A REVIEW

INDICATOR-BASED TOOLS FOR ASSESSING OCEAN RISKS AND VULNERABILITIES

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1. INTRODUCTION

> *The complexity of ocean risk is mirrored in the complexity of resilience, which is multidimensional and dynamic. The global community will need to gain experience in understanding and addressing more complicated risks in the coming years.*
>
> Ocean Risks in SIDS and LDCs

The future of the ocean economy depends on our ability to navigate, mitigate and adapt to climate change and other environmental and socioeconomic shocks and their interlinked impacts. This brief provides an overview of existing indicator-based tools to assess ocean risks and vulnerabilities based on a systematic review of peer-reviewed articles and grey literature. We conducted a systematic review of peer-reviewed articles and grey literature to examine different approaches to conceptualizing risk and vulnerability, and the variety of metrics and data used in existing indicator-based assessments.

Our previous synthesis on ocean risks in SIDS and LDCs found that these countries depend on the ocean in multiple and interacting ways (Tokunaga et al. 2021). Many countries rely heavily on fisheries and coastal tourism as primary sources of income, and both sectors depend on healthy marine and coastal environments. At the same time, coastal urbanization trends threaten ecosystems upon which these sectors rely. Climate change impacts -- such as sea level rise and ocean warming and acidification -- add to existing risks. The COVID-19 pandemic also has caused major disruption to tourism-dependent economies (Gu et al. 2022; Škare, Soriano, and Porada-Rochoń 2021)

In this review, we paid particular attention to conceptual and theoretical frameworks used by existing studies and explored the types of risks and vulnerabilities assessed. We also examined to what extent data for SIDS and LDCs are included in available assessments by focusing on Sub-Saharan Africa, a region known to be particularly vulnerable to climate change and global-scale socioeconomic shocks. We also examined how existing assessments have dealt with data availability issues and to what extent proxies can be used to overcome such issues. We conclude our brief by noting the potential of a fuzzy logic modelling approach to deal with data-poor contexts and how such a framework, in combination with projections under shared socio-economic pathways (SSP) (Riahi et al. 2017) for SIDS and LDCs, can be used to develop a more integrated understanding of climate risks in the future.

Our review aims to support future tool development to facilitate an improved understanding of complex and coupled ocean risks and vulnerabilities. Our focus on indicator-based assessment tools is motivated by the desire to support the development of data-poor and flexible approaches for assessing ocean risks and vulnerabilities in Small Island Developing States (SIDS) and Least Developed Countries (LDCs). Both environmental and socio-economic data often are unavailable for many of these countries and where they are available, they may not be updated on a regular basis for a variety of reasons (e.g., lack of financial and/or human capacity).

2. REVIEW METHODS

Our systematic review follows the PSALSAR approach[i] (Mengist, Soromessa, and Legese 2020). This approach is based in turn on the PICOC framework[ii] study scope as described below:

Population

Indicator-based assessments and assessment tools that evaluate ocean risks and vulnerabilities. Types of risks include climate risks, weather-related natural disaster risks, geophysical natural disaster risks, and ocean economy risks, such as fisheries, aquaculture, and coastal tourism.

Intervention

Identify 1) types of hazards or stressors evaluated, 2) spatial scale, 3) spatial scale (e.g., national, regional, state, community, economic sector) of the assessment, 4) temporal scale of the assessment, 5) conceptual or theoretical framework used to construct the metrics, 6) metrics or variables used to evaluate the risks and vulnerabilities, 7) assessment and data availability for SIDS and LDC in Sub-Saharan Africa.

Comparison

Differences between assessment approaches applied to evaluate ocean risks and vulnerabilities.

Outcomes

*Synthesis of existing knowledge on indicator-based ocean risk and vulnerability assessments, specifically related to the items described under **Intervention**.*

Context

Trends of assessment approaches, existing knowledge of ocean risks and vulnerabilities, geographical distribution of existing assessments, study distribution based on the types of risks and vulnerabilities assessed.

i PSALSAR stands for Protocol, Search, Appraisal, Synthesis, Analysis, and Report.

ii PICOC stands for Population, Intervention, Comparison, Outcome(s), and Context

The search strategy was established by determining the literature database and repositories, search keyword string and terms, and search criteria. We conducted searches in three database/repositories: Web of Science (WoS) was used to search peer-reviewed articles; United Nations Digital Library was used to search publications by international organizations; and Harvard Kennedy School Think Tank Search was used to search reports published by think tanks, NGOs and other similar entities. The think tank search yielded websites that list publications by their staff, news articles, policy briefs, or blog posts or case studies that are not associated with the specific tool or without a mention of assessment tools. These were excluded from further screening. **Table 1** describes the search terms and criteria. To complement this process, we also relied on the project team's expertise, soliciting each project member to identify studies they were aware of within the scope of the review.

Figure 1 describes the search and review process. In total, the searches yielded 1087 items and we assessed a total of 885 articles based on inclusion and exclusion criteria. These articles and reports were first screened for their study method and scope. Inclusion criteria were whether the study/project i) applied or developed an indicator-based assessment, and ii) considered both human and natural systems jointly. Exclusion criteria are listed in Figure 1. For example, studies that investigate climate change impacts only on certain fish species or environmental features (e.g., beaches, corals, etc.) were excluded. For reports and studies that are repeated annually or more frequently, we only included the most recent version. The first screening was conducted using Rayyan, an online tool for systematic literature review. For peer-reviewed articles, article titles, keywords, and abstracts were reviewed as part of the first screening. For non-peer reviewed articles and reports, study titles, summaries, table of contents, and figures and tables were reviewed as part of the first screening. When they did not reveal the necessary information to make the inclusion/exclusion decision, the entire document was scanned briefly.

Table 1

Databases/ repositories	Search string and terms	
Web of Science	Web of Science Core Collection; Language = English; Data type = Article; Years = 2014 – 2022 (Search conducted on Mar 7, 2022)	Search 1: ((((((TS=(ocean risk*)) OR TS=(ocean vulnerabilit*)) OR TS=(coastal risk*)) OR TS=(coastal vulnerabilit*)) AND TS=(assess* OR inde*)) AND PY=(2014-2022)) and Highly Cited Papers or Hot Papers[i] Search 2: TS=("ocean economy" OR "blue economy") AND TS = (risk assess* OR vulnerability assess* OR risk inde* OR vulnerability inde*); Search 3: (TS=("Small Island Developing State*" OR "Least Developed Countr*")) AND TS=(risk* OR vulnerabilit*) and Highly Cited Papers or Hot Papers[ii]
United Nations Digital Library https://digitallibrary.un.org/	Resource type = reports, draft reports, and publications; UN bodies = all; Years = 2014 – 2022 (Search conducted on March 8, 2022)	Search 1: ((ocean OR coast*) AND risk* AND (inde* OR assess*)); Search 2: ((ocean OR coast*) AND vulnerabilit* AND (inde* OR assess*)); Search 3: ((risk OR vulnerabilit*) AND (assess* OR inde*)) Note: below search are done with full text, only screened top 50 records Search 4: ocean economy inde* assess* year:2014->2022 Search 5: blue economy inde* assess* year:2014->2022
Harvard Kennedy School Think Tank Search	Years = 2014 – 2022 (Search conducted on March 10, 2022	Search 1: ("ocean risk*" OR "coastal risk*") AND (assess* OR inde*) Search 2: ("ocean vulnerabilit*" OR "coastal vulnerabilit*") AND (assess* OR inde*) Search 3: "ocean economy" AND (risk* OR vulnerabilit*) AND (assess* OR inde*) Search 4: "blue economy" AND (risk* OR vulnerabilit*) AND (assess* OR inde*)

i These searches yielded over 1000 search outputs, and hence restricted the search by adding Highly Cited Papers or Hot Papers as inclusion criteria.

ii These searches yielded over 300 search outputs, and hence restricted the search by adding Highly Cited Papers or Hot Papers as inclusion criteria.

Most studies were excluded after the first screening, leaving 64 documents for the second screening[iii]. The second screening consisted of a full review of the publications and supplementary materials (when available). Again, the articles and reports that did not meet the scope and method were excluded. The final set of articles consisted of 45 indicator-based assessment tools (**Table 2**).

iii In addition, eight articles that reviewed existing risk and vulnerability assessment tools were identified.

These 45 studies were reviewed for 1) types of hazards or stressors evaluated, 2) spatial scale (e.g., national, regional, state, community, economic sector) of the assessment, 3) assessed region, 4) focus domain (e.g., fisheries, food system, national economy, etc.) 5) conceptual or theoretical framework used, 6) metrics or variables used to evaluate risks and vulnerabilities, and 7) assessment and data availability for SIDS and coastal LDCs in Sub-Saharan Africa.

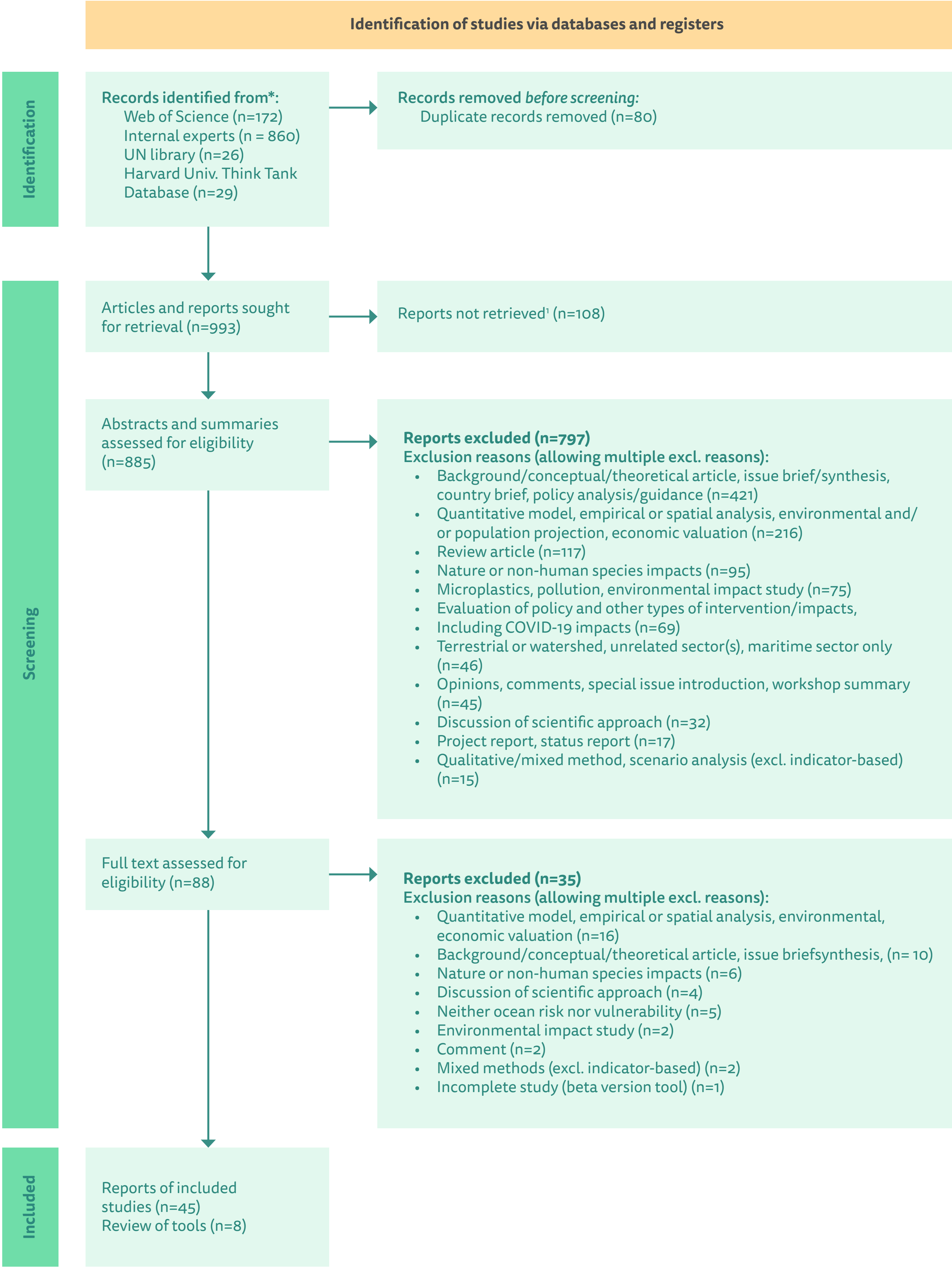

Figure 1. PRISMA flowchart ([1] Articles and reports not retrieved include those articles, reports, and books that are not available online (n=43), outdated recurring reports (n=8), degree theses (n=19), unpublished manuscripts (n=2), computer software user guide (n=2), and articles and reports (only included among those found in experts' library) published before 2008 (n=33). Template obtained from PRISMA)

Table 2. Final publications and associated tools considered in the review

Tool	Year	Reference
Aragão et al.	2022	Aragão, GM, L Lopez-Lopez, A Punzon, E Guijarro, A Esteban, E Garcia, JM Gonzalez-Irusta, J Polo, M Vivas, and M Hidalgo. "The Importance of Regional Differences in Vulnerability to Climate Change for Demersal Fisheries." ICES JOURNAL OF MARINE SCIENCE, March 2022. https://doi.org/icesjms/fsab134.
Ford & Wilcox	2022	Ford, Jessica H, and Chris Wilcox. 2022. "Quantifying Risk Assessments for Monitoring Control and Surveillance of Illegal Fishing." Edited by Mark Gibbs. ICES Journal of Marine Science, March, fsac027. https://doi.org/10.1093/icesjms/fsac027.
SCRT	2022	"IUU Fishing Supply Chain Risk Tool (SCRT)," 2022. Rayyan-790473598. https://www3.weforum.org/docs/WEF_SCRT_IUU_Report_2022.pdf.
GRPS	2021	World Economic Forum. 2021. The Global Risks Report 2021: 16th Edition. Weforum.Org. http://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2021.pdf.
Heck et al.	2021	Heck, Nadine, Michael W. Beck, and Borja Reguero. 2021. "Storm Risk and Marine Fisheries: A Global Assessment." Marine Policy 132 (October): 104698. https://doi.org/10.1016/j.marpol.2021.104698.
Lancet	2021	Romanello, Marina, Alice McGushin, Claudia Di Napoli, Paul Drummond, Nick Hughes, Louis Jamart, Harry Kennard, et al. 2021. "The 2021 Report of the Lancet Countdown on Health and Climate Change: Code Red for a Healthy Future." Lancet 398 (10311): 1619–62. https://doi.org/10.1016/S0140-6736(21)01787-6.
Macusi et al.	2021	Macusi, ED, RC Geronimo, and MD Santos. "Vulnerability Drivers for Small Pelagics and Milkfish Aquaculture Value Chain Determined through Online Participatory Approach." Marine Policy 133 (2021). https://doi.org/10.1016/j.marpol.2021.104710.
Magnan et al.	2021	Magnan, Alexandre K., Hans-Otto Pörtner, Virginie K. E. Duvat, Matthias Garschagen, Valeria A. Guinder, Zinta Zommers, Ove Hoegh-Guldberg, and Jean-Pierre Gattuso. 2021. "Estimating the Global Risk of Anthropogenic Climate Change." Nature Climate Change 11 (10): 879–85. https://doi.org/10.1038/s41558-021-01156-w.
MBI	2021	Soto-Navarro, C. A., M. Harfoot, S. L.L. Hill, J. Campbell, F. Mora, C. Campos, C. Pretorius, et al. 2021. "Towards a Multidimensional Biodiversity Index for National Application." Nature Sustainability. https://doi.org/10.1038/s41893-021-00753-z.
Mynott et al.	2021	Mynott, Frances, Jemma-Anne Lonsdale, and Tammy Stamford. 2021. "Developing an Ecological Risk Assessment to Effectively Manage Marine Resources in Data-Limited Locations: A Case Study for St Helena Sand Extraction." Frontiers in Marine Science 8 (June): 645225. https://doi.org/10.3389/fmars.2021.645225.
Thiault et al.	2021	Thiault, Lauric, Stacy D. Jupiter, Johanna E. Johnson, Joshua E. Cinner, Rebecca M. Jarvis, Scott F. Heron, Joseph M. Maina, Nadine A. Marshall, Paul A. Marshall, and Joachim Claudet. "Harnessing the Potential of Vulnerability Assessments for Managing Social-Ecological Systems." Ecology and Society 26, no. 2 (2021): art1. https://doi.org/10.5751/ES-12167-260201.
Tigchelaar et al.	2021	Tigchelaar, Michelle, William W. L. Cheung, Essam Yassin Mohammed, Michael J. Phillips, Hanna J. Payne, Elizabeth R. Selig, Colette C. C. Wabnitz, et al. 2021. "Compound Climate Risks Threaten Aquatic Food System Benefits." Nature Food 2 (9): 673–82. https://doi.org/10.1038/s43016-021-00368-9.
Appiah et al.	2020	Appiah, S, TO Antwi-Asare, FK Agyire-Tettey, E Abbey, JKM Kuwornu, S Cole, and SK Chimatiro. "Livelihood Vulnerabilities Among Women in Small-Scale Fisheries in Ghana." EUROPEAN JOURNAL OF DEVELOPMENT RESEARCH 33, no. 6 (2021): 1596–1624.
CORVI	2020	Stuart, Jack, Sally Yozell, and Tracy Rouleau. 2020. "The Climate and Ocean Risk Vulnerability Index." Washington, D.C: Stimson Center. https://www.stimson.org/project/corvi/.
Duvat et al.	2020	Duvat, Virginie K.E., Alexandre K. Magnan, Chris T. Perry, Tom Spencer, Johann D. Bell, Colette C.C. Wabnitz, Arthur P. Webb, et al. "Risks to Future Atoll Habitability from Climate-Driven Environmental Changes." Wiley Interdisciplinary Reviews: Climate Change 12, no. 3 (2021): 1–28. https://doi.org/10.1002/wcc.700.
EVI	2020	UNEP Islands. 2020. "Building Resilience in SIDS The Environmental Vulnerability Index." http://islands.unep.ch/EVI%20Final%20Report%202005.pdf.
Fernández-Macho et al.	2020	Fernandez-Macho, J, P Gonzalez, and J Virto. "Assessing Anthropogenic Vulnerability of Coastal Regions: DEA-Based Index and Rankings for the European Atlantic Area." Marine Policy 119 (2020). https://doi.org/10.1016/j.marpol.2020.104030.

Tool	Year	Reference
Miles et al.	2020	Miles, Wendy, Grecni, Zena, Matsutaro, Erbai Xavier, Colin, Patrick, Keener, Victoria, and Golbuu, Yimnang. 2020. "Climate Change in Palau: Indicators and Considerations for Key Sectors." Report for the Pacific Islands Regional Climate Assessment. Honolulu, HI: East-West Center. https://doi.org/10.5281/ZENODO.4124259.
Robinson	2020	Robinson, Stacy-ann. 2020. "A Richness Index for Baselining Climate Change Adaptations in Small Island Developing States." Environmental and Sustainability Indicators 8 (December): 100065. https://doi.org/10.1016/j.indic.2020.100065.
Aswani et al.	2019	Aswani, S., J. A. E. Howard, M. A. Gasalla, S. Jennings, W. Malherbe, I. M. Martins, S. S. Salim, et al. 2019. "An Integrated Framework for Assessing Coastal Community Vulnerability across Cultures, Oceans and Scales." Climate and Development 11 (4): 365–82. https://doi.org/10.1080/17565529.2018.1442795.
Genave	2019	Genave, A. 2019. "Energy Vulnerability in the Southwest Indian Ocean Islands." Journal of the Indian Ocean Region 15 (1): 40–57. https://doi.org/10.1080/19480881.2019.1560760.
Halpern et al.	2019	Halpern, BS, M Frazier, J Afflerbach, JS Lowndes, F Micheli, C O'Hara, C Scarborough, and KA Selkoe. 2019. "Recent Pace of Change in Human Impact on the World's Ocean." Scientific Reports 9 (August). https://doi.org/10.1038/s41598-019-47201-9.
Hosch et al.	2019	Hosch, Gilles, Bradley Soule, Max Schofield, Trevor Thomas, Charles Kilgour, and Tim Huntington. "Any Port in a Storm: Vessel Activity and the Risk of IUU-Caught Fish Passing through the World's Most Important Fishing Ports." Journal of Ocean and Coastal Economics 6, no. 1 (2019). https://cbe.miis.edu/joce/vol6/iss1/1.
Pinnegar et al.	2019	Pinnegar, John K, Georg H Engelhard, Norman J Norris, Derrick Theophille, Riviere Delanco Sebastien, and Manuel Hidalgo. 2019. "Assessing Vulnerability and Adaptive Capacity of the Fisheries Sector in Dominica: Long-Term Climate Change and Catastrophic Hu
Smith et al.	2019	Smith, Lisa M., Linda C. Harwell, J. Kevin Summers, Justin Bousquin, Kyle D. Buck, James E. Harvey, and Michelle McLaughlin. 2019. "Using Re-Scaled Resilience Screening Index Results and Location Quotients for Socio-Ecological Characterizations in U.S. Coastal Regions." Frontiers in Environmental Science 7 (June). https://doi.org/10.3389/fenvs.2019.00096.
Thiault et al.	2019	Thiault, Lauric, Camilo Mora, Joshua E Cinner, William W L Cheung, Nicholas A J Graham, Fraser A. Januchowski-Hartley, David Mouillot, U Rashid Sumaila, and Joachim Claudet. 2019. "Escaping the Perfect Storm of Simultaneous Climate Change Impacts on Agriculture and Marine Fisheries." Science Advances 5 (11): eaaw9976. https://doi.org/10.1126/sciadv.aaw9976.
Uddin et al.	2019	Uddin, MN, AKMS Islam, SK Bala, GMT Islam, S Adhikary, D Saha, S Haque, MGR Fahad, and R Akter. 2019. "Mapping of Climate Vulnerability of the Coastal Region of Bangladesh Using Principal Component Analysis." Applied Geography 102 (January): 47–57. https://doi.org/10.1016/j.apgeog.2018.12.011.
Blasiak et al.	2017	Blasiak, Robert, Jessica Spijkers, Kanae Tokunaga, Jeremy Pittman, Nobuyuki Yagi, and Henrik Österblom. 2017. "Climate Change and Marine Fisheries: Least Developed Countries Top Global Index of Vulnerability." Edited by Brian R. MacKenzie. PLOS ONE 12 (6): e0179632. https://doi.org/10.1371/journal.pone.0179632.
Ding et al.	2017	Ding, Qi, Xinjun Chen, Ray Hilborn, and Yong Chen. 2017. "Vulnerability to Impacts of Climate Change on Marine Fisheries and Food Security." Marine Policy. https://doi.org/10.1016/j.marpol.2017.05.011.
Mohammed et al.	2017	Mohammed, KK, G Dash, S Kumari, KR Sreenath, NP Makwana, S Sen Dash, TV Ambrose, SS Shyam, V Kripa, and PU Zacharia. 2017. "Vulnerability of Coastal Fisher Households to Climate Change: A Case Study from Gujarat, India." Turkish Journal of Fisheries and Aquatic Sciences 17 (1): 193–203. https://doi.org/10.4194/1303-2712-v17_1_21.
Nguyen et al.	2017	Nguyen, Cuong Viet, Ralph Horne, John Fien, and France Cheong. 2017. "Assessment of Social Vulnerability to Climate Change at the Local Scale: Development and Application of a Social Vulnerability Index." Climatic Change 143 (3): 355–70.
Feindouno & Goujon	2016	Sosso, Feindouno, and Michael Goujon. 2016. "The Retrospective Economic Vulnerability Index, 2015 Update." FERDI.
Frusher et al.	2016	Frusher, Stewart, Ingrid van Putten, Marcus Haward, Alistair J. Hobday, Neil J. Holbrook, Sarah Jennings, Nadine Marshall, Sarah Metcalf, Gretta T. Pecl, and Malcolm Tull. 2016. "From Physics to Fish to Folk: Supporting Coastal Regional Communities to Understand Their Vulnerability to Climate Change in Australia." Fisheries Oceanography 25 (April): 19–28. https://doi.org/10.1111/fog.12139.

Tool	Year	Reference
Maina et al.	2016	Maina, Joseph, Justus Kithiia, Josh Cinner, Ezra Neale, Sylvia Noble, Daniel Charles, and James E.M. Watson. "Integrating Social–Ecological Vulnerability Assessments with Climate Forecasts to Improve Local Climate Adaptation Planning for Coral Reef Fisheries in Papua New Guinea." Regional Environmental Change 16, no. 3 (2016): 881–91. https://doi.org/10.1007/s10113-015-0807-0.
Monnereau et al.	2016	Monnereau, Iris, Robin Mahon, Patrick McConney, Leonard Nurse, Rachel Turner, and Henri Vallès. 2016. "The Impact of Methodological Choices on the Outcome of National-Level Climate Change Vulnerability Assessments: An Example from the Global Fisheries Sector." Fish and Fisheries 18 (4): 717–31. https://doi.org/10.1111/faf.12199.
Weis et al.	2016	Weis, Shawn W. Margles, Vera N. Agostini, Lynnette M. Roth, Ben Gilmer, Steven R. Schill, John English Knowles, and Ruth Blyther. 2016. "Assessing Vulnerability: An Integrated Approach for Mapping Adaptive Capacity, Sensitivity, and Exposure." Climatic Change 136 (3–4): 615–29. https://doi.org/10.1007/s10584-016-1642-0.
Cinner et al.	2015	Cinner, Joshua E., Cindy Huchery, Christina C. Hicks, Tim M. Daw, Nadine Marshall, Andrew Wamukota, and Edward H. Allison. 2015. "Changes in Adaptive Capacity of Kenyan Fishing Communities." Nature Climate Change 5 (9): 872–76. https://doi.org/10.1038/nclimate2690.
Coastal Index	2015	Viavattene, Christophe, José Jiménez, Damon Owen, Sally Priest, Dennis Parker, Paula Micou, and Sophie Ly. "Coastal Risk Assessment Framework Guidance Document," 2015. http://risckit.cloudapp.net/risckit/#/.
Islam et al.	2014	Islam, Md. Monirul, Susannah Sallu, Klaus Hubacek, and Jouni Paavola. 2014. "Vulnerability of Fishery-Based Livelihoods to the Impacts of Climate Variability and Change: Insights from Coastal Bangladesh." Regional Environmental Change 14 (1): 281–94. https://doi.org/10.1007/s10113-013-0487-6.
Johnson et al.	2014	Johnson, Teresa R., Anna M. Henry, and Cameron Thompson. 2014. "Qualitative Indicators of Social Resilience in Small-Scale Fishing Communities: An Emphasis on Perceptions and Practice." Human Ecology Review 20 (02). https://doi.org/10.22459/HER.20.02.2014.05.
Morzaria-Luna et al.	2014	Morzaria-Luna, Hem Nalini, Peggy Turk-Boyer, and Marcia Moreno-Baez. 2014. "Social Indicators of Vulnerability for Fishing Communities in the Northern Gulf of California, Mexico: Implications for Climate Change." Marine Policy 45 (March): 182–93. https://doi.org/10.1016/j.marpol.2013.10.013.
Salim et al.	2014	Salim, SS, V Kripa, PU Zachariah, A Mohan, TV Ambrose, and M Rani. "Vulnerability Assessment of Coastal Fisher Households in Kerala: A Climate Change Perspective." Indian Journal of Fisheries 61, no. 4 (2014): 98–103. http://eprints.cmfri.org.in/id/eprint/10301.
Shah et al.	2013	Shah, Kalim U., Hari Bansha Dulal, Craig Johnson, and April Baptiste. 2013. "Understanding Livelihood Vulnerability to Climate Change: Applying the Livelihood Vulnerability Index in Trinidad and Tobago." Geoforum 47 (June): 125–37. https://doi.org/10.1016/j.geoforum.2013.04.004.
Cinner et al.	2012	Cinner, J.E., T.R. McClanahan, N.A.J. Graham, T.M. Daw, J. Maina, S.M. Stead, A. Wamukota, K. Brown, and Ö. Bodin. 2012. "Vulnerability of Coastal Communities to Key Impacts of Climate Change on Coral Reef Fisheries." Global Environmental Change 22 (1): 12–20. https://doi.org/10.1016/j.gloenvcha.2011.09.018.
Allison et al.	2009	Allison, Edward H., Allison L. Perry, Marie-Caroline Badjeck, W. Neil Adger, Katrina Brown, Declan Conway, Ashley S. Halls, et al. 2009. "Vulnerability of National Economies to the Impacts of Climate Change on Fisheries." Fish and Fisheries 10 (2): 173–96. https://doi.org/10.1111/j.1467-2979.2008.00310.x.

3. RESULTS

Table 3 provides a general overview of each tool examined. The studies considered as part of this review included 11 global assessments and 12 assessments focused on SIDS and coastal LDCs. In terms of the scale of these assessments, 16 studies evaluated risks and/or vulnerabilities at a national scale and 22 studies evaluated risks and/or vulnerabilities at a sub-national scale.

Most of the studies examined climate change or climate change-related hazards or risks. Many studies have adopted versions of the framework for assessing risks and vulnerabilities used in IPCC's Fourth Assessment Report (AR4) (i.e., Vulnerability as a function of ***Exposure, Sensitivity, and Adaptive Capacity***) and Fifth Assessment Report (AR5) (Risk as a function of ***Hazard, Exposure, and Vulnerability***). (Fig. 2). The version detailed in AR4 was the one used more extensively across reviewed works and was adopted by 20 studies.

Most of the studies examined climate change or climate change-related hazards or risks.

Table 3 Overview of publications and associated tools reviewed

Tool	Year	Primary Developer	Assessed Region	Focus Sector/System/ Domain	Risk/Hazard	Scale	Conceptual Framework
Aragão et al.	2022	Aragão et al.	Spain	Demersal fisheries	Climate change	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Ford & Wilcox	2022	Ford & Wilcox	N/A	Fisheries	IUU fishing	Vessel	Risk indicators as weighted averages of indicator categories
SCRT	2022	SCRT	N/A	Fisheries	IUU fishing	Vessel	List of indicators
GRPS	2021	World Economic Forum	Global	Multiple: Economic, Environmental, Geopolitical, Societal, Technological	Economic, Environmental, Geopolitical, Societal, Technological	Global/ Individual Experts	Global risk: an uncertain event or condition that, if it occurs, can cause significant negative impact for several countries or industries within the next 10 years.
Heck et al.	2021	Heck et al.	Global	Marine fisheries	Storm	National	Risk = fn(Hazard, Exposure, fn(Sensitivity, Adaptive Capacity))
Lancet	2021	Romanello et al.	Global	Health and climate change	Climate change	National	Indicator for monitoring
Macusi et al.	2021	Macusi et al.	The Philippines	Fisheries and aquaculture value chains	Multiple	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Magnan et al.	2021	Magnan et al.	N/A	Multiple: All sectors considered in the 2018-2019 IPCC special reports	Climate change	Global	Global risk = sum of risk metrics; RCP 2.6 vs RCP8.5, 1.5 degree C vs. 2 degree C, Regional disparities, Adaptation benefits
MBI	2021	Soto-Navarro et al.	N/A	Biodiversity	Biodiversity loss	National	MBI = Biodiversity State + People
Mynott et al.	2021	Mynott et al.	St Helena Island	Multiple: All sectors considered in the 2018-2019 IPCC special reports	Sand extraction	EEZ, MPA	Environmental risk calculated by following a decision tree
Thiault et al.	2021	Thiault et al.	N/A	Social-ecological systems	Social, Environmental, and Cliamte change	N/A	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Tigchelaar et al.	2021	Tigchelaar et al.	Global	Aquatic food system	Climate change	National	Climate risk = fn(Hazard, Exposure, Vulnerability)
Appiah et al.	2020	Appiah et al.	West District of Ghana	Women in small-scale fisheries livelihood vulnerability	Multiple	Sub-national	Multi-dimensional livelihood vulnerablity index (MLVI) = Vulnerability headcount ratio x Intensity of vulnerability
CORVI	2020	Stuart et al. (Stimson Center)	Mombasa, Kenya; Dar El Salaam, Tanzania; Kingston, Jamaica; Castries, Saint Lucia	Multiple: Financial, Political, Ecological	Climate and ocean	Sub-national	Baseline, Past Trend, Expected Trend, Magnitude, Impact
Duvat et al.	2020	Duvat et al.	Central Indian Ocean, Western and Central Pacific	Atoll habitability	Multiple	Sub-national	Cumulative risk to atoll habitability = 14 risk criteria

Tool	Year	Primary Developer	Assessed Region	Focus Sector/System/ Domain	Risk/Hazard	Scale	Conceptual Framework
EVI	2020	UNEP	SIDS	Environmental vulnerability	Multiple	National	List of indicators
Fernández-Macho et al.	2020	Fernández-Macho et al.	European Atlantic Area	Coastal areas	Multiple human impacts (maritime-related activities)	Sub-national	Risk indicators = fn(Marine spill risk, Port activities, Tourism activities, Protection of coastal areas, Water quality and waste management), Deta Envelop Method applied
Miles et al.	2020	Miles et al.	Palau	Climate change impact	Climate change	National	List of indicators
Robinson	2020	Robinson	SIDS	Climate change adaptation	Climate change	National	Richness index (Modified Adaptiation Initiatives Index) derived by coding of national adaptation actions
Aswani et al.	2019	Aswani et al.	Five fast warming regions in the southern hemisphere	Coastal communities	Climate change	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Genave	2019	Genave	Southwest Indian Ocean islands	Energy	Energy security	National	Energy vulnerability = Indicators
Halpern et al.	2019	Halpern et al.	Global	Ocean	Multiple human impacts	National, EEZ	Cumulative human impacts = sum of human impacts for each stressor for each ~1km resolution, where human impacts for each stressor = Sum of (stressor x ecosystem x vulnerability)
Hosch et al.	2019	Hosch et al.	Global	Fishing ports	IUU fishing	Sub-national	Risk index = weighted scores of general, internal, and external risk ocmponent
Pinnegar et al.	2019	Pinnegar et al.	Dominica	Fisheries	Climate change, Hurricane	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Smith et al.	2019	Smith et al.	United States	Coastal SES	Natural hazard events	Sub-national	Climate Resilience Index = 5 domains (risk, governance, society, built environment and natural environment)
Thiault et al.	2019	Thiault et al.	Global	Agriculture and marine fisheries	Climate change	National	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Uddin et al.	2019	Uddin et al.	Bangladesh	Coastal region	Climate change	National	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Blasiak et al.	2017	Blasiak et al.	Global	Marine fisheries	Climate change	National	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Ding et al.	2017	Ding et al.	Global	Marine fisheries, Food security	Climate change	National	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Mohammed et al.	2017	Mohammed et al.	Gujarat, India	Coastal fishing communities	Climate change	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Nguyen et al.	2017	Nguyen et al.	Quy Nhon, Vietnam	Social vulnerability	Climate change	Sub-national	Social vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)

Tool	Year	Primary Developer	Assessed Region	Focus Sector/System/Domain	Risk/Hazard	Scale	Conceptual Framework
Feindouno & Goujon	2016	Sosso & Goujon	Developing countries	National economic vulnerability	Exogenous shocks	National	Economic vulnerability index = Mean(Exposure sub-index, Shocks sub-index)
Frusher et al.	2016	Frusher et al.	Australia	Coastal communities	Climate change	Sub-national	Ecological & socio-economic vulnerability = fn(Exposure, Sensitivity, Adaptive capacity)
Maina et al.	2016	Maina et al.	Papua New Guinea	Coastal fishing communities	Climate change	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Monnereau et al.	2016	Monnereau et al.	Global	Fisheries	Climate change	National	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Weis et al.	2016	Weis et al.	Grenada	National vulnerability	Flooding	National	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Cinner et al.	2015	Cinner et al.	Kenya	Fishing communities	Environmental change	Sub-national	Social adaptive capacity = fn(Human agency, access to credit, occupational mobility, occupational multiplicity, social capital, material style of life, gear diversity, community infrastrucutre, trusto
Coastal Index	2015	RISC-KIT	N/A	Coastal communities	Multiple	Sub-national	Coastal Index = fn(hazard indicator, exposure indicator)
Islam et al.	2014	Islam et al.	Bangladesh	Fishery-based livelihoods	Climate variability	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Johnson et al.	2014	Johnson et al.	Maine, USA	Fishery-dependent communities	Multiple	Sub-national	Resilience = fn(survival, social identity, diversification, getting by, optimism)
Morzaria-Luna et al.	2014	Morzaria-Luna et al.	Northern Gulf of California, Mexico	Fishing communities	Multiple	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Salim et al.	2014	Salim et al.	Kerala, India	Coastal fishing communities	Climate change	Sub-national	Vulnerability PARS (Parameter, attribute, resilient indicator and score) = Environment, Fishery, Social, Economic, Development drivers
Shah et al.	2013	Shah et al.	Trinidad & Tobago	Agriculture and natural resource-dependent communities	Climate change	Sub-national	Livelihood vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Cinner et al.	2012	Cinner et al.	Kenya, Tanzania, Seychelles, Mauritius, Madagascar	Coral reef fisheries	Climate change	Sub-national	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)
Allison et al.	2009	Allison et al.	Global	Fisheries	Climate change	National	Vulnerability = fn(Exposure, Sensitivity, Adaptive Capacity)

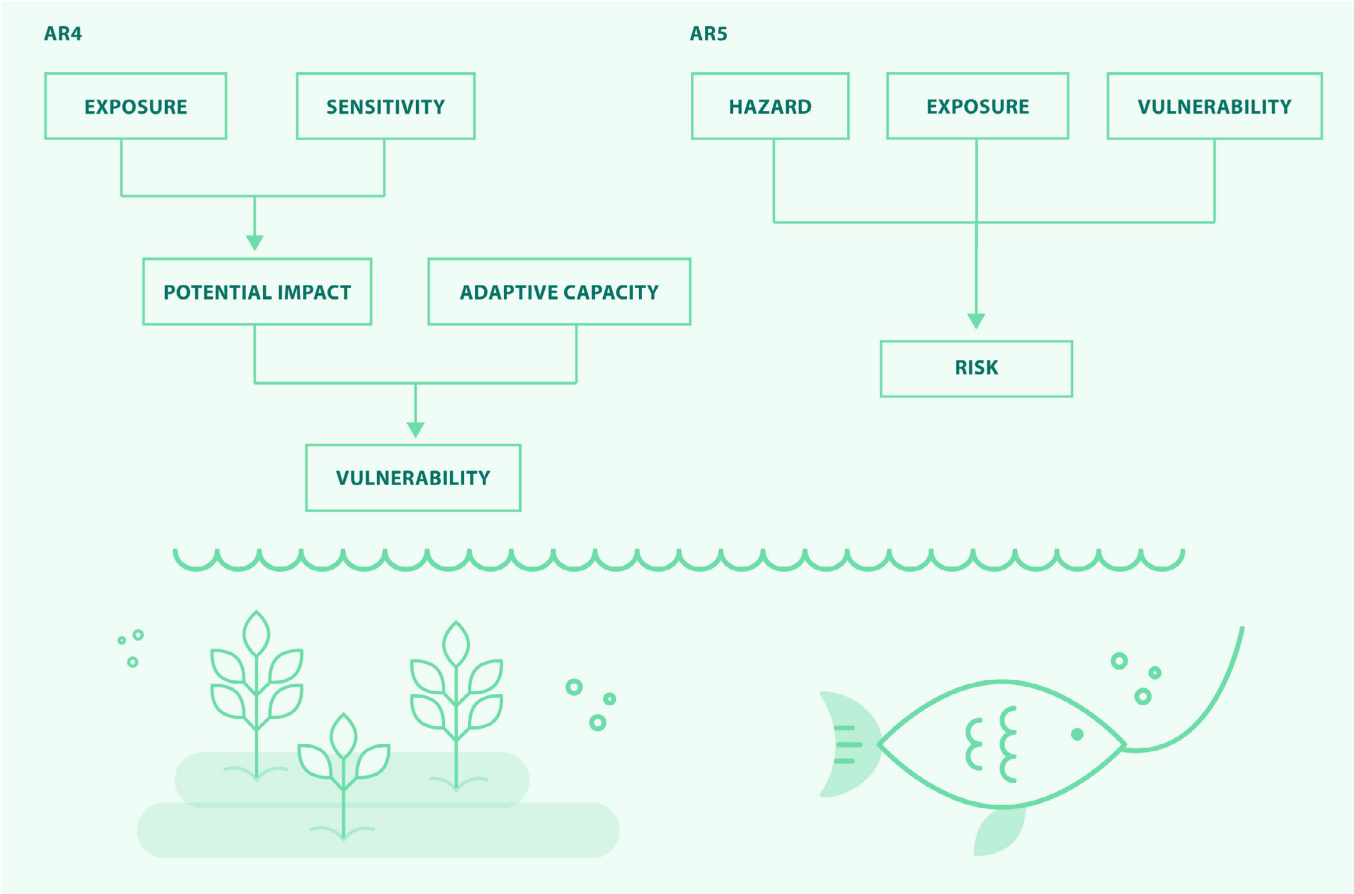

Figure 2. IPCC framework of vulnerability (AR4) and risk (AR5).

Since the studies examined a diverse set of risks and vulnerabilities at different scales and using different frameworks, it is unsurprising that the corresponding metrics also varied. On average, each study examined 26 metrics[i]. **Table 4** lists the categories of metrics considered in the publications reviewed by this study.

i This number is our best estimate based on the information provided by each study. At least one study did not list the entire set of metrics considered in the study and several studies used composite metrics taken from other studies. Thus, the actual average number of data and metrics considered may be different than what is included in our analysis.

Among studies that either conducted detailed assessments or described available datasets, 26 studies relied on multiple published sources of data. Most of these studies provided a list of data sources or aggregate metrics or indicator scores. Twelve studies conducted primary data collection through surveys of experts or households, interviews, or workshops. About a third of the studies explicitly stated how they treated missing data or observations. Two studies used averaging; three studies used different gap-filling methods depending on the metrics, indicators or assessed country; two studies used expert judgment or other sources of information; and four studies omitted the countries or regions with missing data. We further examined the availability of data for Sub-Saharan SIDS and LDCs. For this, we relied on the list of SIDS and LDCs compiled by our previous synthesis report on ocean risks in SIDS and LDCs, which identified 22 SIDS/LDCs in Sub-Saharan Africa. Only six studies included assessments for these countries. For those that included assessments for these countries, some of the metrics data were not available and had to rely on gap-filling methods (Figure 1, 'Not available').

Table 4. Overview of metric categories detailed in the publications reviewed as part of this study. For more granular details provided for each metric as part of the original works, please see the supplementary data. Tick marks indicate the component(s) of risk or vulnerability examined by the reviewed publications for each metric category.

Metric categories	Hazard	Exposure	Sensitivity	Adaptive capacity	Vulnerability	Risk	Resilience	Other
Arctic change						o		
Atmospheric temperature	o	o				o		o
Biodiversity & ecosystem services			o		o	o	o	o
Biological sensitivity			o		o			
Climate change (composite)		o						
Composite index of exposure	o	o				o		
Environmental change		o	o	o		o		
Erosion	o	o				o		
Flooding	o	o				o		o
Freshwater	o			o		o		o
Human impacts & environmental degradation	o	o	o	o	o	o		o
Humidity		o						
Marine environmental protection	o			o				
Monsoon		o			o			
Natural disasters & extreme events	o	o			o	o		o
Ocean acidification	o	o						o
Precipitation	o	o			o	o		o
Radiation		o						
Sea ice	o							
Sea level rise	o	o	o		o	o		o
Sea temperature	o	o				o		o
Species adaptive capacity				o				
Storm	o	o		o		o		o
Waves & currents		o						
Wind	o	o						
Agricultural production	o	o	o	o	o	o		o

Metric categories	Hazard	Exposure	Sensitivity	Adaptive capacity	Vulnerability	Risk	Resilience	Other
Aquaculture production	o		o		o			
Fisheries employment		o	o					
Fisheries management			o	o		o		
Fisheries production	o	o	o	o	o	o		
Fishing behavior						o		o
Fishing fleet characteristic			o	o				
Land use		o						
Natural capital		o		o		o		o
Other natural resource production			o					
Sector dependency		o	o	o	o	o		
Small-scale fisheries	o		o	o	o	o		o
Access to financial services				o	o			o
Access to information			o	o				o
Capital & assets			o	o		o		o
Climate policy				o		o		
Coastal population		o	o			o		
Demographic		o	o	o	o	o	o	
Diversification of economic activities			o	o	o	o	o	o
Economic development	o		o	o	o			
Education			o	o	o	o		o
Emergency services			o			o		
Emissions & climate change mitigation	o	o		o				o
Energy security					o			
Environmental policy	o	o					o	
Food & nutritional security		o	o		o	o		
GDP				o	o	o		
Gender			o	o				
Geopolitics						o		
Governance quality				o	o	o		
Green economy						o		o
Health		o	o	o	o	o	o	o
Housing quality			o	o			o	
Human capital & employment		o		o	o	o	o	o
Income & livelihoods			o	o				o

Metric categories	Hazard	Exposure	Sensitivity	Adaptive capacity	Vulnerability	Risk	Resilience	Other
Indigenous & local knowledge			o	o				o
Information & communication technology				o	o	o		
Infrastructure	o	o	o	o	o	o	o	o
Insurance				o				
International trade	o		o	o				
Knowledge & learning				o				
Macroeconomy		o		o		o		
Maritime sector								o
Migration		o	o	o	o	o		
Port activities						o		
Poverty & income inequality			o	o	o	o		
Public engagement				o				o
Public social service				o		o		
Resource conflicts				o				
Science & technology	o			o	o	o		o
Seafood economy & value chain		o	o	o				
Social capital		o	o	o	o	o	o	o
Social diversity		o		o		o		
Spatial mobility				o				
Tourism						o		
Views & attitudes				o		o	o	
Voluntary environmental measures						o		

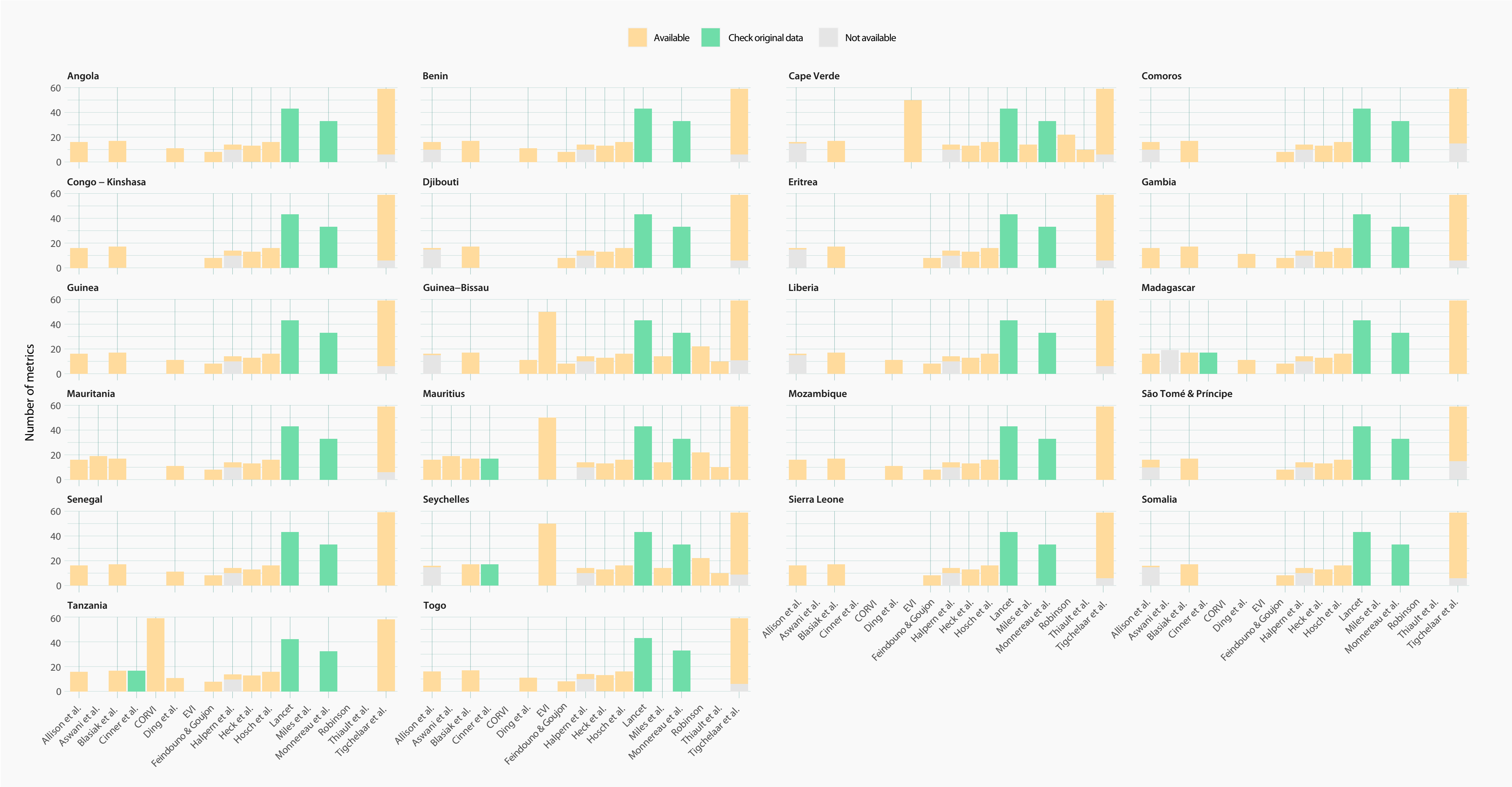

Figure 3. Assessment and data availability for Sub-Saharan SIDS and LDCs for the 17 studies that included the assessments of Sub-Saharan SIDS and LDCs. Horizontal axis shows the total number of metrics examined by each study. Different colors the number of metrics based on data availability (Available vs. Check original data (i.e., not immediately clear from the study) vs. Not available).

4. CONCLUSION

Existing indicator-based assessments investigate different types of ocean risks but the majority focus on climate change and related stressors. 23 of these studies are built on the conceptual framework suggested by the previous IPCC assessments. The different frameworks proposed by IPCC AR4 and AR5 are not conceptually consistent, limiting our ability to make direct comparisons across studies using these two frameworks.

While studies generally considered multiple stressors or risks, they often neglect complex interlinkages and cumulative impacts across them. A notable exception to this is Duvat et al. 2020, that examined cumulative risk of climate change hazards to atoll habitability and developed a risk assessment framework by considering conceptual pathways for how multiple hazards impact different components of the atoll system. The lack of studies considering and sufficient data to conduct assessments for Sub-Saharan SIDS and coastal LDCs poses a significant challenge for this region to prepare for and manage future risks. Uneven understanding of ocean risks can exacerbate existing inequity. To support adaptive capacity, be anticipatory, future research needs to address ways to 1) understand interlinked and cumulative impacts from multiple stressors and risks, 2) conduct regular environmental and socioeconomic surveys in data-poor regions, and 3) overcome data challenges by developing and strengthening data-poor assessment methods. One such data-poor approach includes the use of fuzzy logic that is well suited to dealing with uncertainties, data gaps, interpretation of indicators and integration of data from disparate sources, including expert knowledge, and/or that that may not have been collected in the same fashion or according to the same standard. One of the studies included in our review (Tigchelaar et al. 2021) applied this method building on previous research (e.g., Jones and Cheung 2018). In the context of SIDS and coastal LDCs data of varying quality as well as data gaps for given metrics and or countries for instance were and are likely to be a recurrent problem. However, given that these regions are also likely to bear some of the most significant impacts of climate change, and are currently home to some of the most vulnerable populations, lack of data cannot and should not limit action. Therefore, frameworks that seek to include uncertainty or differing perceptions from different disciplines are of particular interest and should be the subject of future study and advancement.

Uneven understanding of ocean risks can exacerbate existing inequity.

Specifically, fuzzy logic considers values as part of overlapping states (e.g., low and medium or medium and high), instead of allowing a single value for a given metric. Importantly, the framework allows for expert feedback to develop evaluation criteria and to provide informed inputs when no other data exists. As stated in Cisneros-Montemayor et al. (2018), "[t]here are four key qualities that this fuzzy logic approach capitalizes on: (1) the ability to combine multidisciplinary and multiscale data, which is vital for new integrated policy goals; (2) transparency of the entire framework (assumptions, data considered, scoring mechanisms, etc.), which allows for and indeed encourages multi-stakeholder collaboration; (3) flexibility to make adaptive modifications to assumptions or data inputs, while still maintaining consistent evaluation criteria with results that can be compared over time and across regions; (4) making uncertainty and differences in perceptions explicit, which is important for integrated policies that must necessarily deal with multiple uncertainties in data, system linkages, and stakeholder preferences and objectives." Such an approach should be explored as part of future studies and may be particularly relevant in the context of investigating climate change hazards under contrasting scenarios that link RCP climate simulations with scenarios that describe global developments leading to different challenges for mitigation and adaptation to climate change, so called Shared Socio-economic Pathways (SSPs) – for instance, Shared Socio-economic Pathway (SSP) 1—Representative Concentration Pathway (RCP) 2.6 (SSP1-2.6) and SSP5-8.5. SSP1-2.6 and SSP5-8.5, which represent a 'strong mitigation' low-emissions pathway and a 'no mitigation' high-emissions pathway, respectively (O'Neill et al. 2016; 2017).

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For the complete reference information of the studies reviewed by this report, please see the supplementary information available from: https://docs.google.com/spreadsheets/d/195GcaBsieQOAIGaqNaopYalU9NeVVSiVv3OQdqNqDbc/edit?usp=sharing

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