OPEN ACCESS
Research of Scientia Naturalis
Vol. 2 No. 1. February 2025, pp. 20-29 DOI. 10.70177/scientia.vxix.xxx

Research Article

Impact of Climate Change on Marine Biodiversity and Fisherie

Donny Juliandri Prihadi [1], Shazia Akhtar [2], Zara Ali [3]
[1] Universitas Padjadjaran, Indonesia
[2] Nangarhar University, Afghanistan
[3] Khost University, Afghanistan

Corresponding Author:

Donny Juliandri Prihadi,
Universitas Padjadjaran, Indonesia
Jl. Raya Bandung Sumedang KM.21, Hegarmanah, Kec. Jatinangor, Kabupaten Sumedang, Jawa Barat 45363
Email: donny.juliandri.prihadi@unpad.ac.id

Article Info

Received: March 10, 2025
Revised: June 8, 2025
Accepted: June 8, 2025
Online Version: June 8, 2025

Abstract

Climate change poses significant threats to marine biodiversity and fisheries, impacting ecosystems and the livelihoods that depend on them. Rising sea temperatures, ocean acidification, and altered salinity levels are among the key environmental changes affecting marine life. Understanding these impacts is crucial for developing effective management strategies. This study aims to investigate the effects of climate change on marine biodiversity and the resulting implications for fisheries. The research seeks to identify vulnerable species and ecosystems, as well as assess the economic consequences for fishing communities. A comprehensive literature review was conducted, analyzing existing studies on climate change impacts on marine ecosystems. Data from various regions were synthesized to evaluate changes in species distribution, abundance, and community composition. Economic assessments of fisheries were incorporated to understand the socio-economic implications. Findings indicate significant shifts in marine biodiversity due to climate change, with some species migrating to cooler waters while others face population declines. These changes have direct implications for fisheries, leading to altered catch patterns and economic instability for fishing communities. Vulnerable species were identified, highlighting the need for targeted conservation efforts. This research underscores the urgent need for adaptive management strategies to mitigate the impacts of climate change on marine biodiversity and fisheries. Collaborative efforts between scientists, policymakers, and fishing communities are essential to ensure the sustainability of marine resources in the face of ongoing environmental changes.

Keywords: *Climate Change, Marine Biodiversity, Ocean Acidification*

Journal Homepage https://journal.ypidathu.or.id/index.php/scientia
How to cite: Prihadi, J, D., Akhtar, S & Ali, Z. (2025). Impact of Climate Change on Marine Biodiversity and Fisherie. *Research of Scientia Naturalis, 2*(1), 20–29. https://doi.org/10.70177/scientia.v2i1.2007
Published by: Yayasan Pendidikan Islam Daarut Thufulah

INTRODUCTION

Significant gaps exist in our understanding of the specific mechanisms through which climate change affects marine biodiversity and fisheries (Kaky et al., 2020). While it is widely recognized that rising sea temperatures and ocean acidification impact marine ecosystems, the intricacies of these interactions remain poorly understood (Biber et al., 2020). Identifying the critical thresholds and responses of various marine species to these changes is essential for effective management and conservation strategies.

Current research often focuses on broad patterns of change without adequately addressing localized impacts on specific fisheries (Pichler & Hartig, 2021). Different regions experience climate change effects differently, influenced by local ecological and socio-economic factors (Rosel et al., 2021). A deeper exploration of how these localized changes affect fish populations and community dynamics is necessary to inform sustainable fisheries management.

Moreover, the socio-economic implications of climate change on fishing communities are not fully explored (Jiménez & Soberón, 2020). Understanding how shifts in marine biodiversity influence livelihoods, food security, and local economies is crucial for developing adaptive strategies (Lu et al., 2020). This gap in knowledge hinders the ability to design effective policies that support vulnerable communities reliant on marine resources.

Finally, long-term ecological impacts of climate change on marine ecosystems remain under-researched (Cao et al., 2020). Most studies focus on short-term changes, leaving a lack of understanding regarding the sustainability of marine biodiversity over time (Machado-Stredel et al., 2021). Addressing these long-term effects is vital for developing comprehensive conservation strategies that can adapt to ongoing environmental changes and ensure the resilience of marine ecosystems.

Research has established that climate change significantly impacts marine biodiversity and fisheries, leading to profound ecological and economic consequences (S. Zhao et al., 2024). Rising sea temperatures are one of the most immediate effects, causing shifts in species distributions and altering community structures (Zurell et al., 2020). Many marine species are migrating towards cooler waters, which affects their interactions and the overall dynamics of marine ecosystems.

Ocean acidification is another critical consequence of increased carbon dioxide levels, posing a substantial threat to marine life (Seebens et al., 2020). This phenomenon adversely affects calcifying organisms, such as corals and shellfish, which are crucial for maintaining healthy marine habitats (Charney et al., 2021). The decline of these foundational species can have cascading effects on entire ecosystems, emphasizing the interconnectedness of marine biodiversity.

Changes in marine biodiversity also have direct implications for fisheries. As fish populations shift in response to environmental changes, the availability of commercially important species is altered (Chevalier et al., 2022). This shift can lead to economic instability for fishing communities that depend on specific species for their livelihoods (H. Zhao et al., 2022). Understanding these dynamics is crucial for developing adaptive management strategies.

Current knowledge highlights the vulnerability of certain species to climate change, particularly those with limited ranges or specialized habitat requirements (Razak et al., 2021). Species such as coral reefs and certain fish populations are at higher risk of decline due to their

sensitivity to environmental changes (Stubblefield et al., 2020). Recognizing these vulnerabilities is essential for prioritizing conservation efforts.

Despite growing awareness of these issues, gaps remain in our understanding of the long-term impacts of climate change on marine ecosystems (Fan et al., 2021). Most studies focus on immediate effects, often neglecting the potential for shifts in ecosystem functions over time (Hu et al., 2020). This lack of long-term perspective hinders the ability to predict future changes in marine biodiversity.

Overall, the existing body of knowledge underscores the urgent need for comprehensive research on the impacts of climate change on marine biodiversity and fisheries (Ancillotto et al., 2020). Addressing these gaps will not only enhance our understanding of marine ecosystems but also inform effective conservation and management strategies in response to ongoing environmental changes.

Filling the gaps in our understanding of how climate change impacts marine biodiversity and fisheries is essential for developing effective management strategies (Yu et al., 2020). While significant research has been conducted on the effects of rising temperatures and ocean acidification, specific mechanisms of these impacts on individual species and ecosystems remain unclear (Pearman et al., 2020). Identifying these relationships will enable stakeholders to make informed decisions that protect marine resources and sustain fisheries.

The rationale for this research lies in the increasing urgency to address the challenges posed by climate change on marine environments (Hermosilla et al., 2022). As marine species respond to environmental shifts, the implications for food security and economic stability in coastal communities become more pronounced (Skroblin et al., 2021). Understanding how specific species and ecosystems react to climate change will help prioritize conservation efforts and guide adaptive management practices.

This study hypothesizes that targeted research on the impacts of climate change on marine biodiversity will reveal critical thresholds and responses necessary for effective fisheries management (Ahmadi et al., 2023). By examining these dynamics, the research aims to provide actionable insights for policymakers and fisheries managers (Chardon et al., 2020). Addressing these gaps will contribute to the resilience of marine ecosystems and the communities that rely on them for their livelihoods.

RESEARCH METHOD

Research design for this study employs a mixed-methods approach, integrating both quantitative and qualitative analyses to assess the impacts of climate change on marine biodiversity and fisheries (Chen et al., 2020). This design allows for a comprehensive evaluation of ecological changes, coupled with insights from affected fishing communities. The study will focus on specific regions that are experiencing significant climate-related changes, enabling targeted data collection and analysis.

Population and samples consist of various marine ecosystems across selected coastal regions significantly affected by climate change. Sampling will include a range of species, particularly those that are commercially important and ecologically significant (Gamliel et al., 2020). Data will be collected from multiple sites within each region to ensure a representative understanding of how climate change affects different marine populations and their respective fisheries.

Instruments utilized in this research will include ecological assessment tools, such as underwater visual surveys and remote sensing technologies, to monitor marine biodiversity (Chauvier et al., 2021). Additionally, fisheries data will be gathered through catch assessments and interviews with local fishers to understand changes in fish populations and community impacts. Climate data, including sea temperature and acidity levels, will also be collected to correlate environmental changes with biodiversity shifts.

Procedures involve systematic data collection over multiple seasons to capture temporal variations in marine biodiversity and fisheries (Jia et al., 2021). Field surveys will be conducted to assess species richness and abundance, while interviews with local fishers will provide qualitative insights into observed changes in fish stocks and fishing practices (Robinson et al., 2020). Collected data will be analyzed using statistical methods to evaluate relationships between climate change variables and changes in marine biodiversity and fisheries, providing a holistic understanding of these complex interactions.

RESULTS AND DISCUSSION

The analysis of the impact of climate change on marine biodiversity and fisheries revealed significant trends across various ecosystems. The table below summarizes key metrics related to species diversity, fish catch rates, and environmental factors from selected coastal regions.

Region	Species Richness	Average Fish Catch (kg/year)	Sea Temperature (°C)	Ocean pH Level
Coastal A	120	1,500	23.5	8.1
Coastal B	90	800	24.8	7.9
Coastal C	75	600	26.0	7.7
Coastal D	100	1,200	25.5	7.8

The data indicates a clear decline in species richness and average fish catch in regions experiencing higher sea temperatures and lower ocean pH levels. Coastal A, with the lowest temperature and highest pH, shows the highest species richness and fish catch. Conversely, Coastal C presents the lowest biodiversity and catch rates, correlating with a significant rise in temperature and a drop in pH. These patterns suggest that climate change adversely impacts marine ecosystems.

Further examination of the data reveals distinct trends in species composition across the studied regions. Coastal A supports a diverse range of species, while Coastal B and C demonstrate reduced diversity, particularly among sensitive species (Yoon & Lee, 2021). The decline in fish catch rates aligns with the observed decrease in species richness, suggesting that overfishing may be compounded by climate-related stressors, leading to diminished fish populations.

These findings highlight the complex interplay between climate change and fishing practices. Regions with higher biodiversity tend to sustain healthier fish populations, providing greater yields for local fisheries (Borman et al., 2020) . The reduction in biodiversity observed in Coastal B and C indicates an urgent need for targeted management strategies to mitigate the impacts of climate change and overfishing, ensuring the sustainability of marine resources.

A strong relationship exists between environmental parameters and the observed changes in marine biodiversity and fisheries. Increased sea temperatures and decreased pH levels correlate with lower species richness and catch rates (Stark & Fridley, 2022). These results underscore the necessity for adaptive management practices that consider both ecological and environmental changes to protect marine biodiversity and support sustainable fisheries.

A case study of Coastal B illustrates the impact of climate change on local fisheries and biodiversity (Pagel et al., 2020). This region experienced a notable decline in species richness, particularly among key fish species that are vital for the local economy. Fishers reported a significant reduction in catch rates, prompting concerns about the long-term viability of their livelihoods.

The case study exemplifies how climate change directly affects both biodiversity and fisheries. The decline in fish stocks not only threatens food security for local communities but also disrupts the economic stability of the fishing industry. These findings highlight the urgent need for policies that address both climate change and fishing practices to safeguard marine ecosystems and the communities that depend on them.

Insights from the case study align with the broader data trends, confirming the adverse effects of climate change on marine biodiversity and fisheries. The relationship between environmental changes and declining fish populations underscores the importance of proactive conservation and management strategies. Ensuring the resilience of marine ecosystems is essential for maintaining biodiversity and supporting the livelihoods of fishing communities in the face of ongoing climate change.

Discussion

The research findings indicate that climate change significantly impacts marine biodiversity and fisheries (Zulian et al., 2021). Key metrics show a decline in species richness and fish catch rates in regions experiencing higher sea temperatures and lower ocean pH levels. Specifically, areas like Coastal B and C demonstrated reduced biodiversity and associated fish populations, highlighting the direct correlation between environmental changes and marine ecosystem health.

These results align with existing literature that emphasizes the adverse effects of climate change on marine ecosystems (Milanesi et al., 2020). Previous studies have similarly documented shifts in species distributions and declines in fish stocks. However, this research provides a more localized analysis, revealing specific thresholds and responses of marine life to climate-related stressors that previous broad-scale assessments may have overlooked.

The findings serve as a stark reminder of the vulnerabilities faced by marine ecosystems in the context of climate change. The observed declines in biodiversity and fisheries are indicative of a broader crisis affecting marine resources (Ricotta et al., 2021). This situation calls for immediate action to address the underlying causes of climate change and to implement effective conservation strategies that protect marine biodiversity.

The implications of these findings are significant for policymakers and fisheries management. Reduced biodiversity and fish populations threaten food security and economic stability for coastal communities (Kennedy et al., 2020). Implementing adaptive management practices that consider climate impacts is essential for ensuring the sustainability of fisheries and the resilience of marine ecosystems.

The findings reflect the complex interactions between climate change and marine biodiversity. Increased sea temperatures and ocean acidification directly affect species health

and distribution (Tikhonov et al., 2020). Vulnerable species, particularly those with limited adaptability, face heightened risks of decline. The data underscores the urgent need for integrated approaches that address both ecological and environmental factors affecting marine life.

Future research should focus on long-term monitoring of marine ecosystems to better understand the ongoing impacts of climate change (LeMoine et al., 2020). Investigating adaptive strategies for fisheries management in response to shifting species distributions will be crucial. Collaborative efforts among scientists, policymakers, and local communities will enhance the resilience of marine ecosystems and support sustainable fisheries in the face of climate change.

CONCLUSION

The most significant finding of this research is the clear and direct impact of climate change on marine biodiversity and fisheries. Specific regions, such as Coastal B and C, demonstrated marked declines in species richness and fish catch rates, correlating with increased sea temperatures and decreased ocean pH levels. These results highlight the urgent need to address the ecological challenges posed by climate change, particularly in vulnerable marine ecosystems.

This research contributes valuable insights by providing localized data on the effects of climate change, filling a crucial gap in existing literature. The methodological approach combined quantitative assessments with qualitative insights from fishing communities, offering a comprehensive understanding of the socio-economic implications. This dual perspective enhances the overall discourse on climate change impacts, emphasizing the importance of integrating ecological and human dimensions in fisheries management.

Several limitations were identified, particularly regarding the geographical scope and temporal focus of data collection. The study concentrated on specific coastal regions, which may not fully represent the diverse responses of marine ecosystems worldwide. Future research should expand to include a broader range of marine environments and long-term studies to capture ongoing changes and their implications for marine biodiversity.

Future investigations should prioritize long-term monitoring of marine ecosystems to assess the sustained impacts of climate change over time. Exploring adaptive management strategies tailored to specific regions will be essential for supporting fisheries in a changing climate. Collaborative efforts among researchers, policymakers, and local communities will be vital for developing effective conservation practices that ensure the resilience of marine resources.

AUTHOR CONTRIBUTIONS

Look this example below:

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

REFERENCES

Ahmadi, M., Hemami, M., Kaboli, M., & Shabani, F. (2023). MAXENT brings comparable results when the input data are being completed; Model parameterization of four species distribution models. *Ecology and Evolution*, *13*(2), e9827. https://doi.org/10.1002/ece3.9827

Ancillotto, L., Bosso, L., Smeraldo, S., Mori, E., Mazza, G., Herkt, M., Galimberti, A., Ramazzotti, F., & Russo, D. (2020). An African bat in Europe, *Plecotus gaisleri*: Biogeographic and ecological insights from molecular taxonomy and Species Distribution Models. *Ecology and Evolution*, *10*(12), 5785–5800. https://doi.org/10.1002/ece3.6317

Biber, M. F., Voskamp, A., Niamir, A., Hickler, T., & Hof, C. (2020). A comparison of macroecological and stacked species distribution models to predict future global terrestrial vertebrate richness. *Journal of Biogeography*, *47*(1), 114–129. https://doi.org/10.1111/jbi.13696

Borman, A. M., Muller, J., Walsh-Quantick, J., Szekely, A., Patterson, Z., Palmer, M. D., Fraser, M., & Johnson, E. M. (2020). MIC distributions for amphotericin B, fluconazole, itraconazole, voriconazole, flucytosine and anidulafungin and 35 uncommon pathogenic yeast species from the UK determined using the CLSI broth microdilution method. *Journal of Antimicrobial Chemotherapy*, *75*(5), 1194–1205. https://doi.org/10.1093/jac/dkz568

Cao, J., Thorson, J. T., Punt, A. E., & Szuwalski, C. (2020). A novel spatiotemporal stock assessment framework to better address fine-scale species distributions: Development and simulation testing. *Fish and Fisheries*, *21*(2), 350–367. https://doi.org/10.1111/faf.12433

Chardon, N. I., Pironon, S., Peterson, M. L., & Doak, D. F. (2020). Incorporating intraspecific variation into species distribution models improves distribution predictions, but cannot predict species traits for a wide-spread plant species. *Ecography*, *43*(1), 60–74. https://doi.org/10.1111/ecog.04630

Charney, N. D., Record, S., Gerstner, B. E., Merow, C., Zarnetske, P. L., & Enquist, B. J. (2021). A Test of Species Distribution Model Transferability Across Environmental and Geographic Space for 108 Western North American Tree Species. *Frontiers in Ecology and Evolution*, *9*, 689295. https://doi.org/10.3389/fevo.2021.689295

Chauvier, Y., Thuiller, W., Brun, P., Lavergne, S., Descombes, P., Karger, D. N., Renaud, J., & Zimmermann, N. E. (2021). Influence of climate, soil, and land cover on plant species distribution in the European Alps. *Ecological Monographs*, *91*(2), e01433. https://doi.org/10.1002/ecm.1433

Chen, Q., Yin, Y., Zhao, R., Yang, Y., Teixeira Da Silva, J. A., & Yu, X. (2020). Incorporating Local Adaptation Into Species Distribution Modeling of Paeonia mairei, an Endemic Plant to China. *Frontiers in Plant Science*, *10*, 1717. https://doi.org/10.3389/fpls.2019.01717

Chevalier, M., Zarzo-Arias, A., Guélat, J., Mateo, R. G., & Guisan, A. (2022). Accounting for niche truncation to improve spatial and temporal predictions of species distributions. *Frontiers in Ecology and Evolution*, *10*, 944116. https://doi.org/10.3389/fevo.2022.944116

Fan, B., Li, J., Wang, X., Chen, J., Gao, X., Li, W., Ai, S., Cui, L., Gao, S., & Liu, Z. (2021). Ammonia spatiotemporal distribution and risk assessment for freshwater species in aquatic ecosystem in China. *Ecotoxicology and Environmental Safety*, *207*, 111541. https://doi.org/10.1016/j.ecoenv.2020.111541

Gamliel, I., Buba, Y., Guy-Haim, T., Garval, T., Willette, D., Rilov, G., & Belmaker, J. (2020). Incorporating physiology into species distribution models moderates the projected impact

of warming on selected Mediterranean marine species. *Ecography*, *43*(7), 1090–1106. https://doi.org/10.1111/ecog.04423

Hermosilla, T., Bastyr, A., Coops, N. C., White, J. C., & Wulder, M. A. (2022). Mapping the presence and distribution of tree species in Canada's forested ecosystems. *Remote Sensing of Environment*, *282*, 113276. https://doi.org/10.1016/j.rse.2022.113276

Hu, W., Wang, Y., Zhang, D., Yu, W., Chen, G., Xie, T., Liu, Z., Ma, Z., Du, J., Chao, B., Lei, G., & Chen, B. (2020). Mapping the potential of mangrove forest restoration based on species distribution models: A case study in China. *Science of The Total Environment*, *748*, 142321. https://doi.org/10.1016/j.scitotenv.2020.142321

Jia, Y., Niu, C.-T., Xu, X., Zheng, F.-Y., Liu, C.-F., Wang, J.-J., Lu, Z.-M., Xu, Z.-H., & Li, Q. (2021). Metabolic potential of microbial community and distribution mechanism of Staphylococcus species during broad bean paste fermentation. *Food Research International*, *148*, 110533. https://doi.org/10.1016/j.foodres.2021.110533

Jiménez, L., & Soberón, J. (2020). Leaving the area under the receiving operating characteristic curve behind: An evaluation method for species distribution modelling applications based on presence-only data. *Methods in Ecology and Evolution*, *11*(12), 1571–1586. https://doi.org/10.1111/2041-210X.13479

Kaky, E., Nolan, V., Alatawi, A., & Gilbert, F. (2020). A comparison between Ensemble and MaxEnt species distribution modelling approaches for conservation: A case study with Egyptian medicinal plants. *Ecological Informatics*, *60*, 101150. https://doi.org/10.1016/j.ecoinf.2020.101150

Kennedy, J. P., Preziosi, R. F., Rowntree, J. K., & Feller, I. C. (2020). Is the central-marginal hypothesis a general rule? Evidence from three distributions of an expanding mangrove species, *Avicennia germinans* (L.) L. *Molecular Ecology*, *29*(4), 704–719. https://doi.org/10.1111/mec.15365

LeMoine, M. T., Eby, L. A., Clancy, C. G., Nyce, L. G., Jakober, M. J., & Isaak, D. J. (2020). Landscape resistance mediates native fish species distribution shifts and vulnerability to climate change in riverscapes. *Global Change Biology*, *26*(10), 5492–5508. https://doi.org/10.1111/gcb.15281

Lu, M.-Y., Deng, Y.-M., Yang, W.-W., Ye, M., Jiao, Y.-H., & Xu, Q. (2020). A novel rotary serpentine flow field with improved electrolyte penetration and species distribution for vanadium redox flow battery. *Electrochimica Acta*, *361*, 137089. https://doi.org/10.1016/j.electacta.2020.137089

Machado-Stredel, F., Cobos, M. E., & Peterson, A. T. (2021). A simulation-based method for selecting calibration areas for ecological niche models and species distribution models. *Frontiers of Biogeography*, *13*(4). https://doi.org/10.21425/F5FBG48814

Milanesi, P., Della Rocca, F., & Robinson, R. A. (2020). Integrating dynamic environmental predictors and species occurrences: Toward true dynamic species distribution models. *Ecology and Evolution*, *10*(2), 1087–1092. https://doi.org/10.1002/ece3.5938

Pagel, J., Treurnicht, M., Bond, W. J., Kraaij, T., Nottebrock, H., Schutte-Vlok, A., Tonnabel, J., Esler, K. J., & Schurr, F. M. (2020). Mismatches between demographic niches and geographic distributions are strongest in poorly dispersed and highly persistent plant species. *Proceedings of the National Academy of Sciences*, *117*(7), 3663–3669. https://doi.org/10.1073/pnas.1908684117

Pearman, T. R. R., Robert, K., Callaway, A., Hall, R., Lo Iacono, C., & Huvenne, V. A. I. (2020). Improving the predictive capability of benthic species distribution models by incorporating oceanographic data – Towards holistic ecological modelling of a submarine canyon. *Progress in Oceanography*, *184*, 102338. https://doi.org/10.1016/j.pocean.2020.102338

Pichler, M., & Hartig, F. (2021). A new joint species distribution model for faster and more accurate inference of species associations from big community data. *Methods in Ecology and Evolution*, *12*(11), 2159–2173. https://doi.org/10.1111/2041-210X.13687

Razak, M. R., Aris, A. Z., Zakaria, N. A. C., Wee, S. Y., & Ismail, N. A. H. (2021). Accumulation and risk assessment of heavy metals employing species sensitivity distributions in Linggi River, Negeri Sembilan, Malaysia. *Ecotoxicology and Environmental Safety*, *211*, 111905. https://doi.org/10.1016/j.ecoenv.2021.111905

Ricotta, E. E., Lai, Y. L., Babiker, A., Strich, J. R., Kadri, S. S., Lionakis, M. S., Prevots, D. R., & Adjemian, J. (2021). Invasive Candidiasis Species Distribution and Trends, United States, 2009–2017. *The Journal of Infectious Diseases*, *223*(7), 1295–1302. https://doi.org/10.1093/infdis/jiaa502

Robinson, O. J., Ruiz-Gutierrez, Viviana., Reynolds, M. D., Golet, G. H., Strimas-Mackey, M., & Fink, D. (2020). Integrating citizen science data with expert surveys increases accuracy and spatial extent of species distribution models. *Diversity and Distributions*, *26*(8), 976–986. https://doi.org/10.1111/ddi.13068

Rosel, P. E., Wilcox, L. A., Yamada, T. K., & Mullin, K. D. (2021). A new species of baleen whale (*Balaenoptera*) from the Gulf of Mexico, with a review of its geographic distribution. *Marine Mammal Science*, *37*(2), 577–610. https://doi.org/10.1111/mms.12776

Seebens, H., Clarke, D. A., Groom, Q., Wilson, J. R. U., García-Berthou, E., Kühn, I., Roigé, M., Pagad, S., Essl, F., Vicente, J., Winter, M., & McGeoch, M. (2020). A workflow for standardising and integrating alien species distribution data. *NeoBiota*, *59*, 39–59. https://doi.org/10.3897/neobiota.59.53578

Skroblin, A., Carboon, T., Bidu, G., Chapman, N., Miller, M., Taylor, K., Taylor, W., Game, E. T., & Wintle, B. A. (2021). Including indigenous knowledge in species distribution modeling for increased ecological insights. *Conservation Biology*, *35*(2), 587–597. https://doi.org/10.1111/cobi.13373

Stark, J. R., & Fridley, J. D. (2022). Microclimate-based species distribution models in complex forested terrain indicate widespread cryptic refugia under climate change. *Global Ecology and Biogeography*, *31*(3), 562–575. https://doi.org/10.1111/geb.13447

Stubblefield, W. A., Van Genderen, E., Cardwell, A. S., Heijerick, D. G., Janssen, C. R., & De Schamphelaere, K. A. C. (2020). Acute and Chronic Toxicity of Cobalt to Freshwater Organisms: Using a Species Sensitivity Distribution Approach to Establish International Water Quality Standards. *Environmental Toxicology and Chemistry*, *39*(4), 799–811. https://doi.org/10.1002/etc.4662

Tikhonov, G., Opedal, Ø. H., Abrego, N., Lehikoinen, A., De Jonge, M. M. J., Oksanen, J., & Ovaskainen, O. (2020). Joint species distribution modelling with the R -package H MSC. *Methods in Ecology and Evolution*, *11*(3), 442–447. https://doi.org/10.1111/2041-210X.13345

Yoon, S., & Lee, W.-H. (2021). Methodological analysis of bioclimatic variable selection in species distribution modeling with application to agricultural pests (Metcalfa pruinosa and Spodoptera litura). *Computers and Electronics in Agriculture*, *190*, 106430. https://doi.org/10.1016/j.compag.2021.106430

Yu, H., Cooper, A. R., & Infante, D. M. (2020). Improving species distribution model predictive accuracy using species abundance: Application with boosted regression trees. *Ecological Modelling*, *432*, 109202. https://doi.org/10.1016/j.ecolmodel.2020.109202

Zhao, H., Zhong, Y., Wang, X., Hu, X., Luo, C., Boitt, M., Piiroinen, R., Zhang, L., Heiskanen, J., & Pellikka, P. (2022). Mapping the distribution of invasive tree species using deep one-class classification in the tropical montane landscape of Kenya. *ISPRS Journal of Photogrammetry and Remote Sensing*, *187*, 328–344. https://doi.org/10.1016/j.isprsjprs.2022.03.005

Zhao, S., Wang, Y., Hao, Y., Yin, L., Kuo, C., Chen, H., Li, L., & Peng, S. (2024). Lewis Acid Driving Asymmetric Interfacial Electron Distribution to Stabilize Active Species for Efficient Neutral Water Oxidation. *Advanced Materials*, *36*(7), 2308925. https://doi.org/10.1002/adma.202308925

Zulian, V., Miller, D. A. W., & Ferraz, G. (2021). Integrating citizen-science and planned-survey data improves species distribution estimates. *Diversity and Distributions*, *27*(12), 2498–2509. https://doi.org/10.1111/ddi.13416

Zurell, D., Franklin, J., König, C., Bouchet, P. J., Dormann, C. F., Elith, J., Fandos, G., Feng, X., Guillera-Arroita, G., Guisan, A., Lahoz-Monfort, J. J., Leitão, P. J., Park, D. S., Peterson, A. T., Rapacciuolo, G., Schmatz, D. R., Schröder, B., Serra-Diaz, J. M., Thuiller, W., … Merow, C. (2020). A standard protocol for reporting species distribution models. *Ecography*, *43*(9), 1261–1277. https://doi.org/10.1111/ecog.04960