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Review

A Comprehensive Review of Climatic Threats and Adaptation of Marine Biodiversity

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Abstract: Oceans play a vital role in socioeconomic and environmental development by supporting activities such as tourism, recreation, and food provision while providing important ecosystem services. However, concerns have been raised about the threat that climate change poses to the functions of oceans. This study examines the impacts, threats, and adaptation strategies of climate change and marine biodiversity. Using bibliometric and secondary data analysis, this study determines that climate change leads to rising sea temperatures, marine heatwaves, acidification, and increasing sea levels. These factors undermine the significance of ocean ecosystem services. This study also identifies the significant risks posed by climate change to marine species diversity and distribution, primarily through habitat degradation and shifts in species ranges. Scholarly focus on these challenges has grown over time, focusing on adaptation strategies and building resilience to mitigate adverse impacts. This study critically evaluates various adaptation measures, including nature-based and human-based solutions such as habitat restoration, policy and legislative frameworks, and their potential to protect marine ecosystems. It provides detailed discussions on the effectiveness of adaptation strategies such as marine protected areas (MPAs), mangrove and coral reef restoration, and species range shifts. This review also emphasises the significance of indigenous knowledge systems and community participation in marine conservation efforts to achieve holistic and sustainable management. It highlights the need for enhanced international cooperation and a transdisciplinary approach to address the complex interplay between climate change and marine biodiversity. Additionally, this study suggests that funding for research gaps and conservation can be secured through tourism revenue and other climate funding mechanisms.

Keywords: marine biodiversity; climate change adaptation; marine protected areas (MPAs); habitat restoration; sustainable ocean management; VOSviewer

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1. Introduction

Oceans play a central role in the socioeconomic development of many countries worldwide [1–3]. They provide numerous ecosystem services [4]. As a result, a significant portion of the population (about 40%) resides near the coastline [5]. Oceans also serve as recreational and tourist destinations [6]. Many coastal areas have multiple beaches, attracting millions of people who come to enjoy these tourism offerings [7–9]. In addition to beaches, oceans are utilised by tourists and recreation enthusiasts for activities such as snorkelling, water sports, and other recreational pursuits that are crucial for human well-being and development in the context of marine tourism [10]. These tourism activities support millions of jobs, livelihoods, and communities [11].

Oceans are home to numerous species of plants and animals [12,13]. These marine animals and plant species are crucial for maintaining a vibrant marine ecosystem and biodiversity. Some of these animals and plants are harvested and utilised by humans daily. Marine fish, for example, are consumed by people from all social classes and are

an important source of nutrition [14]. In many impoverished communities, fish species effectively address issues of malnutrition and food insecurity [15]. Ocean fish also play a central role in poverty alleviation efforts in fish-dependent communities [16,17].

Oceans are central in weather and climate, as they determine weather systems [18,19]. They also act as carbon sinks, making them crucial in the fight against climate change [20]. Additionally, oceans trap a significant amount of heat [21,22], helping to regulate global temperatures, which are increasing because of global warming. Because of these factors, oceans are considered essential in driving several Sustainable Development Goals (SDGs) [23]. Through various mechanisms, oceans can contribute to addressing the global challenges society faces today.

Oceans have faced multiple challenges and threats from anthropogenic activities despite their importance. The current challenges of climate change have not spared them [24–26]. The growth in the global human population has burdened the oceans [27,28], leading to immense pollution. Plastic from various human activities is an ocean eyesore and a threat to marine life [29]. Additionally, the oceans have suffered greatly from devastating oil spills that have harmed marine life [30], threatening their sustainability. From a climate perspective, the oceans have borne the brunt of rising sea levels [31,32], ocean acidification [33], and global warming, resulting in ocean warming [34].

In recognition of the threats faced by the oceans, the United Nations has declared the period from 2021 to 2030 as the Decade of Ocean Science for Sustainable Development. This initiative aims to celebrate the role of oceans while also addressing and tackling the various threats they face. The Decade of Ocean Science for Sustainable Development calls for increased ocean research to better understand these threats and find solutions, including climate change [35].

This study is a response to that call, and its objective is to conduct a comprehensive review of the climatic threats to marine biodiversity and evaluate the state of scientific knowledge. This study, therefore, seeks to conduct a comprehensive review of climate threats to marine biodiversity and explore adaptation strategies. This study also aims to identify key trends and gaps to inform future research and conservation efforts. This study contributes to the state of climate change knowledge on oceans to inform policy and practice regarding climatic threats to biodiversity and adaptation strategies. It also identifies key research priorities.

2. Materials and Methods

This study employed a multi-method approach to address the research question effectively. The adopted approaches included a critical literature review and systematic document analysis of Scopus Indexed articles published between 2003 and 2023. Only material that was published during the period in question was included and had to address issues of climate change impacts and adaptation on marine life. This study used specific search terms, such as “climate change”, “marine biodiversity”, and “adaptation”, to identify relevant documents. A total of 295 documents were identified, out of which 290 were in English and aligned with the study’s thematic areas. The abstracts of all 290 documents were thoroughly examined. Figure 1 provides an overview of the reviewed articles. Once it was confirmed that the articles were relevant to the study, they were exported in CSV format from the Scopus database and saved in a folder for analysis using VOSviewer version 1.6.20. VOSviewer offers various analysis options, such as core authorship, keyword co-occurrence, citation, bibliographic coupling, and co-citation maps. In this study, co-occurrence analysis was conducted, with all keywords considered, and full counting was used as the counting method. A minimum threshold of ten keyword occurrences was set, resulting in 82 articles meeting this criterion. The total strength of co-occurrence links with other keywords was calculated for each of the 82 keywords. The keywords with the highest total link strength were selected for further analysis.

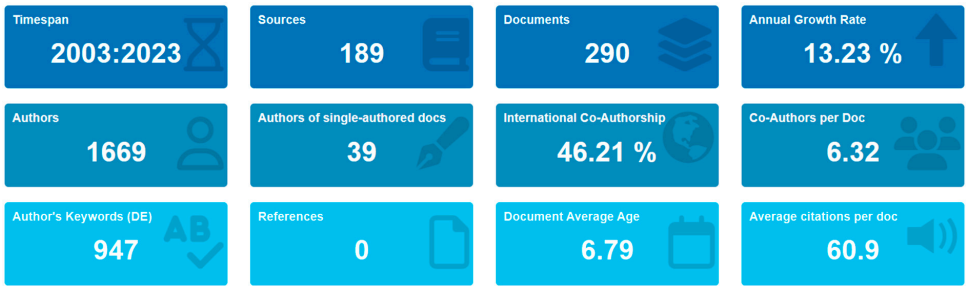


Figure 1. Mapping of the articles used for systematic literature review and bibliometric analysis Source: Author compilation.

Additional analysis was conducted using R version 4.3.2. Bibliometric analysis for this was equally exported using Scopus BibTeX. These were run using the biblioshiny function. The following command was entered: > library (bibliometrix). After that, to prompt the Biblioshiny app, the digit biblioshiny () was punctured into the system. Various prompts were conducted, as developed by Aria and Cuccurullo [36].

Critical document analysis was conducted for the 82 documents, categorised under the documents that address climate change impacts on marine biodiversity and those that deal with how marine biodiversity adapts to climate-related environmental changes. Content and thematic analyses were used to analyse these data under these broad categories and relevant subthemes for each to ensure the write-up. Major themes fell under two broad categories: climate change's impact on marine ecosystems and adaptation. From the adaptation perspective, an exploration of ecosystem-based approaches and human interventions from an economic and social perspective was explored. To enrich the study, additional secondary data on the state of oceans were obtained from archival data and placed in the current context. Data used in the Intergovernmental Panel on Climate Change IPCC were used to identify gaps and future scenarios and support, substantiate, and triangulate findings from bibliometric data findings. To this end, the study is not a mere analysis of historical studies. Rather, it provides a comprehensive picture of realities with regard to marine life and the nexus of climate change.

3. Results

3.1. Publication Trends in Climate Change and Marine Biodiversity

This study examined materials published in Scopus Index journal outlets from 2003 to 2023 (Figure 2). It found that the number of articles studying climate change, marine biodiversity, and adaptation increased from about 2 publications to over 25 publications by the end of 2023. Overall, there has been a consistent rise in the number of publications addressing these topics. This increase can be attributed to the growing challenges faced by marine biodiversity due to the escalating impact of climate change.

This study revealed that most publications (61.3%) consist of journal articles (Figure 3). Additionally, a significant portion of the publications were in the form of reviews, bringing the total combined percentage of articles to over 80%. On the other hand, book chapters accounted for approximately 11% of the publications, indicating that the issue of climate change and marine biodiversity has not received much attention in this format. Similarly, conference proceedings have not extensively covered the topics of climate change and marine biodiversity adaptation. The Scopus Index accounted for a mere 4.1% of the publications, which could be attributed to the complexity and high financial costs of conducting such studies.

The studies conducted on marine biodiversity adaptation and climate change have been transdisciplinary, with many published regarding environmental science, agriculture, and biology. A substantial number of publications were also found regarding Earth and planetary science and social sciences. A transdisciplinary approach is crucial to addressing all aspects of this important research area, as it enables the consideration of multiple perspectives when tackling these issues.

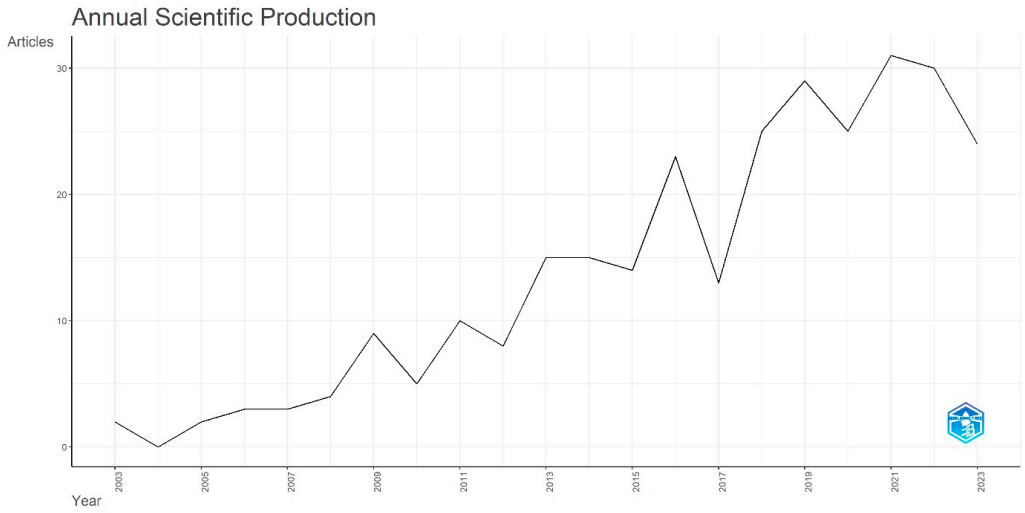


Figure 2. Trend in the number of publications on climate change and marine biodiversity adaptation.

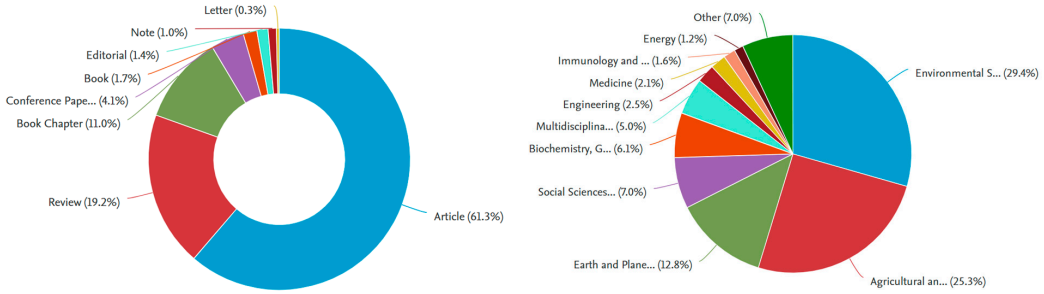


Figure 3. Marine biodiversity adaptation and climate change publication outlets and research areas.

As with other areas of scientific inquiry, researchers in the Global North have been more invested in climate change and marine biodiversity than Global South academics, judging by the volume of work produced, as seen in Figure 4. This study found that, in most cases, these studies were conducted by states with coastlines with the highest concentrations. These studies were conducted by the USA, the United Kingdom, Australia, Canada, France, and other states in the Global North. Very little has been done in Africa, with studies emerging in South Africa and several states in South America. Only a few states in South America have not explored the dynamics of biodiversity and climate change in that region. On the other hand, no studies have been conducted in many states on the west coast of Africa and in island states such as Madagascar. This could point to significant knowledge gaps in some regions. There are also significant knowledge gaps in the Arctic region. It is worth noting the considerable interest exhibited in this matter by Asian countries, including China.

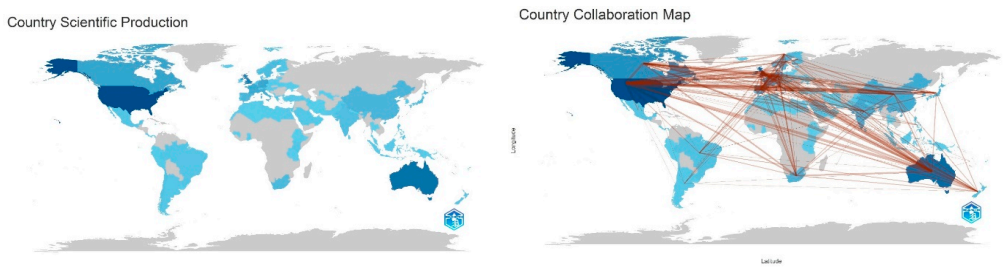


Figure 4. Publishing countries and collaborations between countries.

With regards to collaborations, there has been much collaboration between the North and North and very little to talk about between the North and the South. Most collaborating

researchers were from the United States, which had collaborations with researchers from 66 countries; USA researchers have worked with researchers from 64 countries; Germany, 48 countries; and Australia and France, 47 countries. South African researchers collaborated with 28 countries, but none of the countries South Africa collaborated with are top publishers in the space.

3.2. Research Focus Area in Climate Change and Marine Biodiversity

Over time, there has been an evolution in the discussions about climate change, marine biodiversity, and climate change, as shown in Figure 5. Climate change has been a central issue. There has been an acknowledgement that anthropogenic climate change has been responsible for multiple challenges affecting marine biodiversity. The work conducted thus far covers a range of issues that have transformed over time, given the evolving development within the climate change space.

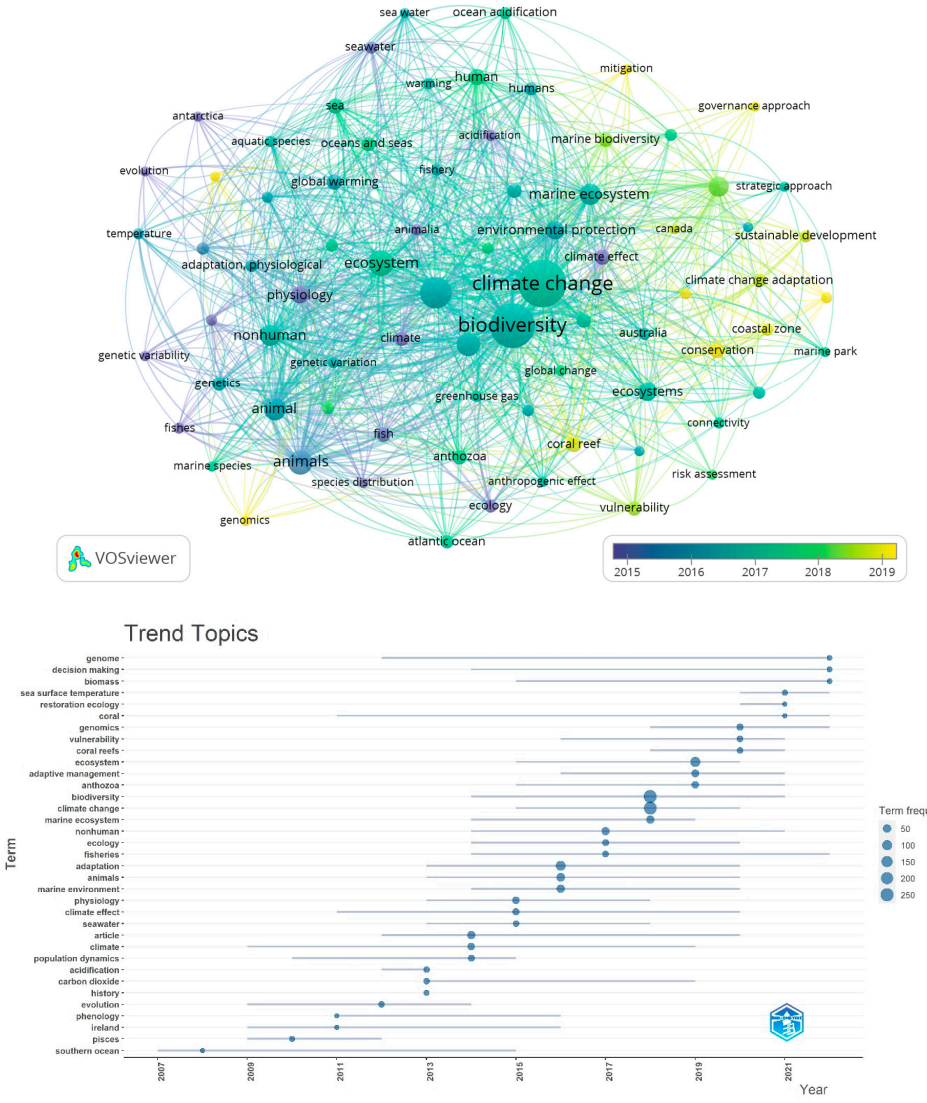


Figure 5. Trend in marine biodiversity and climate change, 2003–2023.

3.3. Impact of Climate Change on Marine Biodiversity

Chaudhary et al. [37], one of the most cited scholars in the field of climate change and marine biodiversity, cite global warming as a key driver of climate change, which poses a challenge to marine biodiversity. The increase in sea surface temperatures, a topic that has been extensively researched in the field of climate change and marine biodiversity

(Figure 5), is believed to be responsible for latitudinal shifts in marine species. This study found that, as temperatures rise, there has been a decline in species and species richness along the equator, with species moving towards the poles in search of more suitable habitats. These findings are supported by other scholars, such as Lin et al. [38], who studied marine fish at various taxonomic levels and observed decreased species diversity at the equator, with the Northern Hemisphere having greater species diversity. In another study, Lin et al. [39] found that the number of fish species with higher taxon and phylogenetic similarity decreases with latitude and ocean depth because of climate change. Lin and Costello [40] also found that fish body size and trophic level increase with latitude because of climate change, likely because of changes in temperature and oxygen levels. On the other hand, Manes et al. [41] noted that the projected increase in temperature could lead to the extinction of endemic marine and island species. These changes concern ecologists and the general population that relies on fish species, as they can limit access to critical protein sources, particularly in developing countries.

The increase in water temperature is blamed for altering water's physical and chemical quality by causing changes in its oxygen levels. An increase in water temperature reduces the solubility of oxygen in ocean water. This has resulted in declining oxygen levels in ocean water and coastal waters, with serious adverse effects on biogeochemical cycles and global food security [42]. According to Santos [43], the decline in oxygen in sandy beaches has resulted in changes in pH, which have been linked to declines in species richness and the extinction of certain species.

Kim et al. [44] conducted a comprehensive study of 741 scleractinian coral species from various parts of the world. They found that coral reefs are under immense pressure and vulnerability worldwide. The highest vulnerabilities were noted in the tropics, specifically in areas close to the equator in America; the Southwest African tropics; and areas around Australasia's tropics, particularly in areas surrounding Australia. Coral in high latitudes was found to be less vulnerable than in the tropics. The extreme weather events unleashed by climate change and anthropogenic activities have contributed to this vulnerability. The tropics have witnessed several extreme weather events that threaten coral reefs, such as increased heatwaves. Holbrook et al. [45] found that the occurrence of marine heatwaves is a challenge, causing the destruction of marine life and biodiversity and requiring adaptive measures to be put in place. This notion was supported by Welch et al. [46], who argued that observed marine heatwave episodes have resulted in shifts in various marine species, including marine predators. The Southern Hemisphere and coastal species have been particularly affected, and the highest impact has been felt in areas that have experienced the highest intensity of marine heatwaves.

The fisheries were equally affected by marine heatwaves between 2015 and 2018, raising societal concerns. Marine heatwaves resulted in a drastic decline in fish stocks at a rapid rate and a decrease in other biodiversity [47]. Consequently, it is easy to see that climate change has implications for the physiology of flora and fauna, ultimately affecting species richness and diversity.

Apart from suffering the harsh realities of global warming caused by anthropogenic-driven climate change, tropical species must also battle other extreme weather events that adversely impact coral reefs. Extreme weather events, such as tropical cyclones in some coral-reef-rich regions, like the Southwest Indian Ocean [48], have faced tremendous tropical cyclones in the recent past, which could have damaged mangroves and coral reefs. High tides and high winds that often characterise tropical cyclones can physically damage coral reefs. Cheal et al. [49] found that tropical cyclones of higher intensity have severely damaged large swaths of coral reefs in the Great Barrier Reef, with the worst expected as tropical cyclones are expected to increase their intensity with increased global warming [50]. While Dixon et al. [51] acknowledged the risk to coral reefs from tropical cyclones, they also noted the complexity of this risk as some downscaled data point to mixed results depending on the characteristics of cyclones in Western Australia.

In Madagascar, a study of the relationship between tropical cyclones and coral reefs found that tropical cyclones have decreased coral cover by 1.4% to 45.8% because of the damaging effect of wind and sea surges. Nevertheless, evidence shows that these corals have recovered and exceeded pre-cyclone periods after these tropical cyclones. Of concern are the adverse changes in the taxonomic structure of corals that emerge after a tropical cyclone, which could alter the aquatic ecosystem of coral reefs. In Taiwan, Lin et al. [52] found the impact of tropical cyclones to be damaging in marine protected areas. This pattern is more or less the same in other areas with coral reefs, such as the Philippines [53] and other areas in the Americas that are prone to tropical cyclones.

Changes in rainfall patterns also have an effect on ocean biodiversity. Changes in precipitation patterns can increase freshwater runoff and sediments in coastal waters. This can smother corals and disrupt their delicate balance with surrounding marine life. This is supported by Adam et al. [54], who argued that rainfall patterns on land impact coral communities and their biodiversity. Haapkylä et al. [55] argued that increased rainfall results in diseases for corals near the shore, which leads to biodiversity loss. Undoubtedly, the increased incidence of drought would affect biodiversity in coastal communities, as it will alter sea–land water interactions, resulting in changes in the chemical composition of the water. This could be compounded by the rise in sea levels, resulting in changes to the ocean ecosystem [56]. Other land activities, such as global warming, can affect the productivity of sea turtles and their food chain in the ocean [57].

Sea level rise, one of the global community's challenges, is also challenging for marine biodiversity in many respects [58]. Rising sea levels can significantly impact coastal ecosystems, including algal rims and plant communities in salt marshes. Part of the observed evidence of the destructive effects of rising sea levels is the destruction of mangroves, critical habitats for marine species [59]. Mangroves have suffered the worst of various aspects of climate change, including rising sea levels, destruction from coastal erosion due to rising sea levels, and coastal flooding [60–62].

4. Discussion

This study identifies multiple threats to marine ecosystems and biodiversity. Multiple threats and stressors to ocean marine life and ecosystems have evolved as climatic threats have evolved. These threats are not uniform and vary depending on the latitudinal location of the ocean space. The threats to marine biodiversity are a concern, as they affect the capacity to provide ecosystem services crucial for human socioeconomic development. While studies have been conducted that cover climatic threats, there are still uncertainties concerning some threats regarding the level of threat posed by some climatic parameters, given knowledge gaps on how continued changes in the climate will play out in the future and how such changes will alter marine life.

While there has been much interest in evaluating the impact of climate change on biodiversity over the years, intense focus has also been paid to addressing adaptation measures to deal with the adverse impacts of climate emergence (Figure 4). This is critical to ensuring that the ecosystem services provided by oceans, such as tourism, recreation, food, and other human needs, are protected from being adversely affected by climate change. The following section addresses some of the measures that have been proposed and have dominated the climate change marine and biodiversity debate.

4.1. Adaptation of Marine Biodiversity

There is no denying that oceans serve a significant role in providing critical ecosystem services. However, addressing the interplay between marine biodiversity, climate change, and adaptation strategies is a multifaceted and critical issue that requires the global community to address the increased carbon emissions that drive climate change and that are a crucial driver of ocean acidification, threatening marine ecosystems.

The studies (Figure 5) demonstrated the importance of climate change adaptation, a theme that has gained traction in recent years (2017–2023). Adaptation and resilience

building are critical to ensuring marine life does not collapse or go extinct because of climate change pressure. Among other things, it is clear that the need for marine biodiversity conservation is a key consideration that has also gained traction in achieving sustainable development [63]. Academics suggest a range of adaptation measures, which are being put forward to ensure that marine biodiversity is protected. Climate adaptation can counteract the outcomes of environmental changes through genetic adaptation and acclimatisation, range shifts, and modifications to community compositions for some species.

4.2. Nature-Based Adaptation Solutions to Climatic Threats to Marine Ecosystems

There is also a strong push towards establishing marine protected areas as adaptation measures to climate change and other human impacts. Evidence shows that only a small portion of the oceans have been designated as protected areas (Figure 6). Of the protected areas, 29,583,671 km^2 (or 8.16%) of the ocean is covered by MPAs, as seen in Figure 6, shown in dark blue. Most of the ocean space remains vulnerable to climate and human impacts.

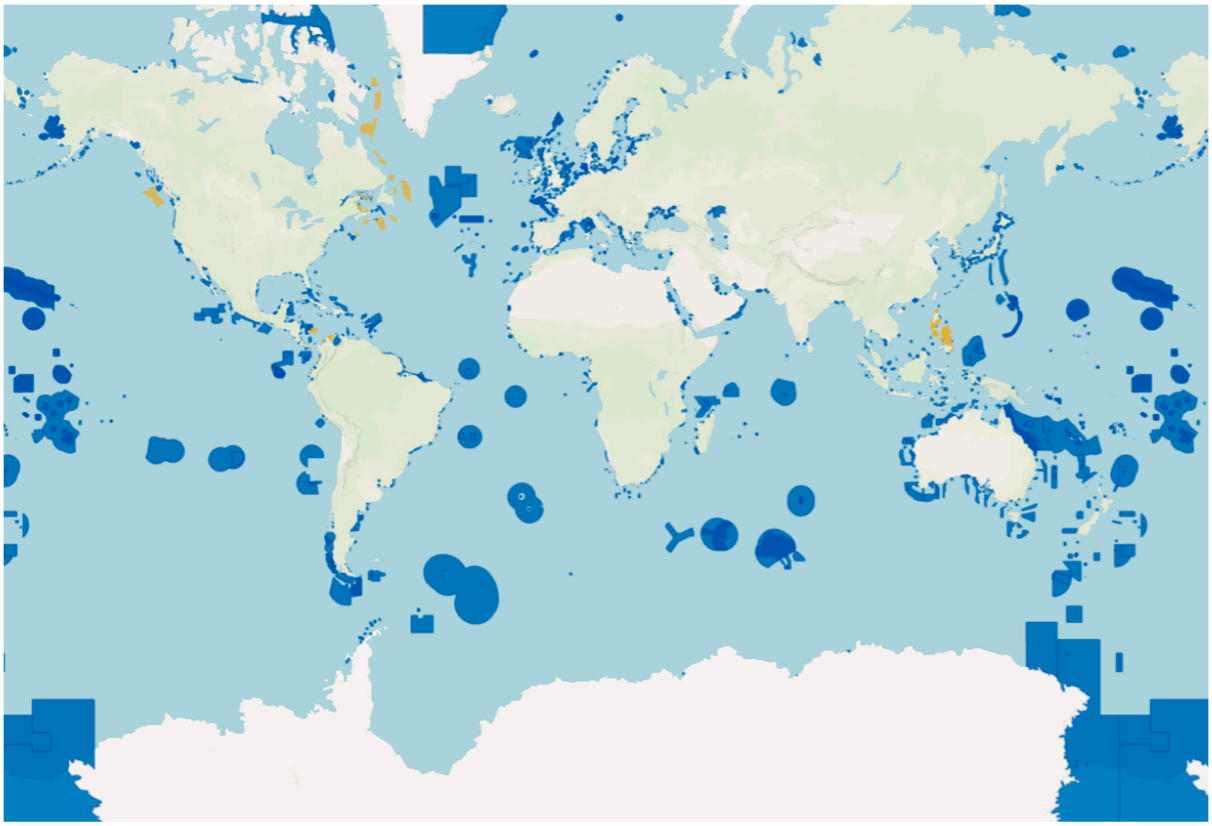


Figure 6. Distribution of marine protected areas (MPAs). Source: Protected Planet [64].

Climate change has also been noted to adversely affect mangroves, which play a central role in protecting coastal marine biodiversity. Mangrove and coral reef restoration are being championed as part of nature-based solutions to tackle climate change [65,66]. Mangrove restoration has been conducted across the world with varying levels of success depending on socioeconomic and environmental conditions at various sites [67,68]. Given the centrality of coral reefs, some adaptation techniques have focused on finding innovative ways to restore corals through scientific measures [6,69,70]. Various strategies for coral propagation have been adopted to ensure their resilience and restore the habitat for marine life. Methods such as coral gardening have shown varying degrees of success depending on the methods employed [71].

Other scholars believe that marine species have been involved in range shifts as an adaptation strategy. The range shift mechanism involves species moving to new areas with more favourable environmental conditions [72,73]. This adaptation technique has been

observed in both terrestrial and marine species. Range shifts typically occur poleward or upward on land and can manifest as depth shifts at sea. However, range shifts may be constrained by factors like habitat fragmentation and time, particularly for sessile species. The poleward shift in species will create challenges for those regions species are moving away from. There are also fears that this adaptation will result in challenges, as it will disrupt the food chain for higher-latitude areas by introducing new predators to those ecosystems [73].

Climate change can significantly alter community compositions through trophic, parasitic, and mutualistic network changes. This reorganisation of species assemblages can lead to ecosystem adaptation, but it can also result in the loss of important functional traits or functions, particularly if key species are affected. Therefore, this form of adaptation is problematic in many respects, and there is much uncertainty in this regard (Figure 7).

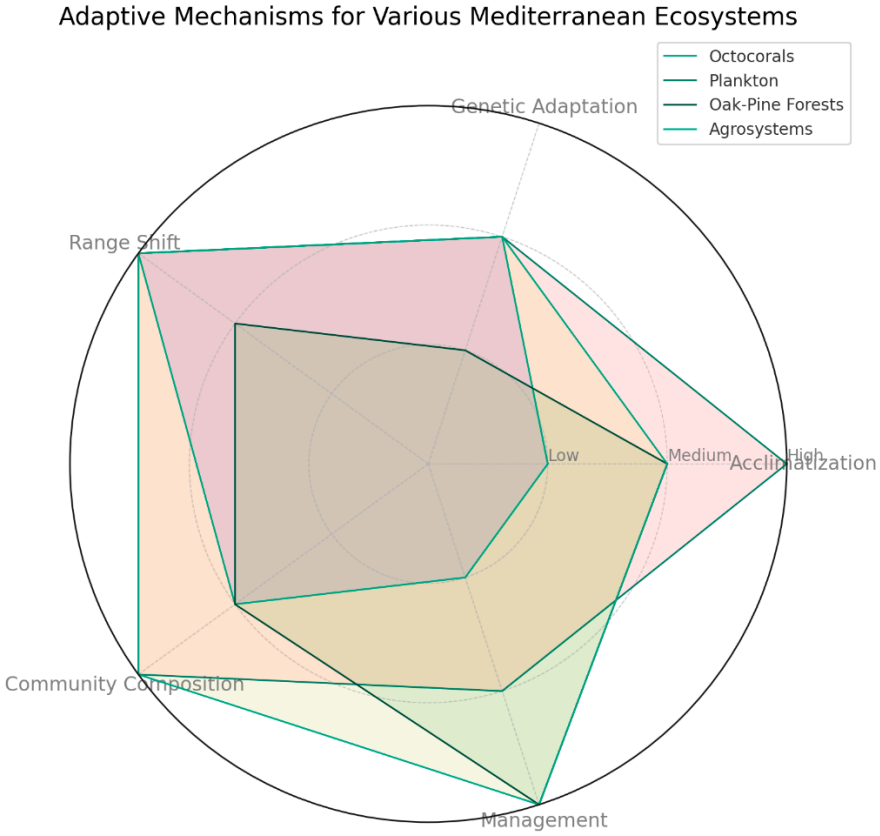


Figure 7. Some adaptation measures for various Mediterranean ecosystems.

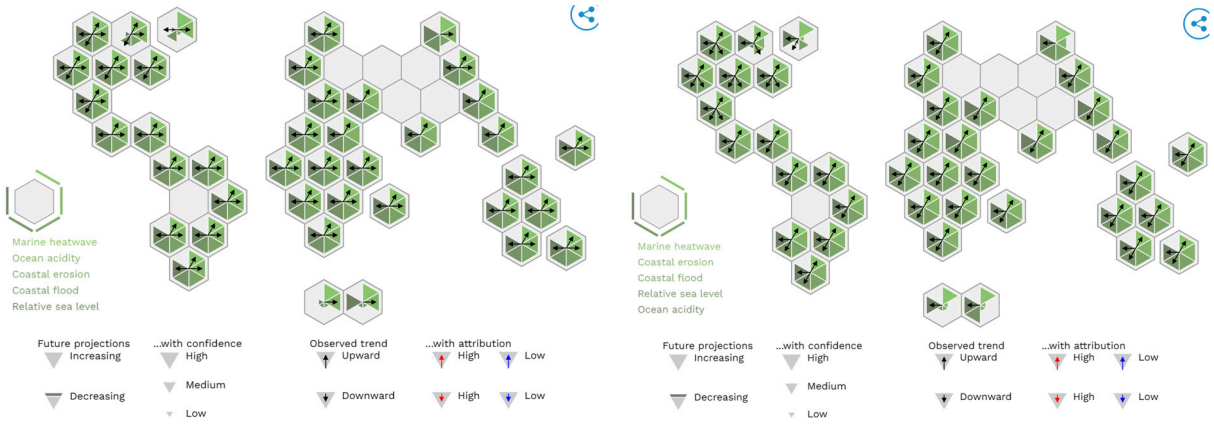
4.3. Human Adaptation Strategies for Climate Change and Marine Biodiversity

Policy and legislation are believed to play a central role in the marine adaptation space. They shape action and assist in shaping marine biodiversity action. Local and international actions, such as the Paris Agreement and Agenda 2030 for Sustainable Development (also known as the Sustainable Development Goals) have been central in shaping climate change action and promoting sustainable development. The EU's Marine Environmental Policy has been used to drive European marine biodiversity protection.

The Convention on Biological Diversity protects biodiversity and has expanded marine protected areas (MPAs) in South Africa, which help protect marine life along the coastline. This legal and policy framework provides directives and resources to protect marine species, including financial resources for activities like anti-poaching in MPAs. Indigenous knowledge systems and coastal community participation are also important in protecting marine biodiversity, especially in areas under the jurisdiction of indigenous communities. Environmental education, research, and monitoring are critical in raising awareness and shaping adaptation debates.

4.4. Gaps and Future Research Focus Areas

There are still gaps in knowledge regarding past and future ocean climate scenarios for several geographic regions (Figure 8), with the IPCC AR6 noting that confidence levels on some aspects still need to be improved, which requires additional research and understanding. Given these knowledge gaps, there are limitations regarding how marine life can adapt to climate change, and continued research and monitoring are needed. Climate change can affect marine life genetics, and continuous monitoring and research are necessary. Some regions lack the financial resources needed for marine ecosystem research, so unlocking funding is important for biodiversity protection and understanding geographic knowledge gaps. As the field of marine biodiversity and climate change science grows, there is a need to refine sampling and modelling techniques to reduce bias and uncertainties.



(**a**) (**b**)

Figure 8. (**a**) Past ocean climate change parameter changes and (**b**) future climatic trends. Source: IPCC [74].

5. Conclusions

This study found that the relationship between marine biodiversity and climate change is complex, given the ocean's various interacting factors. Major threats identified by this study include the impact of increasing sea ocean temperatures, rising sea levels, increased intensity of tropical cyclones, changing oceanic wind systems, coastal flooding and erosion, ocean deoxygenation, and ocean acidification, to mention but a few. The threat from climate change is often worsened and compounded by other human activities, such as ocean and coastal pollution, with devastating impacts on marine life, altering the rich ocean biodiversity. Several species are at risk of extinction from climate change and other anthropogenic activities. While marine biodiversity faces significant threats from climate change, there is clear evidence of resilience from certain climatic parameters. With uncertainties on how climate change will affect the ocean's marine environment and species, there is a need to put conservation and adaptation measures in place. This study found that there are diverse adaptation strategies to ensure the protection of marine biodiversity. Such adaptation measures range from direct actions like habitat restoration to broader approaches like international policy agreements. The success of these strategies hinges on a combination of scientific understanding, international cooperation, and local engagement.

Increased threats from climate change and uncertainties mean that there is a need for continued research in some areas and continued conservation protection of certain species. Such research and conservation require financing, and there is a need to unlock funding for the same, particularly those activities that benefit from marine resources, such as tourism and recreation. The current global climate finance mechanism must provide criteria that provide funding for research, conservation, and the protection of marine resources to ensure the sustainability of ocean marine life going forward.

In many spheres, there is a need for more comprehensive data on the impacts of climate change on marine biodiversity. Achieving this requires international collaboration to address global issues like climate change. Regarding climate change adaptation, marine ocean climate change science needs to adopt flexible and adaptive strategies to changing conditions.

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References

1. Nash, K.L.; van Putten, I.; Alexander, K.A.; Bettiol, S.; Cvitanovic, C.; Farmery, A.K.; Flies, E.J.; Ison, S.; Kelly, R.; Mackay, M.; et al. Oceans and society: Feedbacks between ocean and human health. *Rev. Fish Biol. Fish.* **2022**, *32*, 161–187. [CrossRef]
2. Fleming, L.E.; Rabbottini, L.; Depledge, M.H.; Alcantara-Creencia, L.; Gerwick, W.H.; Goh, H.C.; Bennett, B. Overview of Oceans and Human Health. In *Oceans and Human Health*; Lora, L.B.-G., Fleming, E., Eds.; Academic Press: Cambridge, MA, USA, 2023; pp. 1–20.
3. Baker, S.; Constant, N.; Nicol, P. Oceans justice: Trade-offs between Sustainable Development Goals in the Seychelles. *Mar. Policy* **2023**, *147*, 105357. [CrossRef]
4. Cordero-Penín, V.; Abramic, A.; García-Mendoza, A.; Otero-Ferrer, F.; Haroun, R. Mapping marine ecosystem services potential across an oceanic archipelago: Applicability and limitations for decision-making. *Ecosyst. Serv.* **2023**, *60*, 101517. [CrossRef]
5. Barros-Platiau, A.F.; Câmara, P.E.; de Oliveira, C.C.; Granja e Barros, F.H. Ocean Governance in the Anthropocene: A New Approach in the Era of Climate Emergency. In *Eco-Politics and Global Climate Change*; Tripathi, S.B., Ed.; Springer Nature: Cham, Switzerland, 2024; pp. 59–72.
6. Dube, K.; Nhamo, G.; Mearns, K. Beyond's response to the twin challenges of pollution and climate change in the context of SDGs. In *Scaling up SDGs Implementation: Emerging Cases from State, Development and Private Sectors*; Nhamo, G.O., Ed.; Springer: Cham, Switzerland, 2020; pp. 87–98.
7. Papageorgiou, M. Coastal and marine tourism: A challenging factor in Marine Spatial Planning. *Ocean Coast. Manag.* **2016**, *129*, 44–48. [CrossRef]
8. Yustika, B.P.; Goni, J.I.C. Network Structure in Coastal and Marine Tourism: Diving into the Three Clusters. *Tour. Plan. Dev.* **2020**, *17*, 515–536. [CrossRef]
9. Cisneros-Montemayor, A.M.; Townsel, A.; Gonzales, C.M.; Haas, A.R.; Navarro-Holm, E.E.; Salorio-Zuñiga, T.; Johnson, A.F. Nature-based marine tourism in the Gulf of California and Baja California Peninsula: Economic benefits and key species. *Nat. Resour. Forum* **2020**, *44*, 111–128. [CrossRef]
10. Morse, M.; McCauley, D.; Orofino, S.; Stears, K.; Mladjov, S.; Caselle, J.; Clavelle, T.; Freedman, R. Preferential selection of marine protected areas by the recreational scuba diving industry. *Mar. Policy* **2024**, *159*, 105908. [CrossRef]
11. Farjami, H.; Azizpour, J.; Andi, S. Manifestation of internal waves in the Southern Caspian Sea using satellite imagery. *Reg. Stud. Mar. Sci.* **2024**, *69*, 103294. [CrossRef]
12. Christensen, V.; Coll, M.; Buszowski, J.; Cheung, W.W.L.; Frölicher, T.; Steenbeek, J.; Stock, C.A.; Watson, R.A.; Walters, C.J. The global ocean is an ecosystem: Simulating marine life and fisheries. *Glob. Ecol. Biogeogr.* **2015**, *24*, 507–517. [CrossRef]
13. Davenport, T. Singapore and the Protection of the Marine Environment. In *Peace with Nature: 50 Inspiring Essays on Nature and the Environment*; Koh, T., Lye, H., Eds.; World Scientific: Singapore, 2024; pp. 63–68. [CrossRef]
14. Pradhan, S.K.; Nayak, P.K.; Haque, C.E. Mapping Social-Ecological-Oriented Dried Fish Value Chain: Evidence from Coastal Communities of Odisha and West Bengal in India. *Coasts* **2023**, *3*, 45–73. [CrossRef]
15. Sadik-Zada, E.R.; Ferrari, M.; Gonzalez, A.; Yusubova, L. Could Deep-Sea Fisheries Contribute to the Food Security of Our Planet? Pros and Cons. *Sustainability* **2023**, *15*, 14778. [CrossRef]
16. Robles-Zavala, E. Coastal livelihoods, poverty and well-being in Mexico. A case study of institutional and social constraints. *J. Coast. Conserv.* **2014**, *18*, 431–448. [CrossRef]
17. Damasio, L.M.A.; Pennino, M.G.; Villasante, S.; Carvalho, A.R.; Lopes, P.F.M. Adaptive factors and strategies in small-scale fisheries economies. *Rev. Fish Biol. Fish.* **2023**, *33*, 739–750. [CrossRef]
18. Zhang, D.; Chiodi, A.; Zhang, C.; Foltz, G.; Cronin, M.; Mordy, C.; Cross, J.; Cokelet, E.; Zhang, J.; Meinig, C.; et al. Observing Extreme Ocean and Weather Events Using Innovative Saildrone Uncrewed Surface Vehicles. *Oceanography* **2023**, *36*, 70–77. [CrossRef]
19. Alsayed, A.Y.; Alsaafani, M.A.; Al-Subhi, A.M.; Alraddadi, T.M.; Taqi, A.M. Seasonal Variability in Ocean Heat Content and Heat Flux in the Arabian Gulf. *J. Mar. Sci. Eng.* **2023**, *11*, 532. [CrossRef]

20. Gruber, N.; Bakker, D.C.; DeVries, T.; Gregor, L.; Hauck, J.; Landschützer, P.; Müller, J.D. Trends and variability in the ocean carbon sink. *Nat. Rev. Earth Environ.* **2023**, *4*, 119–134. [CrossRef]
21. Chen, Y.; Zhang, Z.; Wang, X.; Liu, X.; Zhou, M. Interannual variations of heat budget in the lower layer of the eastern Ross Sea shelf and the forcing mechanisms in the Southern Ocean State Estimate. *Int. J. Clim.* **2023**, *43*, 5055–5076. [CrossRef]
22. SO-CHIC Consortium; Sallée, J.B.; Abrahamsen, E.P.; Allaigre, C.; Auger, M.; Ayres, H.; Zhou, S. Southern ocean carbon and heat impact on climate. *Philos. Trans. R. Soc. A* **2023**, *381*, 20220056.
23. Pandey, U.C.; Nayak, S.R.; Roka, K.; Jain, T.K. Oceans and Sustainable Development. In *SDG14–Life Below Water: Towards Sustainable Management of Our Oceans*; Emerald Publishing Limited: Bingley, UK, 2021; pp. 17–42. [CrossRef]
24. Laubenstein, T.; Smith, T.F.; Hobday, A.J.; Pecl, G.T.; Evans, K.; Fulton, E.A.; O'Donnell, T. Threats to Australia's oceans and coasts: A systematic review. *Ocean Coast. Manag.* **2023**, *231*, 106331. [CrossRef]
25. Chen, J.; Chen, H.; Smith, T.F.; Rangel-Buitrago, N. Analyzing the impact and evolution of ocean & coastal management: 30 years in retrospect. *Ocean Coast. Manag.* **2023**, *242*, 106697.
26. Armoudian, M.; Stevens, G.; Stephenson, F.; Ellis, J. New Zealand's media and the crisis in the ocean: News norms and scientific urgency. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2023**, *33*, 606–619. [CrossRef]
27. Halpern, B.S.; Walbridge, S.; Selkoe, K.A.; Kappel, C.V.; Micheli, F.; d'Agrosa, C.; Watson, R. A global map of human impact on marine ecosystems. *Science* **2008**, *319*, 948–952. [CrossRef] [PubMed]
28. Mai, L.; He, H.; Sun, X.F.; Zeng, E.Y. Riverine inputs of land-based microplastics and affiliated hydrophobic organic contaminants to the global oceans. In *Microplastic Contamination in Aquatic Environments*; Zeng, E.Y., Ed.; Elsevier: Amsterdam, The Netherlands, 2024; pp. 311–329. [CrossRef]
29. Rangel-Buitrago, N.; Ben-Haddad, M.; Nicoll, K.; Galgani, F.; Neal, W.J. Marine plastic pollution in the Anthropocene: A linguistic toolkit for holistic understanding and action. *Ocean Coast. Manag.* **2024**, *248*, 106967. [CrossRef]
30. Samra, R.M.A.; Ali, R. Tracking the behavior of an accidental oil spill and its impacts on the marine environment in the Eastern Mediterranean. *Mar. Pollut. Bull.* **2024**, *198*, 115887. [CrossRef] [PubMed]
31. Dube, K.; Chapungu, L.; Fitchett, J. Meteorological and Climatic Aspects of Cyclone Idai and Kenneth. In *Cyclones in Southern Africa*; Sustainable Development Goals Series; Nhamo, G., Dube, K., Eds.; Springer: Cham, Switzerland, 2021; pp. 19–36. [CrossRef]
32. Mgadle, A.; Dube, K.; Lekaota, L. Conservation and Sustainability of Coastal City Tourism in the Advent of Seal Level Rise in Durban, South Africa. *Tour. Mar. Environ.* **2022**, *17*, 179–196. [CrossRef]
33. Figuerola, B.; Hancock, A.M.; Bax, N.; Cummings, V.J.; Downey, R.; Griffiths, H.J.; Stark, J.S. A review and meta-analysis of potential impacts of ocean acidification on marine calcifiers from the Southern Ocean. *Front. Mar. Sci.* **2021**, *8*, 584445. [CrossRef]
34. Baag, S.; Mandal, S. Combined effects of ocean warming and acidification on marine fish and shellfish: A molecule to ecosystem perspective. *Sci. Total. Environ.* **2022**, *802*, 149807. [CrossRef] [PubMed]
35. Pearlman, J.; Buttigieg, P.L.; Bushnell, M.; Delgado, C.; Hermes, J.; Heslop, E.; Hörstmann, C.; Isensee, K.; Karstensen, J.; Lambert, A.; et al. Evolving and Sustaining Ocean Best Practices to Enable Interoperability in the UN Decade of Ocean Science for Sustainable Development. *Front. Mar. Sci.* **2021**, *8*, 619685. [CrossRef]
36. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
37. Chaudhary, C.; Richardson, A.J.; Schoeman, D.S.; Costello, M.J. Global warming is causing a more pronounced dip in marine species richness around the equator. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2015094118. [CrossRef]
38. Lin, H.; Corkrey, R.; Kaschner, K.; Garilao, C.; Costello, M.J. Latitudinal diversity gradients for five taxonomic levels of marine fish in depth zones. *Ecol. Res.* **2021**, *36*, 266–280. [CrossRef]
39. Lin, H.-Y.; Wright, S.; Costello, M.J. Numbers of fish species, higher taxa, and phylogenetic similarity decrease with latitude and depth, and deep-sea assemblages are unique. *PeerJ* **2023**, *11*, e16116. [CrossRef] [PubMed]
40. Lin, H.-Y.; Costello, M.J. Body size and trophic level increase with latitude, and decrease in the deep-sea and Antarctica, for marine fish species. *PeerJ* **2023**, *11*, e15880. [CrossRef] [PubMed]
41. Manes, S.; Costello, M.J.; Beckett, H.; Debnath, A.; Devenish-Nelson, E.; Grey, K.-A.; Jenkins, R.; Khan, T.M.; Kiessling, W.; Krause, C.; et al. Endemism increases species' climate change risk in areas of global biodiversity importance. *Biol. Conserv.* **2021**, *257*, 109070. [CrossRef]
42. Breitburg, D.; Levin, L.A.; Oschlies, A.; Grégoire, M.; Chavez, F.P.; Conley, D.J.; Garçon, V.; Gilbert, D.; Gutiérrez, D.; Isensee, K.; et al. Declining oxygen in the global ocean and coastal waters. *Science* **2018**, *359*, eaam7240. [CrossRef] [PubMed]
43. Santos, D. Offshore extinctions: Ocean acidification impacting interstitial fauna. *Int. J. Environ. Sci. Technol.* **2023**, *20*, 6859–6864. [CrossRef]
44. Kim, S.W.; Sommer, B.; Beger, M.; Pandolfi, J.M. Regional and global climate risks for reef corals: Incorporating species-specific vulnerability and exposure to climate hazards. *Glob. Chang. Biol.* **2023**, *29*, 4140–4151. [CrossRef] [PubMed]
45. Holbrook, N.J.; Gupta, A.S.; Oliver, E.C.J.; Hobday, A.J.; Benthuysen, J.A.; Scannell, H.A.; Smale, D.A.; Wernberg, T. Keeping pace with marine heatwaves. *Nat. Rev. Earth Environ.* **2020**, *1*, 482–493. [CrossRef]
46. Welch, H.; Savoca, M.S.; Brodie, S.; Jacox, M.G.; Muhling, B.A.; Clay, T.A.; Cimino, M.A.; Benson, S.R.; Block, B.A.; Conners, M.G.; et al. Impacts of marine heatwaves on top predator distributions are variable but predictable. *Nat. Commun.* **2023**, *14*, 5188. [CrossRef]

47. Cheung, W.W.L.; Frölicher, T.L. Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific. *Sci. Rep.* **2020**, *10*, 6678. [CrossRef]
48. Dube, K. Tourism and climate change vulnerabilities: A focus on African destinations. In *Handbook on Tourism and Conservation*; Mbaiwa, J.E., Kolawole, O.D., Hambira, W.L., Mogende, E., Eds.; Edward Elgar Publishing: Cheltenham, UK, 2023; pp. 86–100.
49. Cheal, A.J.; MacNeil, M.A.; Emslie, M.J.; Sweatman, H. The threat to coral reefs from more intense cyclones under climate change. *Glob. Chang. Biol.* **2017**, *23*, 1511–1524. [CrossRef]
50. Dube, K.; Nhamo, G.; Chikodzi, D. Rising sea level and its implications on coastal tourism development in Cape Town, South Africa. *J. Outdoor Recreat. Tour.* **2021**, *33*, 100346. [CrossRef]
51. Dixon, A.M.; Puotinen, M.; Ramsay, H.A.; Beger, M. Coral Reef Exposure to Damaging Tropical Cyclone Waves in a Warming Climate. *Earth's Future* **2022**, *10*, e2021EF002600. [CrossRef]
52. Lin, Y.-C.; Feng, S.-N.; Lai, C.-Y.; Tseng, H.-T.; Huang, C.-W. Applying deep learning to predict SST variation and tropical cyclone patterns that influence coral bleaching. *Ecol. Inform.* **2023**, *77*, 102261. [CrossRef]
53. Price, B.A.; Harvey, E.S.; Mangubhai, S.; Saunders, B.J.; Puotinen, M.; Goetze, J.S. Responses of benthic habitat and fish to severe tropical cyclone Winston in Fiji. *Coral Reefs* **2021**, *40*, 807–819. [CrossRef]
54. Adam, T.C.; Burkepile, D.E.; Holbrook, S.J.; Carpenter, R.C.; Claudet, J.; Loiseau, C.; Thiault, L.; Brooks, A.J.; Washburn, L.; Schmitt, R.J. Landscape-scale patterns of nutrient enrichment in a coral reef ecosystem: Implications for coral to algae phase shifts. *Ecol. Appl.* **2021**, *31*, e2227. [CrossRef] [PubMed]
55. Haapkylä, J.; Unsworth, R.K.; Flavell, M.; Bourne, D.G.; Schaffelke, B.; Willis, B.L. Seasonal rainfall and runoff promote coral disease on an inshore reef. *PLoS ONE* **2011**, *6*, e16893. [CrossRef]
56. Dube, K.; Chikodzi, D. Examining current and future challenges of sea level rise on coastal national parks. *Geoj. Tour. Geosites* **2023**, *50*, 1573–1580. [CrossRef]
57. Sibitane, Z.E.; Dube, K.; Lekaota, L. Global Warming and Its Implications on Nature Tourism at Phinda Private Game Reserve, South Africa. *Int. J. Environ. Res. Public Health* **2022**, *19*, 5487. [CrossRef]
58. Prakash, S. Impact of climate change on aquatic ecosystem and its biodiversity: An overview. *Int. J. Biol. Innov.* **2021**, *3*, 312–317. [CrossRef]
59. Befus, K.M.; Barnard, P.L.; Hoover, D.J.; Hart, J.A.F.; Voss, C.I. Increasing threat of coastal groundwater hazards from sea-level rise in California. *Nat. Clim. Chang.* **2020**, *10*, 946–952. [CrossRef]
60. Ellison, J.C. Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetl. Ecol. Manag.* **2015**, *23*, 115–137. [CrossRef]
61. Cohen, M.C.; Figueiredo, B.L.; Oliveira, N.N.; Fontes, N.A.; França, M.C.; Pessenda, L.C.; de Souza, A.V.; Macario, K.; Giannini, P.C.; Bendassolli, J.A.; et al. Impacts of Holocene and modern sea-level changes on estuarine mangroves from northeastern Brazil. *Earth Surf. Process. Landforms* **2020**, *45*, 375–392. [CrossRef]
62. Xiao, H.; Su, F.; Fu, D.; Wang, Q.; Huang, C. Coastal Mangrove Response to Marine Erosion: Evaluating the Impacts of Spatial Distribution and Vegetation Growth in Bangkok Bay from 1987 to 2017. *Remote Sens.* **2020**, *12*, 220. [CrossRef]
63. Wilson, K.L.; Tittensor, D.P.; Worm, B.; Lotze, H.K. Incorporating climate change adaptation into marine protected area planning. *Glob. Chang. Biol.* **2020**, *26*, 3251–3267. [CrossRef] [PubMed]
64. Protected Planet. Marine Protected Areas. 2024. Available online: https://www.protectedplanet.net/en/thematic-areas/marine-protected-areas (accessed on 25 January 2024).
65. Seddon, N.; Chausson, A.; Berry, P.; Girardin, C.A.; Smith, A.; Turner, B. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philos. Trans. R. Soc. B* **2020**, *375*, e15. [CrossRef] [PubMed]
66. Smith, A.C.; Tasnim, T.; Irfanullah, H.M.; Turner, B.; Chausson, A.; Seddon, N. Nature-based Solutions in Bangladesh: Evidence of Effectiveness for Addressing Climate Change and Other Sustainable Development Goals. *Front. Environ. Sci.* **2021**, *9*, 511. [CrossRef]
67. Lovelock, C.E.; Barbier, E.; Duarte, C.M. Tackling the mangrove restoration challenge. *PLoS Biol.* **2022**, *20*, e3001836. [CrossRef]
68. Ellison, A.M.; Felson, A.J.; Friess, D.A. Mangrove rehabilitation and restoration as experimental adaptive management. *Front. Mar. Sci.* **2020**, *7*, 327. [CrossRef]
69. Shaver, E.C.; McLeod, E.; Hein, M.Y.; Palumbi, S.R.; Quigley, K.; Vardi, T.; Mumby, P.J.; Smith, D.; Montoya-Maya, P.; Muller, E.M.; et al. A roadmap to integrating resilience into the practice of coral reef restoration. *Glob. Chang. Biol.* **2022**, *28*, 4751–4764. [CrossRef] [PubMed]
70. McLeod, I.M.; Hein, M.Y.; Babcock, R.; Bay, L.; Bourne, D.G.; Cook, N.; Boström-Einarsson, L. Coral restoration and adaptation in Australia: The first five years. *PLoS ONE* **2022**, *17*, e0273325. [CrossRef] [PubMed]
71. Rinkevich, B. Augmenting coral adaptation to climate change via coral gardening (the nursery phase). *J. Environ. Manag.* **2021**, *291*, 112727. [CrossRef] [PubMed]
72. Perry, A.L.; Low, P.J.; Ellis, J.R.; Reynolds, J.D. Climate Change and Distribution Shifts in Marine Fishes. *Science* **2005**, *308*, 1912–1915. [CrossRef] [PubMed]

73. Hodapp, D.; Roca, I.T.; Fiorentino, D.; Garilao, C.; Kaschner, K.; Kesner-Reyes, K.; Froese, R. Climate change disrupts core habitats of marine species. *Glob. Chang. Biol.* **2023**, *29*, 3304–3317. [CrossRef]
74. IPCC. IPCC WGI Interactive Atlas: Regional Synthesis. 28 January 2024. Available online: https://interactive-atlas.ipcc.ch/regional-synthesis#eyJ0eXBlIjoiQ0lEIiwic2VsZWN0ZWRJbmRleCI6WyJtYXJpbmVfaGVhdHdhdmUiLCJjb2FzdGFsX2Vyb3Npb24iLCJjb2FzdGFsX2Zsb29kIiwicmVsYXRpdmVfc2VhX2xldmVsIiwib2NlYW5fbGFrZV9hY2lkaXR5Il0sInNlbGVjdGVkVmFyaWFibGUiOiJjb25maW (accessed on 28 January 2024).