived risks, governance gaps, and priority areas. Future research could complement this perception-based approach with comparative policy evaluations, case studies, or empirical outcome indicators to strengthen causal inference and policy relevance.

Recognizing these limitations does not diminish the value of the study; rather, it clarifies the scope of its contribution and highlights opportunities for future research to build on expert-informed insights into climate-resilient ocean governance.

6. Conclusion

This study examined expert perceptions of climate change impacts on ocean ecosystems, ocean governance frameworks, and coastal adaptation strategies using a mixed-methods expert-elicitation approach. The findings reveal strong consensus among experts that ocean warming, ocean acidification, and biodiversity loss represent the most critical climate-related threats to marine systems, while existing governance frameworks struggle to respond adaptively to accelerating climate risks.

The results highlight persistent governance challenges, including fragmented institutional responsibilities, uneven implementation, and limited community engagement, alongside a shared recognition of the importance of international collaboration and adaptive governance arrangements. Rather than evaluating specific policies, the study contributes by clarifying expert-identified governance gaps and priority areas that require attention in efforts to strengthen climate-resilient ocean governance.

By integrating quantitative patterns with qualitative insights, this research provides an expert-informed perspective that can support agenda-setting, policy prioritization, and future research. Future studies could build on these findings through longitudinal analysis, broader stakeholder inclusion, and empirical evaluation of governance outcomes to further advance evidence-based and adaptive responses to climate change in ocean and coastal governance systems.

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Conflict of Interests

The author declares no conflict of interests.

References

Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in Development Studies*, *3*(3), 179–195. https://doi.org/10.1191/1464993403ps060oa

Adger, W., Neil, A., Nigel, W., & Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change*, *15*(2), 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005

Alverson, K. (2012). Vulnerability, impacts, and adaptation to sea level rise: Taking an ecosystem-based approach. *Oceanography*, *25*(3), 231–235. https://www.jstor.org/stable/24861420

Bennett, N. J., Relano, V., Roumbedakis, K., Blythe, J., Andrachuk, M., Claudet, J., Dawson, N., Gill, D., Lazzari, N., Mahajan, S. L., Muhl, E.-K., Riechers, M., Strand, M., & Villasante, S. (2025). Ocean equity: From assessment to action to improve social equity in ocean governance. *Frontiers in Marine Science*, *12*, Article 1473382. https://doi.org/10.3389/fmars.2025.1473382

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, *10*(5), 1251–1262. https://doi.org/10.2307/2641280

Berrang-Ford, L., Ford, J. D., & Paterson, J. (2011). Are we adapting to climate change? *Global Environmental Change*, *21*(1), 25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012

Bijma, J., Pörtner, H.-O., Yesson, C., & Rogers, A. D. (2013). Climate change and the oceans—What does the future hold? *Marine Pollution Bulletin*, *74*(2), 495–505. https://doi.org/10.1016/j.marpolbul.2013.07.022

Connell, S. D., Kroeker, K. J., Fabricius, K. E., Kline, D. I., & Russell, B. D. (2013). The other ocean acidification problem: CO_2 as a resource among competitors for ecosystem dominance. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*(1627), Article 20120442. https://doi.org/10.1098/rstb.2012.0442

Ding, Q., Chen, X., Hilborn, R., & Chen, Y. (2017). Vulnerability to impacts of climate change on marine fisheries and food security. *Marine Policy*, *83*, 55–61. https://doi.org/10.1016/j.marpol.2017.05.011

Doney, S. C., Fabry, V. J., Feely, R. A., & Kleypas, J. A. (2009). Ocean acidification: The other CO_2 problem. *Annual Review of Marine Science*, *1*, 169–192. https://doi.org/10.1146/annurev.marine.010908.163834

Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J., & Talley, L. D. (2012). Climate change impacts on marine ecosystems. *Annual Review of Marine Science*, *4*, 11–37. https://doi.org/10.1146/annurev-marine-041911-111611

Dutton, A., Carlson, A. E., Long, A. J., Milne, G. A., Clark, P. U., DeConto, R., Horton, B. P., Rahmstorf, S., & Raymo, M. E. (2015). Sea-level rise due to polar ice-sheet mass loss during past warm periods. *Science*, *349*(6244), Article aaa4019. https://doi.org/10.1126/science.aaa4019

Eisenack, K., Möser, S. C., Hoffmann, E., Klein, R. J. T., Oberlack, C., Pechan, A., Rotter, M., & Termeer, C. J. A. M.

(2014). Explaining and overcoming barriers to climate change adaptation. *Nature Climate Change*, *4*, 867–872. https://doi.org/10.1038/nclimate2350

Feely, R. A., & Doney, S. C. (2011). Ocean acidification: The other CO_2 problem. *Limnology and Oceanography e-Lectures*, *3*(1), 1–59. https://doi.org/10.4319/lol.2011.rfeely_sdoney.5

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, *30*, 441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511

Ford, J. D., McDowell, G., Shirley, J., Pitre, M., Siewierski, R., Gough, W., Duerden, F., Pearce, T., Adams, P., & Statham, S. (2013). The dynamic multiscale nature of climate change vulnerability: An Inuit harvesting example. *Annals of the Association of American Geographers*, *103*(5), 1193–1211. https://doi.org/10.1080/00045608.2013.776880

Galappaththi, E. K., Perera, C. D., Illangarathna, G. A., Jayasekara, S. M., & Garbutt, H. (2024). Food security policy and coastal climate adaptation among indigenous and local communities. *Marine Policy*, *170*, Article 106408. https://doi.org/10.1016/j.marpol.2024.106408

Gattuso, J.-P., Magnan, A. K., Billé, R., Cheung, W., Howes, E. L., Joos, F., Allemand, D., Bopp, L., Cooley, S. R., Eakin, C. M., Hoegh-Guldberg, O., Kelly, R., Pörtner, H.-O., Rogers, A. D., Baxter, J. M., Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., . . . Turley, C. M. (2015). Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios. *Science*, *349*(6243), Article aac4722. https://doi.org/10.1126/science.aac4722

Gray, J. S. (1997). Marine biodiversity: Patterns, threats and conservation needs. *Biodiversity & Conservation*, *6*, 153–175. https://doi.org/10.1023/A:1018335901847

Gray, V. (2007). Climate change 2007: The physical science basis summary for policymakers. *Energy & Environment*, *18*(3/4), 433–440. https://doi.org/10.1260/095830507781076194

Grimm, N. B., Chapin, F. S., III, Bierwagen, B., Gonzalez, P., Groffman, P. M., Luo, Y., Melton, F., Nadelhoffer, K., Pairis, A., Raymond, P. A., Schimel, J., & Williamson, C. E. (2013). The impacts of climate change on ecosystem structure and function. *Frontiers in Ecology and the Environment*, *11*(9), 474–482. https://doi.org/10.1890/120282

Haas, B., Mackay, M., Novaglio, C., Fullbrook, L., Murunga, M., Sbrocchi, C., McDonald, J., McCormack, P. C., Alexander, K., Fudge, M., Goldsworthy, L., Boschetti, F., Dutton, I., Dutra, L., McGee, J., Rousseau, Y., Spain, E., Stephenson, R., Vince, J., . . . & Haward, M. (2022). The future of ocean governance. *Reviews in Fish Biology and Fisheries*, *32*, 253–270. https://doi.org/10.1007/s11160-020-09631-x

Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., Lowndes, J. S., Rockwood, R. C., Selig, E. R., Selkoe, K. A., & Walbridge, S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature Communications*, *6*, Article 7615. https://doi.org/10.1038/ncomms8615

Halpern, B. S., Kappel, C. V., Selkoe, K. A., Micheli, F., Ebert, C. M., Kontgis, C., Crain, C. M., Martone, R. G., Shearer, C., & Teck, S. J. (2009). Mapping cumulative human impacts to California current marine ecosystems. *Conservation Letters*, *2*(3), 138–148. https://doi.org/10.1111/j.1755-263X.2009.00058.x

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., Bruno, J. F., Casey, K. S., Ebert, C., Fox, H. E., Fujita, R., Heinemann, D., Lenter, H. S., Madin, E. M. P., Perry, M. T., Selig, E. R., Spalding, M., Steneck, R., & Watson, R. (2008). A global map of human impact on marine ecosystems. *Science*, *319*(5865), 948–952. https://doi.org/10.1126/science.1149345

Haward, M., & Vince, J. (2009). Australian ocean governance—Initiatives and challenges. *Coastal Management*, *37*(1), 1–16. https://doi.org/10.1080/08920750802475368

Hoegh-Guldberg, O., Hughes, L., McIntyre, S., Lindenmayer, D. B., Parmesan, C., Possingham, H. P., &

Thomas, C. D. (2008). Assisted colonization and rapid climate change. *Science*, *321*(5887), 345–346. https://doi.org/10.1126/science.1157897

Hügel, S., & Davies, A. R. (2020). Public participation, engagement, engagement, and climate change adaptation: A review of the research literature. *WIREs Climate Change*, *11*(4), Article e645. https://doi.org/10.1002/wcc.645

Jaeckel, A., Gjerde, K. M., & Ardron, J. A. (2017). Conserving the common heritage of humankind—Options for the deep-seabed mining regime. *Marine Policy*, *78*, 150–157. https://doi.org/10.1016/j.marpol.2017.01.019

Kim, R. E. (2024). The likely impact of the BBNJ Agreement on the architecture of ocean governance. *Marine Policy*, *165*, Article 106188. https://doi.org/10.1016/j.marpol.2024.106190

Lee, S., Paavola, J., & Dessai, S. (2023). Causal mechanisms of common barriers to national adaptation policy processes and practical solutions in South Korea and the UK. *Global Sustainability*, *6*, Article e11. https://doi.org/10.1017/sus.2023.10

Lin, B. B., Ossola, A., Alberti, M., Andersson, E., Bai, X., Dobbs, C., Elmqvist, T., Evans, K. L., Frantzeskaki, N., Fuller, R. A., Gaston, K. J., Haase, D., Jim, C. Y., Konijnendijk, C., Nagendra, H., Niemelä, J., McPhearson, T., Moomaw, W. R., Parnell, S., . . . Tan, P. Y. (2021). Integrating solutions to adapt cities for climate change. *The Lancet Planetary Health*, *5*(7), e479–e486. https://doi.org/10.1016/S2542-5196(21)00135-2

Oliver, T. H., & Morecroft, M. D. (2014). Interactions between climate change and land use change on biodiversity: Attribution problems, risks, and opportunities. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(3), 317–335. https://doi.org/10.1002/wcc.271

Parmesan, C., Burrows, M. T., Duarte, C. M., Poloczanska, E. S., Richardson, A. J., Schoeman, D. S., & Singer, M. C. (2013). Beyond climate change attribution in conservation and ecological research. *Ecology Letters*, *16*(S1), 58–71. https://doi.org/10.1111/ele.12098

Pinsky, M. L., Worm, B., Fogarty, M. J., Sarmiento, J. L., & Levin, S. A. (2013). Marine taxa track local climate velocities. *Science*, *341*(6151), 1239–1242. https://doi.org/10.1126/science.1239352

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*, *90*(5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Rudolph, T. B., Ruckelshaus, M., Swilling, M., Allison, E. H., Österblom, H., Gelcich, S., & Mbatha, P. (2020). A transition to sustainable ocean governance. *Nature Communications*, *11*, Article 3600. https://doi.org/10.1038/s41467-020-17410-2

Shih, Y.-C. (2024). Ocean governance in practice: A study of the application of marine science and technology research techniques to maritime law enforcement in Taiwan. *Marine Policy*, *163*, Article 106081. https://doi.org/10.1016/j.marpol.2024.106081

Shih, Y.-C. (2025). A study of marine environmental protection and biodiversity observation and monitoring mechanisms in Taiwan. *Frontiers in Marine Science*, *12*, Article 1605996. https://doi.org/10.3389/fmars.2025.1605996

Spalding, A. K., & de Ycaza, R. (2020). Navigating shifting regimes of ocean governance: From UNCLOS to Sustainable Development Goal 14. *Environment and Society*, *11*(1), 5–26. https://doi.org/10.3167/ares.2020.110102

Suprayitno, D., Iskandar, S., Dahurandi, K., Hendarto, T., & Rumambi, F. J. (2024). Public policy in the era of climate change: Adapting strategies for sustainable futures. *Migration Letters*, *21*(S6), 945–958. https://migrationletters.com/index.php/ml/article/view/8068

Tvinnereim, E., & Fløttum, K. (2015). Explaining topic prevalence in answers to open-ended survey questions about climate change. *Nature Climate Change*, *5*, 744–747. https://doi.org/10.1038/nclimate2663

UN Framework Convention on Climate Change. (n.d.). *The Paris agreement*. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

UN. (2015). *Transforming our world: The 2030 agenda for sustainable development*. https://sdgs.un.org/2030agenda

Virtanen, E. A., Kallio, N., Nurmi, M., Jernberg, S., Saikkonen, L., & Forsblom, L. (2024). Recreational land use contributes to the loss of marine biodiversity. *People and Nature*, *6*(5), 1758–1773. https://doi.org/10.1002/pan3.10444

Williams, J. W., Ordonez, A., & Svenning, J.-C. (2021). A unifying framework for studying and managing climate-driven rates of ecological change. *Nature Ecology & Evolution*, *5*, 17–26. https://doi.org/10.1038/s41559-020-01344-5

Winther, J.-G., Dai, M., Rist, T., Hoel, A. H., Li, Y., Trice, A., Morrissey, K., Juinio-Mez, M. A., Fernandes, L., Unger, S., Scarano, F. R., Halpin, P., & Whitehouse, S. (2020). Integrated ocean management for a sustainable ocean economy. *Nature Ecology & Evolution*, *4*, 1451–1458. https://doi.org/10.1038/s41559-020-1259-6

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., Jackson, J. B. C., Lotze, H. K., Micheli, F., Palumbi, S. R., Sala, E., Selkoe, K. A., Stachowicz, J. J., & Watson, R. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science*, *314*(5800), 787–790. https://doi.org/10.1126/science.1132294

Yadav, S. S., & Gjerde, K. M. (2020). The ocean, climate change and resilience: Making ocean areas beyond national jurisdiction more resilient to climate change and other anthropogenic activities. *Marine Policy*, *122*, Article 104184. https://doi.org/10.1016/j.marpol.2020.104184

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