OCEAN RISKS IN SIDS AND LDCS

REPORT
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Key messages

Small Island Developing States (SIDS) and Least Developed Countries (LDCs) share certain features that make their development paths susceptible to ocean risks. Their economies are heavily reliant on the natural environment; and they are vitally dependent on public sector employment and foreign financing. These make SIDS and LDCs particularly vulnerable to certain environmental and socioeconomic stressors such as extreme weather and geological events, coastal urbanization, as well as global health and financial crises.

However, SIDS and LDCs are not homogeneous groups, but represent a set of countries and territories that differ across many dimensions. Countries and territories classified as SIDS and LDCs are diverse in terms of population size, levels of economic development, land masses, sizes of territorial sea and exclusive economic zones (EEZs), types and availabilities of natural resources, cultures, histories, and governance systems. Thus, vulnerabilities, adaptive and transformative capacities, and pathways in which ocean risks manifest will vary across coastal communities in SIDS and LDCs.

Ocean risks are coupled complex risks. Ocean risks to coastal communities in SIDS and LDCs are experienced across multiple dimensions. They include environmental stressors linked to climate change, such as floods, tropical storms, as well as shifts in species distributions and abundance. These interact with socioeconomic stressors including fisheries overexploitation, pollution, dredging, and poor land use. The unprecedented levels of hyper-connectivity in our world exacerbate this ocean risk landscape. Events such as pandemics, financial crises and synchronized food shocks propagate more rapidly than in the past and with greater geographic spread, and intersect with broader existing socio-cultural, economic, and political vulnerabilities.

Efforts to quantify risk and vulnerability must pay more explicit attention to the coupled complex nature of ocean risks. For example, impacts from sea level rise tend to be assessed in isolation from the effects of ocean warming. Likewise, fishing communities located in areas that will be inundated due to sea level rise likely will also be affected by changes in fisheries' productivity. In such cases, coastal infrastructure planning to adapt to climate change, for instance, needs to consider possible shifts in use patterns, such as changes in fish processing facilities and market functionalities. Such planning should also consider changes in seafood demand by the global market, demand for environmental conservation, and development of the carbon market, among others, while keeping social equity concerns in mind.

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. This report highlights examples of the socio-economic impacts of displacements and migration, which disrupt local social structures and can reduce or destroy social capital critical for economic growth and resilience. At the same time, an inability to relocate also negatively impacts community resilience and may trap communities in patterns of continually facing future risks. It is important to keep in mind the context-specificity of how ocean risks manifest and impact SIDS and LDCs, meaning a diverse set of approaches will be needed to adequately understand and respond to risk and vulnerability. Context-dependent solutions are essential; for instance, projects tailored to local ecological systems may work better than global-scale approaches under certain conditions. Projects that are designed with local communities can benefit from local knowledge to ensure that project address local demands and reflect socio-cultural contexts to achieve long-term success.

Strengthening of scientific and technical capacities as well as integration of local indigeneous and ecological knowledge can promote resilience, sustainabiilty, and equity. SIDS and LDCs often lack domestic technical capacities and data to conduct their own vulnerability and risk assessments. Thus, investments in building domestic scientific and technical capacities, baseline monitoring, data collection, and deployment of blue techs are critical for mitigating risks to build resilience. At the same time, many communities in SIDS and LDCs hold valuable local indigenous and ecological knowledge that are often neglected in the scientific or decision-making process. Integration of these knowledge systems can benefit disaster response, resource management, and climate adaptation.

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Definitions

Adaptive capacity - the social factors that enable resilience to current, perceived, or expected social-ecological change [1].

Blue economy - sustainable development framework for developing countries addressing equity in access to, development of, and the sharing of benefits from marine resources; offering scope for re-investment in human development and the alleviation of crippling national debt burdens [2].

Displacement - Involuntary and unforeseen movement of people from their place of residence due to weather-related impacts on property and infrastructure [3].

Exclusive economic zones - areas of the sea in which a coastal state has sovereign rights (as prescribed by the 1982 United Nations Convention on the Law of the Sea) regarding the exploring, exploiting, conserving, and managing living and non-living resources of the water column, seabed and subsoil, including energy production from water and wind, in its adjacent section of the continental shelf extending 200 miles from the coastline.

Exposure - nature and degree to which a component is in contact with or subject to a stressor.

Food and nutrition security - food and nutrition security is achieved when adequate food (quantity, quality, safety, socio-cultural acceptability) is available and accessible for and satisfactorily used and utilized by all individuals at all times to live a healthy and active life [4].

Least Developed Countries (LDCs) - a group of countries with low income and/or with socioeconomic vulnerabilities.

Ocean economy - the sum of the economic activities of ocean-based industries, and the assets, goods, and services of marine ecosystems [5].

Ocean observing system - a collection of sensors that collect data, the platforms that host these sensors, and technology that sends the data to a data collection center, often with satellite or cell phone telemetry. Observing systems also include computer models that produce forecasts of ocean conditions [6].

Ocean risks - existing or potential impacts and experiences of socioeconomic and environmental stressors derived from the ocean or associated with the ocean economy that derail SIDS and LDCs from sustainable and equitable development paths.

Resilience - the capacity of a system to cope, adapt or transform in the changing social or environmental conditions [7].

Sensitivity - degree to which a system is directly or indirectly affected or modified by a stressor.

Small Island Developing States (SIDS) - a group of countries and territories that share common social, economic, and environmental challenges in their development paths as small island states.

Social capital - features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit [8].

Stressors - threats to a social-ecological system. Stressors can be socioeconomic (e.g., market shocks, coup d'état, population growth) or environmental (e.g., tropical cyclone, sea level rise, changing water quality).

Vulnerability - degree to which a system (or its attributes) is susceptible to, or unable to cope with, adverse effects of one or more stressors. Vulnerability has three dimensions: exposure, sensitivity, and adaptive capacity [9].

Introduction

Climate change has been impacting marine and coastal ecosystems globally. Carbon emissions from human activities are causing ocean warming, acidification and oxygen loss with some evidence of changes in nutrient cycling and primary production [10]. Increasingly, ocean warming and extreme temperature events (i.e., marine heatwaves) are affecting marine and coastal ecosystems through changes in population productivity and spatial distribution [11–14], impacting fisheries with implications for food production and dependent human communities [15–19]. Distributions of seagrass meadows and mangroves are contracting, while the frequency of large-scale coral bleaching events has increased, causing worldwide reef degradation [20–22]. Small island developing states (SIDS), a group of countries and territories that share common social, economic, and environmental challenges in their development paths, and least developed countries (LDCs), a group of countries with low income and/or with socioeconomic vulnerabilities, are disproportionately vulnerable to these impacts [19,23,24]. Many of these countries have an outsized dependence on marine and coastal resources and healthy ecosystems for income, livelihoods and nutrition security [25–28]. Coastal ecosystems are also critical to their culture and linked to many traditions [29].

We are simultaneously seeing increasing hopes and expectations that the ocean will serve as an engine to sustain future economic development [30]. There is an accelerating scramble for current, and future, ocean benefits that is unfolding with unprecedented intensity and diversity (e.g., fisheries, aquaculture, mining, bioprospecting, shipping, conservation,

Morning after Hurricane Maria, September 2017, between Castle Comfort and Roseau on the Island of Dominica.

communication, tourism, and geopolitics). This scramble for the seas – or "blue acceleration" – presents both risks and opportunities with a range of ecological, economic, equity and policy ramifications. The future of the ocean economy in SIDS and LDCs depends on their ability to navigate this new ocean reality.

The international community has emphasized the need to prioritize SIDS and LDCs in building resilience against climate change and other risks to achieve sustainable development goals; for example, the SIDS Accelerated Modalities of Action (SAMOA) Pathway was adopted in 2014 at the Third International Conference on SIDS (Apia, Samoa), and called for urgent actions and support for SIDS' efforts to achieve their sustainable development. Despite such calls and progress made since, gaps and challenges remain [31], including access to finance to support the sustainable development of key sectors, such as fisheries [32].

This report synthesizes peer-reviewed and grey literature, empirical data, and case-studies to:

1. Highlight prominent environmental and socioeconomic stressors and their impacts on SIDS and LDCs;

2. Describe social-ecological features of SIDS and LDCs that shape their vulnerabilities;

3. Describe potential ways that can support SIDS and LDCs in mitigating ocean risks and building resilience.

Key Features of SIDS and LDCs

Formally, SIDS were recognized at the 1992 United Nations Rio Conference on Environment and Development as having shared unique sustainable development challenges, such as geographical remoteness, low economic diversity, and a heavy reliance on marine and coastal resources [33]. LDCs are determined based on per capita incomes following World Bank's low-income countries (LICs) classification. Designation as LDCs is also associated with the level of human assets and economic vulnerability [34]. LDCs therefore include LICs as well as those lower-middle income countries with low human assets and high economic vulnerability.

These classifications and labels play a critical role in determining access to certain types of financing [35]. For example, there are 24 countries who can receive the World Bank's International Development Association's concessional financing (i.e., no interest, 40-year amortization with 10-year grace period) and their eligibility is determined based on criteria such as per capita income and their status as Small Island States [36]. Official development assistance (ODA) is not available for non-LDC high income countries as well as those that are members of G8 and current and prospective members of the European Union (EU) [37]. Furthermore, LDCs can receive preferential trade deals under the World Trade Organization mechanism [38].

Many SIDS and coastal LDCs have economies that are heavily reliant on coastal and marine ecosystems, and often have vast EEZs with rich fisheries resources. Consequently, communities and households in SIDS and coastal LDCs largely depend on fisheries and aquaculture for nutrients and livelihoods. Developmental finances, but also other types of external resources through international tourism, and sales of fisheries access rights, play an important role in these countries and territories [39]. For example, coastal tourism brings in a large amount of foreign income for many SIDS. In fact, the tourism sector accounts for over 20% of GDP for almost two-thirds of SIDS [40–42] (see also ORRAA Report on Gender)*. Similarly, the sales of fishing licenses to distant water fishing nations comprise a significant portion of public revenue and contribute to essential public services such as education and healthcare [43]. Combined with the general lack of economic diversity, their heavy reliance on external resources makes them vulnerable not only to environmental hazards such as extreme weather and ecosystem changes but also to socioeconomic stressors such as global financial crises, pandemics, and geopolitics.

SIDS and coastal LDCs are especially vulnerable to climate change. For example, global indices of climate change vulnerability highlight that SIDS and LDCs are highly exposed to the impacts of climate change, have a relatively low adaptive capacity, and are among the world's most sensitive states to climate change (Figure 1). The economic damages from climate change are also projected to be high

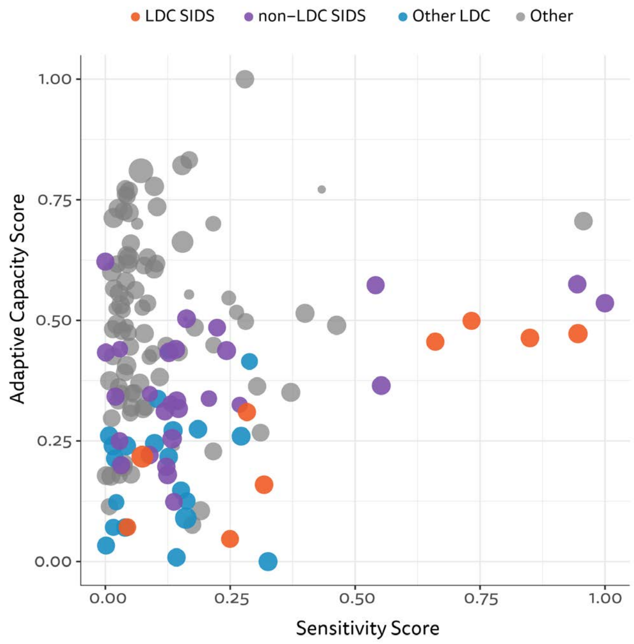

Figure 1. Exposure, Sensitivity, and Adaptive Capacity (Figure shows the climate change sensitivity (horizontal axis) and adaptivity capacity (vertical axis) scores calculated for each Coastal State by Blasiak et al. (2017). The colors indicate LDC SIDS (red), non-LDC SIDS (purple), Other LDC (blue), and other (grey) countries. The size of the dot indicates climate change exposure score calculated from using IPCC RCP scenario (near term projection, as described by Blasiak et al. (2017). Data: Blasiak et al. (2017) supporting information https://doi.org/10.1371/journal.pone.0179632.s001)

* Wabnitz et al (2021) ORRAA Report. https://oceanrisk.earth

Table 1. List of Coastal LDCs and SIDS (Regional classification follows UN region and sub-region classification).*

Region	Subregion	Country		SIDS	LDC	Population, total	GNI per capita, PPP (current international $)	Income group	External debt stocks (% of GNI)	Lending category	Other	Per capita greenhouse gas emissions (kt of CO2 equivalent)
Africa	Northern Africa	Sudan	SDN		LDC	42,813,238	3,990	Lower middle income	77.06	IDA	HIPC	0.013593
	Sub-Saharan Africa	Angola	AGO		LDC	31,825,295	6,380	Lower middle income	63.96	IBRD		0.001659
		Benin	BEN		LDC	11,801,151	3,400	Low income	27.37	IDA	HIPC	0.003447
		Cape Verde	CPV	SIDS		549,935	7,330	Lower middle income	93.90	Blend		0.000773
		Comoros	COM	SIDS	LDC	850,886	3,210	Lower middle income	25.57	IDA	HIPC	0.000779
		Congo - Kinshasa	COD		LDC	86,790,567	1,110	Low income	11.11	IDA	HIPC	0.011624
		Djibouti	DJI		LDC	973,560	5,620	Lower middle income	79.00	IDA		0.003186
		Eritrea	ERI		LDC	3,213,972	1,610	Low income	51.48	IDA	HIPC	
		Gambia	GMB		LDC	2,347,706	2,280	Low income	39.97	IDA	HIPC	0.001853
		Guinea	GIN		LDC	12,771,246	2,650	Low income	23.54	IDA	HIPC	0.009515
		Guinea-Bissau	GNB	SIDS	LDC	1,920,922	2,230	Low income	44.20	IDA	HIPC	0.004738
		Liberia	LBR		LDC	4,937,374	1,320	Low income	49.95	IDA	HIPC	0.000685
		Madagascar	MDG		LDC	26,969,307	1,660	Low income	29.90	IDA	HIPC	0.005277
		Mauritania	MRT		LDC	4,525,696	5,360	Lower middle income	71.55	IDA	HIPC	0.003600
		Mauritius	MUS	SIDS		1,265,711	26,840	Upper middle income		IBRD		0.001634
		Mozambique	MOZ		LDC	30,366,036	1,310	Low income	135.73	IDA	HIPC	0.015296
		São Tomé & Príncipe	STP	SIDS	LDC	215,056	4,130	Lower middle income	60.36	IDA	HIPC	0.001038
		Senegal	SEN		LDC	16,296,364	3,470	Lower middle income	58.83	IDA	HIPC	0.004043

* LDC status were determined by referencing UN Committee for Development Policy Secretariat [174]. SIDS status were determined by referencing UNCTAD [175]. Population, GNI per capita, External debt stocks, and per capita GHG emissions were obtained and calculated from World Bank and are for the most recent data as of April 2021. Red font used for population indicate microstate with countries less than 200,000 people. Red font used for per capita GHG emissions indicate countries with per capita GHG emission higher than OECD countries. These were obtained via R package 'wbstats' (version1.0.4). Income group, World Bank lending category and HIPC listings were obtained from World Bank [36]. Abbreviations: IDA: International Development Association, IBRD: International Bank of Reconstruction and Development, HIPC: Highly Indebted Poor Countries.

Region	Subregion	Country		SIDS	LDC	Population, total	GNI per capita, PPP (current international $)	Income group	External debt stocks (% of GNI)	Lending category	Other	Per capita greenhouse gas emissions (kt of CO2 equivalent)
Africa	Sub-Saharan Africa	Seychelles	SYC	SIDS		97,625	29,470	High income		IBRD		0.010309
		Sierra Leone	SLE		LDC	7,813,215	1,770	Low income	44.42	IDA	HIPC	0.001760
		Somalia	SOM		LDC	15,442,905		Low income	268.83	IDA	HIPC	0.001724
		Tanzania	TZA		LDC	58,005,463	2,700	Low income	31.80	IDA	HIPC	0.005002
		Togo	TGO		LDC	8,082,366	1,670	Low income	40.01	IDA	HIPC	0.003385
Americas	Latin America and the Caribbean	Anguilla	AIA	SIDS								
		Antigua & Barbuda	ATG	SIDS		97,118	21,780	High income		IBRD		0.006114
		Aruba	ABW	SIDS		106,314	36,300	High income				0.009977
		Bahamas	BHS	SIDS		389,482	37,420	High income				0.013381
		Barbados	BRB	SIDS		287,025	15,770	High income				0.005430
		Belize	BLZ	SIDS		390,353	6,700	Upper middle income	80.03	IBRD		0.004645
		British Virgin Islands	VGB	SIDS		30,030		High income				0.004038
		Cayman Islands	CYM	SIDS		64,948	41,790	High income				0.011579
		Cuba	CUB	SIDS		11,333,483		Upper middle income				0.004656
		Curaçao	CUW	SIDS		157,441	26,670	High income				
		Dominica	DMA	SIDS		71,808	12,250	Upper middle income	49.35	Blend		0.003140
		Dominican Republic	DOM	SIDS		10,738,958	18,300	Upper middle income	42.42	IBRD		0.003363
		Grenada	GRD	SIDS		112,003	16,080	Upper middle income	50.31	Blend		0.006759
		Guyana	GUY	SIDS		782,766	13,540	Upper middle income	31.15	IDA	HIPC	0.008129
		Haiti	HTI	SIDS	LDC	11,263,077	3,040	Low income	15.39	IDA	HIPC	0.000862
		Jamaica	JAM	SIDS		2,948,279	9,940	Upper middle income	98.83	IBRD		0.005445

Region	Subregion	Country		SIDS	LDC	Population, total	GNI per capita, PPP (current inter-national $)	Income group	External debt stocks (% of GNI)	Lending category	Other	Per capita greenhouse gas emissions (kt of CO2 equivalent)
Americas	Latin America and the Caribbean	Montserrat	MSR	SIDS								
		Netherlands Antilles	ANT	SIDS								
		Sint Maarten	SXM	SIDS		40,733	35,400	High income				
		St. Kitts & Nevis	KNA	SIDS		52,834	26,360	High income		IBRD		0.002551
		St. Lucia	LCA	SIDS		182,790	15,180	Upper middle income	31.99	Blend		0.003390
		St. Vincent & Grenadines	VCT	SIDS		110,589	12,930	Upper middle income	43.59	Blend		0.002944
		Suriname	SUR	SIDS		581,363	15,310	Upper middle income		IBRD		0.004911
		Trinidad & Tobago	TTO	SIDS		1,394,973	27,140	High income		IBRD		0.045589
		Turks & Caicos Islands	TCA	SIDS		38,191	28,020	High income				0.000508
	Northern America	Bermuda	BMU	SIDS		64,027	86,460	High income				0.009767
Asia	South-eastern Asia	Cambodia	KHM		LDC	16,486,542	4,320	Lower middle income	60.01	IDA		0.008619
		Myanmar (Burma)	MMR		LDC	54,045,420	5,170	Lower middle income	15.16	IDA		0.010278
		Singapore	SGP	SIDS		5,703,569	92,270	High income				0.010524
		Timor-Leste	TLS	SIDS	LDC	1,293,119	4,970	Lower middle income	7.53	Blend		0.000847
	Southern Asia	Bangladesh	BGD		LDC	163,046,16	5,200	Lower middle income	18.01	IDA		0.001214
		Maldives	MDV	SIDS		530,953	18,380	Upper middle income	52.70	IDA		0.001310
	Western Asia	Bahrain	BHR	SIDS		1,641,172	44,250	High income				0.025270
		Yemen	YEM		LDC	29,161,922	3,520	Low income	31.26	IDA		0.001672
Oceania	Melanesia	Fiji	FJI	SIDS		889,953	13,120	Upper middle income	20.22	Blend		0.002610
		New Caledonia	NCL	SIDS		287,800		High income				0.008873

Region	Subregion	Country		SIDS	LDC	Population, total	GNI per capita, PPP (current international $)	Income group	External debt stocks (% of GNI)	Lending category	Other	Per capita greenhouse gas emissions (kt of CO2 equivalent)
Oceania	Melanesia	Papua New Guinea	PNG	SIDS		8,776,109	4,360	Lower middle income	78.81	Blend		0.001453
		Solomon Islands	SLB	SIDS	LDC	669,823	2,750	Lower middle income	22.27	IDA		0.008257
		Vanuatu	VUT	SIDS	LDC	299,882	3,320	Lower middle income	44.59	IDA		0.001788
	Micronesia	Guam	GUM	SIDS		167,294		High income				0.000537
		Kiribati	KIR	SIDS	LDC	117,606	4,650	Lower middle income		IDA		0.000522
		Marshall Islands	MHL	SIDS		58,791	5,090	Upper middle income		IDA		0.000103
		Micronesia (Federated States of)	FSM	SIDS		113,815	3,640	Lower middle income		IDA		0.000536
		Nauru	NRU	SIDS		12,581	17,820	Upper middle income		IBRD		
		Northern Mariana Islands	MNP	SIDS		57,216		High income				0.000230
		Palau	PLW	SIDS		18,008	19,580	High income		IBRD		
	Polynesia	American Samoa	ASM	SIDS		55,312		Upper middle income				0.001056
		Cook Islands	COK	SIDS								
		French Polynesia	PYF	SIDS		279,287		High income				0.002535
		Niue	NIU	SIDS								
		Samoa	WSM	SIDS		197,097	6,500	Upper middle income	50.13	IDA		0.001883
		Tonga	TON	SIDS		104,494	7,000	Upper middle income	34.68	IDA		0.001499
		Tuvalu	TUV	SIDS	LDC	11,646	6,180	Upper middle income		IDA		0.000488

in SIDS and LDCs. For example, recent reviews of existing economic assessments and models of climate change impacts suggest that countries with lower per capita income will see larger GDP losses in the long run [44]. This body of research also argues that such regressive distribution of climate impacts across countries is often not accounted for in the estimation of economic damages from climate change.

Despite having many of the shared features described above, SIDS and LDCs should not be treated as homogenous groups. They represent a diverse set of countries and territories that differ across many dimensions (Table 1). As of 2021, the list of LDCs included 47 countries, 21 of which are Coastal States with exclusive economic zones (EEZs), and the list of SIDS included 58 countries and territories, with 9 countries appearing on both lists (LDC-SIDS) (Table 1). While the majority of the 58 recognized SIDS are sovereign states, 20 of them are classified as territories and/or are not the members of the United Nations [45]. Among SIDS, there is a great variability in terms of land mass, territorial sea, natural resource availabilities, as well as governance systems [42]. For example, Bahrain is an oil producing country, Papua New Guinea is rich in forestry resources, and Tuvalu is a coral atoll. Several SIDS are classified as high-income countries (Table 1).

In summary, certain shared features make SIDS and coastal LDCs particularly vulnerable to certain environmental and socioeconomic stressors such as extreme weather and geological events, coastal urbanization, as well as global health and financial crises. However, differences across dimensions such as population size, levels of economic development, land masses, sizes of territorial sea and EEZs, types and availabilities of natural resources, cultures, histories, and governance systems indicates that vulnerabilities, adaptive and transformative capacities, and pathways in which ocean risks manifest will vary across coastal communities in SIDS and LDCs.

Ocean risk landscape

Globally, 40% of the world's population (i.e., 2.4 billion people) live within 100 km of the coast [46], and these numbers are higher for SIDS and LDCs. Coping with environmental stressors (sometimes referred to as natural hazards) that are ocean-derived has dramatically shaped resource use and human settlement in SIDS and coastal communities across LDCs throughout their histories. However, there is a growing scientific recognition that we live in a time where humans are the dominant force of planetary change – termed the Anthropocene epoch [47]. Human activity is now fundamentally modifying weather patterns, the climate, the cryosphere (i.e., the frozen parts of the Earth), and the ocean. The natural baseline (e.g., frequency and intensity) of many of these ocean-derived environmental stressors is changing. Technological advancement in the past few decades has led humanity to reach deeper and further into the ocean, with rapidly increasing commercial interests driving growth in existing industries and the emergence of new ones [30,48]. The Blue Acceleration, a race among diverse and often competing interests for ocean food, material, and space, is driving an unprecedented expansion in the intensity, and diversity of socioeconomic stressors impacting SIDS and LDC coastal communities (see also ORRAA Report on the Blue Acceleration)*. Together, these environmental (e.g., tropical cyclones, sea level rise) and socioeconomic (e.g., urbanization, financial crises) stressors are creating ocean risks that can derail SIDS and LDCs from sustainable development paths.

The next sections synthesize the impacts and interactions of the key environmental and socioeconomic stressors that are derived from the ocean and/or associated with the ocean economy, including extreme weather and geological events, climate-induced sea level rise, coastal urbanization, global pandemic, financial crises, and the associated ocean risks for SIDS and LDCs.

Natural disasters, sea level rise, and floods

The Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change asserted that global mean sea level will continue to rise through 2100, resulting in more coastal areas experiencing increases in relative sea level, coastal flooding, and coastal erosion [49]. Even if emissions were to stop today, it is likely that sea-level rise (SLR) would increase by an additional 0.7-1.1m by 2300. Considering the "pledged emissions" through 2030, these numbers increase to 0.8-1.4m of committed SLR. If emissions continue beyond 2030, sea level will continue to rise accordingly. SLR is therefore anticipated to be one of the most expensive and irreversible consequences of climate change worldwide. For example, a recent study, using a spatially dynamic model of the world economy, estimated that SLR would reduce global real GDP by 0.19% in present value terms under an intermediate scenario (RCP 4.5) of greenhouse gas emissions [50]. Corresponding country-level estimates of SLR impacts on GDP, welfare, and population project that the countries that will suffer the most GDP and population loss are LDCs,** predominantly those found in sub-Saharan Africa. The study also found varying degrees of impacts within and across global regions (Figure 2). For instance, despite nearby countries projected to experience large welfare and population losses, Mauritania and Sierra Leone are expected see an increase in GDP and population.

SLR, in conjunction with increases in extreme rainfall events, will lead to more frequent and prominent coastal flooding and erosion. Flood risks will be further exacerbated by coastal development driven by population growth and rapid urbanization. A recent global analysis, using spatially detailed inundation maps and night lights data suggested that cities located in areas that are less than 10 meters above sea level have a high annual probability of large-scale floods that could displace >100,000 people [51].

With a 2°C increase in temperature, there will be more intense tropical cyclones and the proportion of Category 4 and 5 tropical cyclones will increase by 13% [42,49]. If major hard infrastructure (e.g., ports, roads) and soft infrastructure (e.g., financial and governance centers) are hit, these impacts will ripple throughout the entire country. SIDS and

* Jouffray et al (2021) ORRAA Report. https://oceanrisk.earth

** This study also estimated the impacts of SLR for land-locked countries.

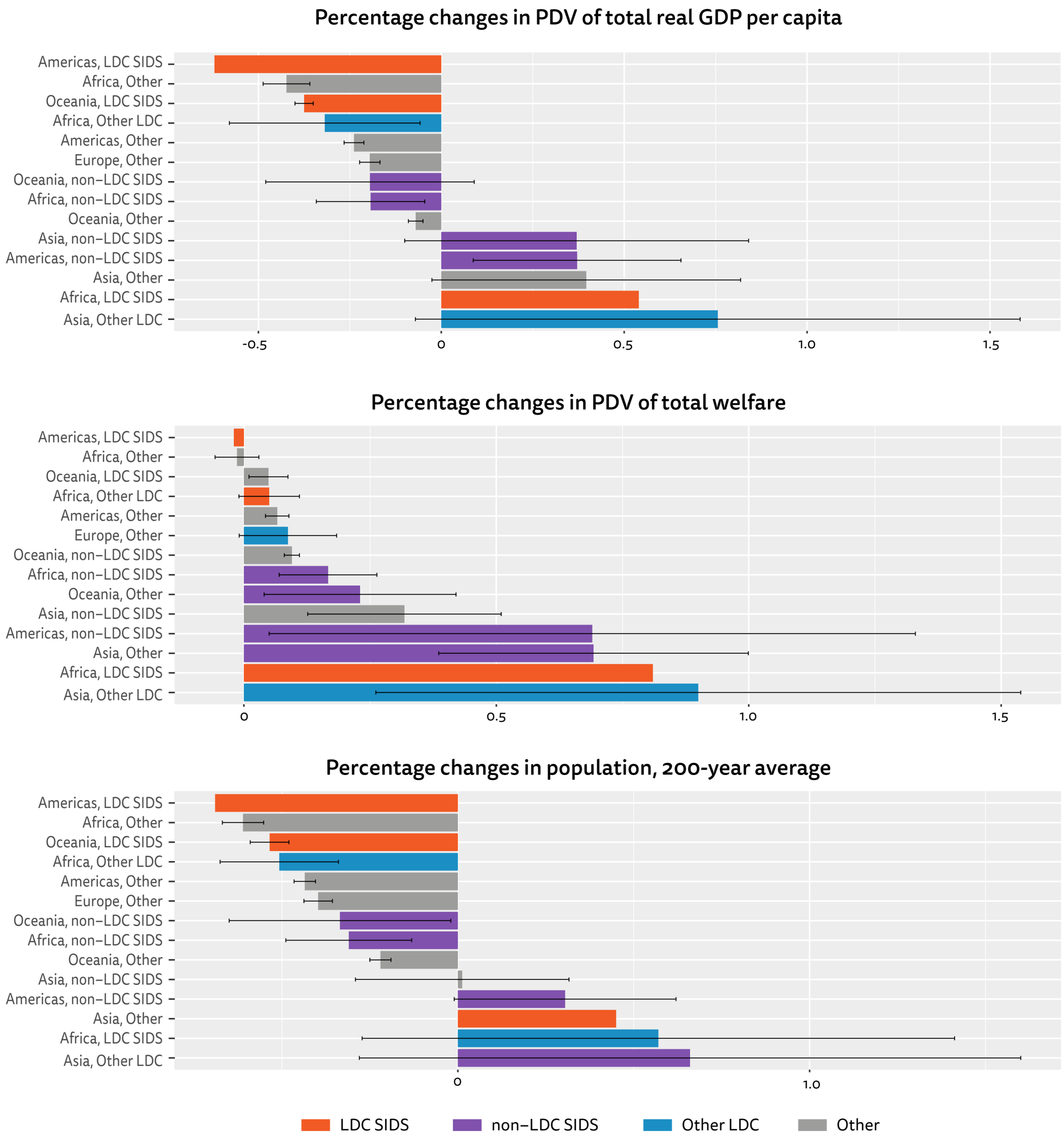

Figure 2. Economic impacts of coastal flooding (Figures show the findings from Desmet et al. 2021 that estimated the impacts of sea level rise on real GDP (top left), welfare (top right), and population (bottom left) in each country. Bars indicate the mean impact).

coastal LDCs often have critical infrastructure such as transportation hubs, healthcare facilities, water treatment plants, desalination plants, and power stations in low-lying areas. This infrastructure is exposed to stressors such as coastal flooding caused by events such as large storms and tsunamis. For instance, airports and ferry terminals that are critical to the economies of Jamaica and St. Lucia will be more frequently inundated over the course of the coming century as a result of sea level rise and stronger storms [52]. Marine flooding can also impact coastal aquifers, decreasing the availability of fresh water supplies [53].

Local socio-economic factors and historical changes to coastal areas can exacerbate the impacts of SLR. Documented cases of coastal inundation and erosion often cite additional circumstances such as vertical subsidence, engineering works, development activities, or beach mining. For instance in the Indian Ocean, on Anjouan Island, Comoros, coral reef fishing and beach mining worsened coastal erosion to extend to the entire island's coastline [54]. On the atoll island of Fongafale Islet, the capital of Tuvalu, urbanization and construction activities in swampland that have taken place since the 1970s have worsened the impacts of SLR [55].

Some SIDS and LDCs are located in areas that are seismically active and are impacted by offshore earthquakes and tsunamis. Many coastal communities in these countries have limited access to advanced warning systems and scientific information that would aid disaster planning [56,57]. Lack of a routine monitoring and data can severely limit their ability to benefit from advanced technologies that are employed by developed countries to reduce their disaster risks from geophysical and weather-related events. Increased international support is critical for building and strengthening local scientific infrastructure as well as human and financial resource capacities. Recent developments in UN-led global observing systems are aiding SIDS and LDCs in accessing, building, and benefiting from relevant scientific advances (Box 1). Further, in conjunction with building scientific capacities, integration of local indigenous knowledge and local ecological knowledge in the scientific and decision-making process can lead to improved understanding of the system. For instance, many communities in Papua New Guinea have made use of local indigenous and ecological knowledge to manage disaster risks [58]. Similarly, these knowledge systems can improve resource management [59,60] and climate change response and adaptation [61].

Ocean warming and ecosystem changes

The ocean has absorbed the bulk of human-induced warming since the industrial era – about 90% of the excess heat [10]. This has caused unambiguous increases in the global average sea surface temperature (SST) over the 20th century. In addition to gradual warming of the ocean, marine heatwaves – defined as "a period of extreme warm near-SST that persists for days to months and can extend up to thousands of kilometers [62]" – are also becoming

Box 1 Ocean observing systems and scientific cooperation

The UN Decade of Ocean Science for Sustainable Development began in 2021. Decisions based on indigenous knowledge or local ecological knowledge, in conjunction with customary rules and practices, have historically contributed to sustainable management of coastal and marine natural resources [59,171] and to planning for and recovery from natural disasters in their coastal communities in SIDS and LDCs [58]. As the world shifts into conditions unprecedented in human history, however, relying solely on past experience can limit these communities as they plan for the future. Coastal communities in highly industrialized countries are increasingly relying on scientific models and projections for vulnerability assessments and adaptation planning. SIDS and LDCs have limited resources to establish and manage ocean observation systems. Yet some regions, namely Caribbean SIDS and Pacific SIDS, respectively, have establish regional alliances for ocean observing systems to cooperate in collecting and using ocean data (IOCARIBE-GOOS in the Caribbean and PI-GOOS in Pacific Islands) [27]. These efforts are both part of the Global Ocean Observing Systems (GOOS) Regional Alliance, an effort led by UNESCO's Intergovernmental Oceanographic Commission (IOC). These regional efforts have led, among other things, to the establishment of a Tsunami Warning System in the Caribbean and inundation projections in Fiji [27].

There are thirteen GOOS Regional Alliances in the world, including IOCARIBE-GOOS, PI-GOOS, and Indian Ocean GOOS (IO-GOOS), and these regional alliances are governed and funded in a variety of ways. Ocean observing systems are costly, and SIDS and LDCs rely heavily on external funds to establish and maintain the systems. IOCARIBE-GOOS is governed by the IOC sub-commission; PI-GOOS is governed by the Pacific Islands Applied Geoscience Commission and Secretariat of the Pacific Regional Environmental Programme, and in the Indian Ocean, IO-GOOS is governed by a memorandum of understanding among marine institutes from 16 countries [181]. These Regional GOOS alliances have been serving as international collaboration platforms for ocean science, and in SIDS, they have led to international collaborations between SIDS and developed economies to attract external funds to develop data and scientific products to support local decisions. Although SIDS and LDCs are limited by their lack of data [42,182],regional GOOS have a tremendous potential to increase their scientific capacity for monitoring, modeling and forecasting to mitigate future risks.

The development of a Framework for Ocean Observing in 2012, which established guidelines for the design and implementation of ocean observing systems, led to increased and strengthened collaboration among ocean observing systems practitioners, institutions, and scientists. Yet, there is a lack of budgetary resources to coordinate and govern ocean observing systems in a sustainable manner [183]. GOOS can play a pivotal role in providing baseline information not only about offshore waters but also about coastal waters to bring benefit to coastal human populations. Continued funding support and investments towards international effort to strengthen GOOS can bring benefits to coastal communities SIDS and coastal LDCs and should be a key component of the UN Decade of Ocean Science for Sustainable Development and aligned efforts.

longer and more intense, with the frequency of the most impactful marine heatwaves over the last few decades having increased more than 20-fold because of anthropogenic global warming [63–65]. By the end of the century, the IPCC projects that these extreme events will become four times more frequent under low emission scenarios (SSP1-2.6), or eight times more frequent under high emission scenarios (SSP5-8.5).

Ocean warming will impact marine ecosystems by changing the abundance and distributions of fish species [66–68]. Tropical regions, where many SIDS and LDCs are located, are particularly vulnerable to these shifts in species as more fish make poleward moves [69–72]. The impacts of directional shifts in fish distribution can be gradual and felt over long periods of time. Coastal fishers who may be able to respond and adapt to the changes at first by traveling farther from their home may not be able to continue to track the changes as the range of shifts become larger over time. Gradual decline in stock abundance could also result in chronic poverty and loss of fishing as livelihoods [73,74].

The fisheries on which many SIDS and LDCs depend for nutrition and livelihoods are often transboundary stocks, which are shared with neighboring countries. Sustainable management of transboundary stocks requires countries to collaborate to set up management arrangements [75–77]. Many SIDS have vast EEZs with highly-migratory species such as tunas, and they often bear more conservation burdens over such resources than distant water fishing nations that operate in their EEZs and nearby international waters [78,79].

Countries have historically struggled to achieve sustainable management of transboundary stocks, and climate change is expected to further exacerbate such challenges [77,80–82]. In this context, effective cooperation will grow increasingly relevant through Regional Fisheries Management Organizations and bilateral or multi-lateral joint management agreements. To align with the sustainable development agenda, these arrangements need to mainstream issues of fairness and equity regarding sharing of benefits as well as burdens of management and conservation [83] (Box 2).

Human migrations and displacements

When disasters hit coastal communities, including those in SIDS and LDCs, people and entire communities can be displaced. Gradual environmental changes or slow-onset climate events can cause displacement as well. In the year 2020 alone, 40.5 million people were displaced globally, with three-quarters of this displacement caused by natural disasters [84].

Between 2008 and 2019, there were nine natural disaster events (seven storms, one flood, and one earthquake) that caused more than one million people to be displaced in just four countries (Bangladesh, Myanmar, Haiti, and Cuba) (Figure 3). In terms of per capita displacements, 17 natural disaster events resulted in the displacement of more than 5% of a country's population. These included 15 storms, one drought, and one earthquake. Nine of these events occurred in Oceania (American Samoa, Fiji, Federated States of Micronesia, Northern Mariana Islands, Palau, Tonga, Tuvalu, and Vanuatu); seven in the Americas (British Virgin Islands, Cuba, Dominica, Haiti, and Sint Maarten (Dutch part)), and one in Africa (Somalia). On average, over 2.9 million people were displaced annually from 2008 to 2019.[*] These numbers would certainly increase if they included people displaced due to long-term gradual changes or slow-onset climate events that disrupt their physical and social infrastructure.

Countries and communities may also choose to migrate as a precautionary measure and use planned relocation as an adaptation strategy. A survey of 86 case studies of community relocation in Pacific Islands found that environmental variability and natural hazards accounted for relocation of communities in 37 of the cases [85]. However, studies of island migration commonly reveal the complexity of a decision to migrate and rarely identify a single cause. For example, research from the Pacific have shown that culture, lifestyle, and a connection to place are more significant drivers of migration than climate [86]. However, financial, legal, and political barriers are expected to inhibit significant levels of environmentally-induced migration within and across countries [87,88].

Migration and displacement can distort social structure, weaken sociocultural fabric, and harm social capital that is critical for economic growth and resilience. The adverse impacts of displacement are felt through multiple areas, including education and health, and ultimately impact human capital and labor productivity [3,84,89]. Coastal communities often draw on social structures and capabilities that can reduce risk and increase adaptive capacity in the face of coastal hazards [90,91]. Permanent relocation of a community to a distant and foreign location can erode culture, tradition, and identity of the displaced people [84,92]. Studies also show that failing to assimilate in the destination communities can result in environmental and resource degradation

* All of the numbers mentioned in this paragraph are calculated based on Internal Displacement Data by International Displacement Monitoring Center (https://www.internal-displacement.org/), as described by Figure 2. Per capita displacement numbers use population data obtained from World Bank and Worldometers.info when population data was missing in World Bank database.

Box 2 Parties to the Nauru Agreement and climate change

SIDS in the Western and Central Pacific have vast EEZs with rich fisheries resources, including highly migratory tropical tuna species. Parties to the Nauru Agreement (PNA), a group which was formed in 1982 by the Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, and Tuvalu,* have been engaged in cooperative and sustainable management of these species. In their EEZs, skipjack tuna alone is valued at over USD2 billion annually [184], and countries have been gaining important revenue through the sale of purse seine fishing access rights to their waters to distant water fishing nations [185,186]. The purse seine skipjack tuna fishery has been managed through a Vessel Day Scheme (VDS), which was introduced in 2007 and implemented in 2012, that allocates the share of effort quotas among the Parties [187,188].** Under this scheme vessel owners can purchase and trade days fishing at sea, within a total allowable effort limit, in places subject to the PNA and Tokelau. The primary motivation for the establishment of the PNA was to form a united front against rich and powerful distant water fishing nations to ensure more equitable negotiation outcomes in the sale of fishing rights while ensuring resource sustainability [43]. In 2019, a vessel day (the trading unit) in PNA waters cost on average USD12,590, with the Parties collectively generating over USD500 million in fisheries-related revenue annually [184]. Revenue from the VDS provides an average 37% of all government revenue across PNA members and Tokelau (Bell et al. 2021), with monies generated from licensing fees key to financing public infrastructure and providing basic services [25].

Recent stock assessments highlight the four key tuna stocks in the western and central Pacific as in a healthy state [189,190]. Skipjack, yellowfin, and bigeye tuna caught with purse seines benefit from MSC certification.*** Yet, as with many fisheries around the globe, tropical tuna are being impacted by climate change [77]. Existing studies project an eastward shift of tuna across the region [191,192]. Climate change is therefore expected to create winners and losers within the PNA as countries located in the western Pacific (e.g., Papua New Guinea) will see their proportion of the stock diminish, while countries located in the central Pacific (e.g., Kiribati) will gain a greater share [72,193,194]. The PNA also face the challenge of tuna moving out of their EEZs into international waters, which is projected to result in revenue loss from fisheries access fees of USD 12 million per year under the conservative Representative Conservation Pathway (RCP) 4.5 scenario by 2050 – or USD 90 million under a high greenhouse gas emissions scenario (i.e., RCP 8.5) [193]. Such change could reduce incentives for cooperative management for countries losing fish [193].

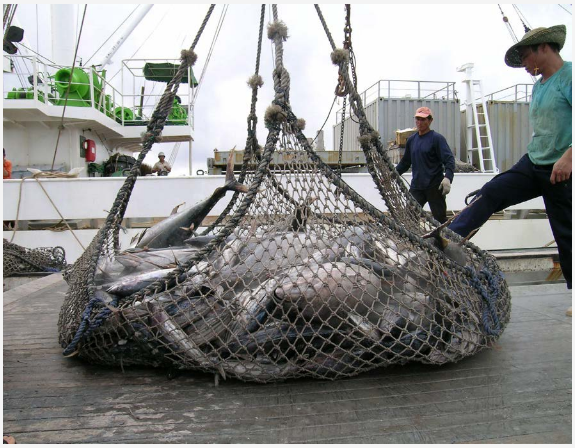

Photo: Quentin Hanich

However, thus far, efforts to manage tuna stocks by the PNA are paying off as they face climate challenges. The VDS has several features that help the PNA adapt to climate change. First, the scheme uses a rolling historical reference of average fishing effort input (i.e., fishing days) from recent years, as opposed to a fixed historical reference, to allocate shares [187,195,196]. The EU Common Fisheries Policy on the other hand, for instance, has EU Member State's quota shares allocated based on catches in the 1970s. The PNA is further responding by adapting their allocation policy to climate change. In the early days of the VDS, the Parties allocated the effort shares based on a the pre-determined formulae that used a mix of the historical fishing efforts from the immediate seven years and the relative stock abundance of each Party's EEZ [197]. Currently, the effort allocation focuses on fishing effort as it has become more challenging to accurately estimate the relative abundance of stocks in each Party's waters [195]. The VDS has another advantage: it allows Parties to trade shares.

As highlighted above, the PNA is not immune to climate change challenges. Yet, existing sustainable fisheries management efforts can help mitigate some of the projected changes. Adaptive management systems such as the VDS can help fisheries management reduce climate risks. Evidence also exists that, where accurate spatial distribution of biomass can be estimated, harvest control rules (i.e., harvest control rules = rules based on stock status indicators that determine how much fishing can take place [198]) that takes changes in biomass into consideration can help fisheries become more resilient to climate change [199]. The PNA's VDS example and this evidence can help inform approaches to climate-proof fisheries management systems around the globe.

* Tokelau participates as an observer to PNA.

** VDS is currently implemented for tuna fisheries that use longline gear as well.

*** Currently, the MSC certification covers those that are caught without fish aggregating device (FAD). As of March 2023, the certification will include those that use FAD as well.

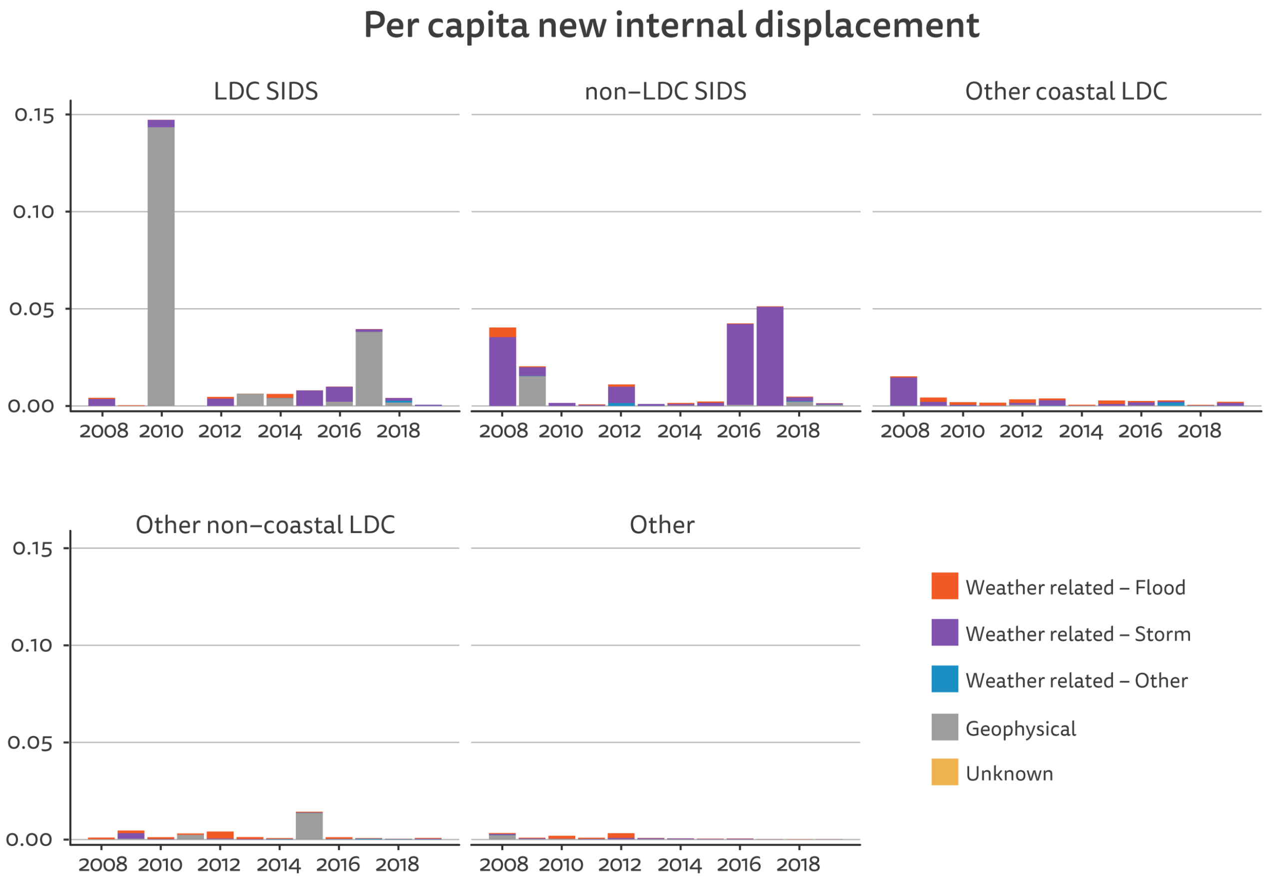

Figure 3. Internal Displacement due to Natural Disasters in SIDS and Coastal LDCs (Figures show per capita (left) and total number of (right) new internal displacement caused by natural disasters from 2008 – 2019 by different hazard types. Data: Internal Displacement Monitoring Centre (https://www.internal-displacement.org/) The definition of internally displaced persons follow the UN definition: "Persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognized State border" (Guiding Principles on Internal Displacement, 1998). For more information, refer to https://www.internal-displacement.org/internal-displacement. Per capita displacement numbers use population data obtained from World Bank and Worldometers.info when population data was missing in World Bank database.)

in the region to which they have been displaced as the new entrants may not be familiar with the informal rules or norms related to resource use [93]. For migration to be considered an adaptation measure, the community needs to be exercising its agency in making any such decisions [94,95].

Dependence on tourism, and the case of COVID-19

Many SIDS and coastal LDCs are highly dependent on income from tourism. For example, two thirds of ODA eligible SIDS are securing more than 20% of their GDP from tourism. Eight of countries have tourism sharing more than 40% of their GDP [41,42]. This high dependence on coastal tourism can result in multiple ocean risks in SIDS and LDC. For example, meeting the food preferences of large numbers of visitors also has serious impacts. On the one hand, it results in demand for high levels of food imports to meet tourists' preferences, while on the other hand, it has nutritional impacts for local communities when tourism creates higher demand for local fish [96,97]. In addition, tourism generates demand for considerable imports of consumer goods and construction materials used for tourism infrastructure.

Coastal tourism further adds stress to the chronic waste problem in SIDS. Per capita waste production by SIDS residents is 48% higher than the global average, and recycling rate is low [98]. Lack of infrastructure, limited space, outdated waste transportation vehicles and narrow roads challenge these countries ability to manage waste and are major culprit of marine litter [98,99]. This chronic waste problem is also closely linked to the fact that tourists produce more waste; thus, development of coastal tourism is poised to further worsen the waste problem.

For tourism-dependent countries, the COVID-19 pandemic has been particularly damaging. By March 2021, 38 countries had experienced complete border closures for at least 40 weeks, including 19 SIDS and 9 LDCs [100]. Most severely hit are Antigua and Barbuda, Belize, Fiji, Maldives and Saint Lucia, who are expected to have their GDPs decrease by more than 16% [41]. The loss of income from coastal tourism impacted communities and household across these countries to cause significant equity concerns (see also ORRAA Report on Gender)*. Panelists at Island Finance Forum 2021 predicted that international travelers would focus on the extent to which healthcare services are available in the destination country in case they get sick when they arrive [101]. This suggests a slow and delayed economic recovery for tourism-dependent SIDS and LDCs.

Using the pandemic as an example, however, we also realize how complex interactions across key economic sectors can either increase or reduce vulnerabilities to ocean risks. For example, a general downturn in coastal tourism also means that beaches and other marine parks are receiving fewer visitors, lowering associated impacts. As such, the COVID-19 pandemic has had some positive effects on environmental conservation in the short-run [102]. For example, a study of 29 urban tourist beaches in seven Latin-American countries (Mexico, Panama, Colombia, Ecuador, Brazil, Cuba, and Puerto Rico) found that lockdowns contributed to decreased socioeconomic stressors such as noise, odor, and litter on beaches, improved dune vegetation, and increased burrow density of crabs in some cases [103]. However, if visitors do not return after the pandemic and the demand for marine parks decreases, there is a concern that countries and communities may not have sufficient financial incentives and resources to continue to protect these areas. Indeed, in a survey about possible impacts of the pandemic on biodiversity conservation, 60% of experienced conservation experts expressed that the pandemic will have negative impacts on biodiversity conservation [104]. Some of the concerns listed include government prioritizing economic recovery over conservation, reduced philanthropy, and increased illegal activities due to reduced enforcement during the pandemic. Fisheries were also affected by the pandemic. The major positive impact was possible recovery of some of the previously depleted fish stocks as a result of prolonged slowdown of commercial fishing activities due to travel restrictions and port closures [105]. The pandemic has also negatively impacted the fishing sector in SIDS and LDCs as demand has fallen for many seafood product exports, and local demand to supply the tourism sector has declined [102,106]. The pandemic also had significant impacts on food systems, including increased use of food sharing to maintain food security within a community and a revival of local food systems in many parts of the world [107,108].

* Wabnitz et al (2021) ORRAA Report. https://oceanrisk.earth

Climate change mitigation

Many SIDS and LDCs have a large potential for ocean and offshore energy (e.g., offshore wind, ocean thermal energy conversion, wave and tidal energy) and other renewable energy (e.g., solar photovoltaic) development [109] (see also ORRAA Report on the Blue Acceleration)**. However, these countries have struggled to harness this potential [110]. SIDS and LDCs are heavily reliant on imported petroleum not only for transportation but also for electricity generation [110].*** As of 2015, at least 24 SIDS relied more than 80% of their energy on imports [111]. Island States spend over USD 67 million on oil, and oil price hikes such as the ones in 2008 contributed to increase external debt for SIDS [112]. This reliance, coupled with the high volatility of petroleum prices compared with renewables and other types of fossil fuels, leads to strains on island economies.

Some of the major causes for limited adoption of renewable energy technologies include lack of policies that provide incentives for renewable energy producers, limited technical capacity, barriers for renewable energy producers to access the electric grid, and isolated island grid systems that are vulnerable to intermittent sources of energy [110,113]. Further, geographical remoteness of SIDS, many of which are located in Indian Ocean and Pacific Ocean, means higher transportation and logistical costs [114]. These factors make it costly to switch to renewable energy sources such as offshore wind. Further, because many of the ocean energy technologies are at early stage of development, there is high technological and financial risks associated with these technologies that limit access to finance [115].

There is also a great variability in terms of household access to electricity in SIDS and LDCs [116]. For these countries, renewable energy development can improve electricity access as well as energy security to enhance their resilience [114]. Out of seventy SIDS and coastal LDCs with records, 19% reported that less than 50% of the population has access to electricity.**** The cost of electricity varies across these countries, with SIDS facing significantly higher costs of electricity compared with continental LDCs [117]. Since tourism is an energy intensive sector, SIDS with tourism-dependent economies emit higher levels of greenhouse gases (GHGs), with some SIDS and LDCs such as Trinidad & Tobago, Bahrain, Bahamas, and Sudan having high GHG emissions per capita (Table 1). The development of a carbon market could be beneficial for climate change mitigation by

** Jouffray et al (2021) ORRAA Report. https://oceanrisk.earth

*** Also based on authors calculation using data published by World Bank (https://data.worldbank.org/indicator/EG.ELC.PETR.ZS).

**** Authors calculation based on data published by World Bank (https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS).

reducing global carbon emissions, but SIDS and LDCs are disadvantaged in terms of their ability to benefit from the carbon market due to the barriers they face in scaling up renewable energy usage.

Macroeconomic shocks and impacts

Many SIDS and LDCs are dependent on external assets through ODA, remittance, and philanthropy. This reliance on foreign financing also makes SIDS and LDCs sensitive to global economic cycles. For example, the funds supplied as official development assistance and other aid assistance by OECD countries often depend on prevailing economic conditions. Since 1970, all OECD member companies have pegged their target of 0.7% of their gross national income to be made available as ODA, although this target has seldom been hit by member states [118]. The amount of funding available therefore fluctuates with the global economic cycle, which is also a key factor for the growth or contraction of the tourism sector, as expenditure for tourism goes down during recessions. Tourism-dependent SIDS and LDCs are therefore doubly impacted during global economic recessions. The 2007-08 financial crisis impacted SIDS more severely than other developing countries for their reliance on tourism by reducing GDP growth rate to 0.9% as compared to over 3% for other developing countries [119].

Climate change can also impact financial markets and asset values, both globally and locally. The literature on climate-related financial risks identifies three types of potential risks to the financial system: (1) physical risks (i.e., environmental stressors such as sea level rise, marine heatwaves, and extreme weather events, and their direct impacts on businesses and households); (2) transition risks (i.e., those that stem from socioeconomic reactions to climate change such as changes in carbon policy, changes in consumer preferences, and changes in production technologies); and (3) liability risks (i.e., those that stem from victims of climate damage demanding compensation) [120,121]. The impacts of these three risk categories manifest themselves in business operations and household activities and are ultimately felt at the financial market system level. For example, decarbonization policies often impact energy sector to switch away from fossil fuels. This energy transition makes fossil fuel resources to lose their value and become stranded. This is an example of transition risk that can pose a significant risk to oil- and gas-producing SIDS such as Trinidad & Tobago, Bahrain, Angola, and Timor-Leste. Further, some of these countries such as Trinidad & Tobago and Bahrain also have high per-capita GHG emissions and thus could also be impacted by global policies to mitigate GHG emissions (Table 1).

Climate-related financial risks, in turn, impact businesses and household activities. Central banks and financial institutions have already been taking actions to mitigate the impacts of these risks. As of December 2020, 83 members and 13 observers, including members from SIDS and LDCs, have joined the Network for Greening the Financial System, a network of central banks and supervisors focused on these issues [122]. While only 12% of central banks currently incorporate sustainability goals into their policy [123], as several countries set sustainability goals as their primary policy objective, there may be hope this will feed into central banks' decisions. Climate change can directly impact financial systems, and therefore, better understanding and incorporation of climate risks and sustainability related goals in central banks' policies can help create overall macroeconomic and financial stability [121,123].

Interdependent risks

As technology develops and enables humans to further expand the range of benefits derived from the ocean, understanding how human activities impact coastal and marine ecosystems grows increasingly complicated (see also ORRAA Report on the Blue Acceleration)*. While it is known that these multiple socioeconomic stressors (e.g. fishing, seabed mining, shipping, and land reclamation) interact, and result in complex impacts on the ocean, we have limited understanding of what they are and how these interactions occur [124,125]. Siloed academic disciplines limit scientific approaches to fully understand the interactions and cumulative impacts of multiple stressors [126]. Climate change will exacerbate this complexity, altering the nature of interactions to create increased uncertainty, and magnifying the impacts of such interacting stressors [127,128]. Ultimately, climate change and its symptoms – ocean warming, acidification, deoxygenation, etc. – will alter the structure and functioning of the overall ecosystem and the benefits that it provides to humans [126,129]. Since the interactions among these multiple stressors pose new ocean risks, these risks need to be considered jointly, and seeking to address individual stressors in isolation will be insufficient to achieve sustainable development goals [128,130] (Box 3).

In coastal ecosystems where local human impacts are already prominent, added climate change stressors will further amplify the interactions across multiple stressors and their effects on local ecosystems [127,131,132]. For instance, anthropogenic climate change is now attributed as a contributing cause for many natural disasters [133]. The increased frequency and magnitude of storms also means there is an increased likelihood that communities will be hit by multiple disasters

* Jouffray et al (2021) ORRAA Report. https://oceanrisk.earth

Box 3 Nutrition, public health, and harmful algal blooms

Ocean and coastal ecosystems provide essential nutrients for many coastal communities in SIDS and LDCs [28,200]. Wild capture fisheries and aquaculture provide 17% of edible meat [201,202], and many coastal communities depend on seafood as sources of healthy nutrients. An analysis predicted that coastal fisheries in 16 of the 22 Pacific Island countries and territories would not be able to provide sufficient nutrition to a rapidly growing population and that improved access to tuna, more-efficient fisheries governance, and expansion of pond aquaculture can collectively improve food security and public health [203,204]. Further, a study found a parallel transition in diet to consume more processed, sweetened, and high calorific food as the changes in natural environment that provide food take place.

Climate change threatens nutritional security of communities in SIDS and LDCs in multiple ways. For instance, climate change will reduce the availability of fish for these communities [205]. Tropical coastal ecosystems are among the world's most at-risk to climate change especially when we take existing threats such as land use changes and overfishing into consideration. In addition to ocean acidification and gradual warming of the waters, more frequent and intense marine heatwaves are expected [206]. The resulting coral bleaching, pole-ward shift of species, and changes in species productivity will significantly reduce the availability of fish and therefore reduce the variety and abundance of marine-derived nutrients to these communities [207], with particularly severe impacts on coastal communities [208]. Explicit linkages between human health and ocean health are evident in many coastal communities in LDCs and SIDS, where alternatives to nutritionally rich seafood are scarce – declines in marine fish populations have been linked to micronutrient deficiencies and corresponding negative health outcomes [207,28,209,210].

Ocean warming is also a factor in increasingly frequent harmful algal blooms (HABs). Marine biotoxins impact marine organisms that feed on toxic algae and cause catastrophic damage to inshore fisheries and aquaculture operations by killing impacted fish and shellfish. They could also cause severe food poisoning for humans who consume impacted fish and shellfish. A recent large-scale global study conducted by IOC found 48% of the HAB events involved seafood toxins, and listed Central America and the Caribbean as one of the regions seeing an increase in HAB events [211]. SIDS and LDCs lack infrastructure and capacity to monitor the occurrences of harmful algal blooms, and thus the consequences of these events can often be fatal or cause long term disabilities due to damage to the nervous system resulting in paralytic, amnesic, and neurologic symptoms [212]. In 2021, an event killed 19 people in Madagascar who consumed a turtle that had fed on toxic algae [213].

Increased and intensified aquaculture production that cause nutrient pollution will increase the risks of HABs [211]. Developed countries are investing in early warning systems and forecasting to monitor harmful algal blooms to reduce the impacts of marine biotoxins on aquaculture [214]. Aquaculture development and coastal subsistence fisheries in SIDS and LDCs alike can benefit from such systems to mitigate future risks to food safety, nutritional security, and economic development.

Photo: Kanae Tokunaga

at the same time. On 12 January 2010, a magnitude 7.0 earthquake struck Haiti and displaced over 1.5 million people, or approximately 15% of the total population (Figure 3). On 14 August 2021, another major earthquake, magnitude 7.2, struck Haiti, amid the global COVID-19 pandemic and immediately after the assassination of the president on 7 July 2021, and was rapidly followed by a direct hit by a Tropical Depression Grace on 16 August 2021. Following the assassination, gang violence increased and displaced over 19,000 people in Port-au-Prince, also impacting food security [134,135]. Tropical Depression Grace left 650,000 in need of humanitarian assistance [135]. These events contributed to deteriorating conditions for stemming the COVID-19 pandemic as it became more difficult to take preventative measures to avoid contracting the disease [135].

The interdependencies of economic sectors in SIDS and LDCs make these countries sensitive to system-wide shocks such as natural disasters and global pandemics and can prolong the recovery from such shocks. Climate change, which produces long-term gradual changes as well as acute shocks, adds to this complexity. This new reality requires a corresponding shift from single-shock or sector-specific risk mindset to a coupled complex risk mindset [136].

Achieving a sustainable, equitable, and resilient ocean economy

This report has focused some of the key environmental and socioeconomic stressors, that are derived from the ocean and associated with the ocean economy and highlighted their associated risks to SIDS and LDCs. The report has also described the complex web of interactions created by multiple stressors and illustrated how ocean risks are coupled complex risks. Resilience has emerged as a popular approach or concept to rethink and reshape development for dynamic and turbulent contexts [137]. Resilience refers to abilities of a social-ecological system to anticipate, absorb, accommodate, or recover from hazardous events [7]. The complexity of ocean risks is mirrored in the complexity of resilience, which is multidimensional and dynamic. As such, context-dependent solutions are essential. The future is expected to bring with it a growing range of highly complex ocean risks. There are a number of strategies for enhancing resilience and several studies have made major progress in synthesizing across disciplines, domains and systems to identify more focused lists of these resilience-enhancing strategies [138–140].

Novel financial tools and insurance products

During the past decade, an increasing number of SIDS have started referring themselves as Large Ocean States or Great Ocean States, recognizing the vast opportunities that ocean provides for their economic development [141–143]. Indeed, the ocean offers unprecedented solutions and opportunities for sustainable and equitable growth [21,144,145]. For instance, the development of offshore renewable energy and the restoration and conservation of blue carbon ecosystems such as mangroves and salt marshes can contribute to reducing GHG emissions and atmospheric levels of GHGs [144].

Foreign financing can play a significant role in amplifying these countries' efforts to diversify and further develop their ocean economy sectors to build resilience. Some of the key financial instruments that can be used to promote a sustainable ocean economy include traditional loans and grants, carbon markets, and insurance instruments [146]. These instruments can be designed to incentivize actions that promote social-ecological system sustainability, conservation, and equity and to reduce risks that could cause SIDS and coastal LDCs to deviate from achieving their development goals. Diversified sources of financial capital are a critical component to building resilience. For example, private equity and venture capital funds can also promote businesses whose objectives are aligned with sustainable and socially equitable economic development; however, less than USD 50 billion is invested in emerging market as opposed to USD 300 billion and USD 150 billion invested in the United States and in Western Europe, respectively [147]. Furthermore, a survey of 440 private investors found that SDG 14 "Life Below Water" is the least attractive SDG as a target for impact investing, citing the difficulty of turning ocean conservation into investment products [148] (Box 4).

Public or philanthropic co-financing or blended finance, where public finance (e.g., ODA, development banks) is used to attract private financing, is critical for a sustainable ocean economy as there are many activities that cannot generate market returns [146].[*] For example, coral reefs support over 25% of marine species and 1 billion people worldwide [150,151]. But, coral reefs are one of the most costly ecosystem to restore, [152–154], often associated with large financial risk and low or uncertain market return. There has a critical lack in financing coral reef conservation, protection, and restoration [150,151,155]. Thus, a blended financing approach has been taken with the establishment of Global Fund for Coral Reefs in September 2020; the major goal for this is to facilitate innovation and attract private market-based investments to conserve and restore coral reefs [151,156]. Blended finance can also be useful for attracting funds to foster ocean and offshore energy developments in SIDS and LDCs.

Access to finance is also an essential attribute of resilience because it can enable communities to respond to shocks and adapt to changes [157]. External climate and development financing continue to represent key avenues to build and strengthen adaptive capacities of LDCs and SIDS to mitigate

* For the discussion of who bears the risk and who gets paid out first, refer to the discussion of capital stack in the Ocean Finance Handbook [149].

Box 4 Sustainable Development Goals

The Sustainable Development Goals (SDGs) represent a shared vision for the future. Ocean-related targets described under SDG14 “Life Below Water” clearly articulate sustainable development priorities for SIDS and LDCs that leverage ocean sectors. There are other SDGs and associated targets that directly address relevant challenges for SIDS and LDCs, including SDG4 Education (e.g., target 4.a that calls for enhancing scholarship and scientific capacities in SIDS and LDCs) and SDG7 Clean Energy (e.g., target 7.b that calls for increased supply of modern and sustainable energy sources in SIDS and LDCs) [130]. At the same time, these development goals reveal important tradeoffs that need to be navigated as well as synergies that can be cultivated to support multiple benefits. For instance, among the nine other targets under SDG14:

- achievement of two targets (target 14.1pollution and 14.3 ocean acidification) could pose conflicts or tradeoffs with target 14.7,
- three targets (target 14.4 restore fish stocks, 14.a Scientific knowledge and technology transfer, and 14.b Access to resources and market for small fishers) support the goal of target 14.7, and
- the remaining four targets (target 14.2 Management of coastal and marine ecosystems, 14.5 Protect 10 percent of marine areas, 14.6 Reform fisheries subsidies, and 14.c implement international law) pose varied impacts on achieving target 14.7 [130].

Understanding linkages across different goals nested within the SDGs can help countries evaluate their progress towards SDGs [180], as well as providing opportunities for creating co-benefits.

SUSTAINABLE DEVELOPMENT GOALS

risks. However, it is also important to highlight complementary measures to build domestic capabilities (see also ORRAA Report on Gender)*. For example, there is evidence that developing internal financing capabilities, as opposed to external financing, is more effective for building disaster resilience [158]. Stability and capabilities of governance and financial systems are critical for not attracting but also improving the effectiveness of foreign financing [150,159]. As such, investments in the domestic finance sector as well as governance sector could help amplify the benefits gained through other funds.

At the country level, the National Adaptation Plan process, established by the UNFCCC’s COP 16 Cancun Adaptation Framework, have resulted in 22 developing countries announcing national adaptation plans (NAPs) (as of March 2021, UNFCCC, 2021). Efforts to develop NAPs in other countries are also underway with support from sources such as the Green Climate Fund, a multi-sector funding mechanism that supports climate mitigation and adaptation [160,161]. Upon approval of their NAPs, countries can draw on support from Green Climate Fund to operationalize them by implementing projects [162]. Regional efforts to coordinate adaptation planning efforts have also started to take shape, including, for instance, through the Caribbean Community Climate Change Center and the Secretariat for the Pacific Regional Environmental Programme [42].

Greater future uncertainty also creates demands for insurance. In the aftermath of the 2010 Haiti earthquake, the Caribbean Catastrophe Risk Insurance Facility (CCRIF), the world’s first multi-country risk pool, established in 2007, provided support to Haiti with over US$ 7.7 million payouts under its parametric insurance scheme [163]. Following the 2021 earthquake, CCRIF was expected to make payouts of approximately US$ 40 million [164]. To hedge against extreme weather events, fisheries index insurance was launched for fisherfolks in Caribbean countries by the Caribbean Oceans and Aquaculture Sustainability Facility (COAST) in July 2019 with funding support from the US State Department [165] (see also ORRAA Report on Gender)**. Under this framework, governments can purchase COAST policies, but to be eligible to participate in this program, they must also implement the Caribbean Community Common Fisheries Policy [166]. COAST is a parametric insurance scheme, and the first of its kind, in supporting fisheries hedge against climate risks. Meanwhile, mutual insurance schemes have commonly been used in Asian countries to insure fishers and aquaculture operations due in part to efforts to stabilize incomes against harvest volatility [167].

Recent studies have found that international adaptation funding in LDC-SIDS has been ineffective at addressing the root causes of the problems [168,169]. For instance, barriers to adaptation to reduce climate-related disaster risks are often rooted in governance and technical capacities as well as cognitive and cultural factors, yet, adaptation projects funded by international adaptation funding are sector specific (e.g., project targeting coastal fishery) [168]. Further, existing public and private funds cannot easily be mobilized to cope with the sudden emergence of new risks such as COVID-19 [41].

* Wabnitz et al (2021) ORRAA Report. https://oceanrisk.earth

** Wabnitz et al (2021) ORRAA Report. https://oceanrisk.earth

Table 2. Examples of different types of risk and vulnerability assessment tools and studies.

Reference	Scope	Key metrics and variables	Assessed countries/ regions
Risk and vulnerability assessments			
Heck et al., 2021 [176]	Assessment of storm risks to fisheries	storm hazard, exposure, sensitivity, lack of adaptive capacity	Country-level/ Global
Thiault et al., 2018 [177]	Mapping of social-ecological vulnerability	ecological exposure, ecological sensitivity, ecological adaptive capacity, social exposure, social sensitivity, social adaptive capacity	Small-scale fishery of Moorea, French Polynesia
Blasiak et al., 2017 [23]	Assessment of climate change vulnerabilities, focus on coastal communities	climate change exposure, sensitivity, adaptive capacity	Country-level/Global
Guillaumont, 2010 [178]	Assessment of macroeconomic vulnerabilities	size and frequency of exogenous shocks (natural shocks and external/export shocks), exposure to shocks, capacity to react to shocks	Country-level/ SIDS and LDCs
Reviews/Critiques			
Comte et al., 2019 [179]	Comparison of eight global vulnerability assessments	Study objectives, definition of vulnerability, Formulae for vulnerability	--
Monnereau et al., 2017 [24]	Assessment of climate change vulnerabilities in fisheries sector, Cross comparison of different assessment methods	Metrics used to quantify exposure, sensitivity, and adaptive capacity	Country-level/Global

Expanding the knowledge base

Economic theory indicates that public financing towards pilot projects can contribute to expanding investments in climate-related projects [170]. Yet, values of conducting pilot projects may not be realized if the knowledge gained through the pilot projects are not transferred to inform future projects or to inform similar projects in other parts of the world. Monitoring and evaluations backed by environmental and socioeconomic data are crucial. Context-dependent solutions are also essential; for instance, projects tailored to local ecological systems may work better than global-scale approaches under certain ecological conditions [131]. A critical examination aimed at prioritizing and selecting cost-efficient measures that can provide multiple benefits or co-benefits is essential for mitigating climate change and its impacts [144]. All of these can benefit from fine-scale and long-term data.

There are many tools with varying scope and objectives that can help assess risks and vulnerabilities to articulate local challenges and opportunities (Table 2). Yet, again, lack of data in SIDS and LDCs as well as domestic technical capacities often limits their abilities to assess vulnerabilities and risks at a finer temporal and geospatial scale. This could limit these countries' abilities to benefit from state-of-the-art scientific models and tools. Investments in baseline monitoring, data collection, and deployment of blue technologies (e.g., underwater drone, AI for fisheries electronic monitoring) can certainly contribute to mitigating ocean risks and to building resilience.

At the same time, many communities and cultures in SIDS and LDCs hold rich local indigenous and ecological knowledge. Yet, these knowledge systems are often neglected and not included in the scientific and decision-making processes. Scientist and decision-makers alike can benefit from these knowledge systems to contextualize their findings to craft context-specific solutions. Integration of local indigenous and ecological knowledge as well as collaborative or participatory approach can be effective at designing solutions that meet the local social-ecological context and at overcoming cognitive or socio-cultural barriers to building resilience [58,171–173].

References

1. Janssen, M. A. & Ostrom, E. Resilience, vulnerability, and adaptation: A cross-cutting theme of the International Human Dimensions Programme on Global Environmental Change. *Glob. Environ. Change* **16**, 237–239 (2006).
2. UNEP. *Blue Economy Concept Paper*. http://www.unep.org/resources/report/blue-economy-concept-paper (2016).
3. Adger, W. N., de Campos, R. S. & Mortreux, C. Mobility, displacement and migration, and their interactions with vulnerability and adaptation to environmental risks. in R*outledge handbook of environmental displacement and migration* (ed. McLeman, R and Gemenne, F) 29–41 (2018).
4. Committee on world food security. *Coming to terms with terminology*. http://www.fao.org/3/MD776E/MD776E.pdf (2012).
5. OECD. Ocean economy. https://www.oecd.org/ocean/topics/ocean-economy/.
6. NERACOOS. About ocean observing systems. *NERACOOS* http://neracoos.org/about/ocean_observing.
7. IPCC. 2012: Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. in *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of the intergovernmental panel on climate change* (eds. Barros, V. et al.) (Cambridge University Press, 2012). doi:10.1017/CBO9781139177245.
8. Putnam, R. D. Bowling alone: America's declining social capital: originally published in Journal of Democracy 6 (1), 1995. *J. Democr.* **6**, 65–78 (1995).
9. Thiault, L. *et al.* Harnessing the potential of vulnerability assessments for managing social-ecological systems. *Ecol. Soc.* **26**, art1 (2021).
10. Bindoff, N. L. *et al.* Changing ocean, marine ecosystems, and dependent communities. in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (2019).
11. Britten, G. L., Dowd, M., Kanary, L. & Worm, B. Extended fisheries recovery timelines in a changing environment. *Nat. Commun.* **8**, 15325 (2017).
12. Pecl, G. T. *et al.* Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* **355**, eaai9214 (2017).
13. Pershing, A. J. *et al.* Challenges to natural and human communities from surprising ocean temperatures. *Proc. Natl. Acad. Sci.* **116**, 18378–18383 (2019).
14. Poloczanska, E. S. *et al.* Global imprint of climate change on marine life. *Nat. Clim. Change* **3**, 919–925 (2013).
15. Lam, V. W. Y. *et al.* Climate change, tropical fisheries and prospects for sustainable development. *Nat. Rev. Earth Environ.* **1**, 440–454 (2020).
16. Lam, V. W. Y., Cheung, W. W. L., Reygondeau, G. & Sumaila, U. R. Projected change in global fisheries revenues under climate change. *Sci. Rep.* **6**, 32607 (2016).
17. Lluch-Cota, S. E., Arreguín-Sánchez, F., Salvadeo, C. J. & Del Monte Luna, P. Climate change impacts, vulnerabilities and adaptations: Northeast Tropical Pacific marine fisheries. in *Impacts of climate change on fisheries and aquaculture Synthesis of current knowledge, adaptation and mitigation options* (eds. Barange, M. et al.) (FAO, 2018).
18. Oxenford, H. A. & Monnereau, I. Climate change impacts, vulnerabilities and adaptations: Western Central Atlantic marine fisheries. in *Impacts of climate change on fisheries and aquaculture Synthesis of current knowledge, adaptation and mitigation options* (eds. Barange, M. et al.) (FAO, 2018).
19. Thiault, L. *et al.* Escaping the perfect storm of simultaneous climate change impacts on agriculture and marine fisheries. *Sci. Adv.* **5**, eaaw9976 (2019).
20. Eddy, T. D. *et al.* Global decline in capacity of coral reefs to provide ecosystem services. *One Earth* **4**, 1278–1285 (2021).
21. Hoegh-Guldberg, O., Poloczanska, E. S., Skirving, W. & Dove, S. Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Front. Mar. Sci.* **4**, 158 (2017).
22. Hughes, T. P. *et al.* Global warming transforms coral reef assemblages. *Nature* **556**, 492–496 (2018).
23. Blasiak, R. *et al.* Climate change and marine fisheries: Least developed countries top global index of vulnerability. *PLOS ONE* **12**, e0179632 (2017).
24. Monnereau, I. *et al.* The impact of methodological choices on the outcome of national-level climate change vulnerability assessments: An example from the global fisheries sector. *Fish Fish.* **18**, 717–731 (2017).
25. Barclay, K. Impacts of tuna industries on coastal communities in Pacific Island countries. *Mar. Policy* **34**, 406–413 (2010).
26. Charlton, K. E. *et al.* Fish, food security and health in Pacific Island countries and territories: a systematic literature review. *BMC Public Health* **16**, 285 (2016).
27. Grimes, S. Ocean science for development in SIDS: Facts and figures. *SciDev.Net* https://www.scidev.net/global/features/ocean-science-development-sids-facts-figures/ (2014).
28. Hicks, C. C. *et al.* Harnessing global fisheries to tackle micronutrient deficiencies. *Nature* **574**, 95–98 (2019).
29. Lau, J. D., Hicks, C. C., Gurney, G. G. & Cinner, J. E. What matters to whom and why? Understanding the importance of coastal ecosystem services in developing coastal communities. *Ecosyst. Serv.* **35**, 219–230 (2019).
30. Jouffray, J.-B., Blasiak, R., Norström, A. V., Österblom, H. & Nyström, M. The Blue acceleration: The trajectory of human expansion into the ocean. *One Earth* **2**, 43–54 (2020).
31. UN. *Mid-Term Review of the SAMOA Pathway High level political declaration*. https://www.un.org/pga/73/wp-content/uploads/sites/53/2019/08/SAMOA-MTR-FINAL.pdf (2019).
32. Blasiak, R. & Wabnitz, C. C. C. Aligning fisheries aid with international development targets and goals. *Mar. Policy* **88**, 86–92 (2018).
33. UN-OHRLLS. *Small Island Developing States: Small Island Big(ger) Stakes*. http://unohrlls.org/custom-content/uploads/2013/08/SIDS-Small-Islands-Bigger-Stakes.pdf (2011).
34. UNCTAD. LDC - What is a least developed country? https://unctad.org/press-material/ldc-what-least-developed-country (2017).
35. Robinson, S. & Dornan, M. International financing for climate change adaptation in small island developing states. *Reg. Environ. Change* **17**, 1103–1115 (2017).
36. World Bank. World Bank Country and Lending Groups. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups (2021).

37. Global Environment Facility. *Note on ODA eligiblity*. https://www.thegef.org/sites/default/files/council-meeting-documents/Note%20on%20ODA%20Eligiblity%2C%20FINAL%20FORMATTED.pdf.
38. WTO. WTO committee explores initiatives to increase developing countries' trading capacities. https://www.wto.org/english/news_e/news21_e/devel_29mar21_e.htm (2021).
39. United Nations. *The Least Developed Countries report 2019*. (United Nations Publications, 2019). doi:10.1163/ej.9789004180048.i-962.602.
40. IMF. Small states resilience to natural disasters and climate change - role for the IMF. *Policy Pap.* **16**, (2016).
41. OECD. COVID-19 pandemic Towards a blue recovery in small island developing states. https://read.oecd-ilibrary.org/view/?ref=1060_1060174-tnkmsj15ap&title=COVID-19-pandemic-Towards-a-blue-recovery-in-small-island-developing-states&_ga=2.77468438.229292467.1628796235-750020651.1616092861 (2021).
42. Thomas, A., Baptiste, A., Martyr-Koller, R., Pringle, P. & Rhiney, K. Climate change and small island developing states. *Annu. Rev. Environ. Resour.* **45**, 1–27 (2020).
43. Pala, C. The mice that roared: how eight tiny countries took on foreign fishing fleets. *The Guardian* (2021).
44. Piontek, F. *et al.* Integrated perspective on translating biophysical to economic impacts of climate change. *Nat. Clim. Change* **11**, 563–572 (2021).
45. UN Department of Economic and Social Affairs. List of SIDS: Sustainable Development Knowledge Platform. https://sustainabledevelopment.un.org/topics/sids/list.
46. UN. Factsheet: People and Oceans. in (UN, 2017).
47. Folke, C. *et al.* Our future in the Anthropocene biosphere. *Ambio* **50**, 834–869 (2021).
48. OECD. *The Ocean Economy in 2030*. (OECD Publishing, 2016).
49. IPCC. 2021: Summary for policymakers. in *Climate change 2021: The Physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Masson-Delmotte, V. et al.) (Cambridge University Press, 2021).
50. Desmet, K. *et al.* Evaluating the economic cost of coastal flooding. *Am. Econ. J. Macroecon.* **13**, 444–486 (2021).
51. Kocornik-Mina, A., McDermott, T. K. J., Michaels, G. & Rauch, F. Flooded Cities. *Am. Econ. J. Appl. Econ.* **12**, 35–66 (2020).
52. Monioudi, I. N. *et al*. Climate change impacts on critical international transportation assets of Caribbean Small Island Developing States (SIDS): the case of Jamaica and Saint Lucia. *Reg. Environ. Change* **18**, 2211–2225 (2018).
53. Rotzoll, K. & Fletcher, C. H. Assessment of groundwater inundation as a consequence of sea-level rise. *Nat. Clim. Change* **3**, 477–481 (2013).
54. Ratter, B. M. W., Petzold, J. & Sinane, K. Considering the locals: coastal construction and destruction in times of climate change on Anjouan, Comoros. *Nat. Resour. Forum* **40**, 112–126 (2016).
55. Yamano, H. *et al.* Atoll island vulnerability to flooding and inundation revealed by historical reconstruction: Fongafale Islet, Funafuti Atoll, Tuvalu. *Glob. Planet. Change* **57**, 407–416 (2007).
56. Bird, D. K., Chagué-Goff, C. & Gero, A. Human Response to Extreme Events: a review of three post-tsunami disaster case studies. *Aust. Geogr.* **42**, 225–239 (2011).
57. Inazu, D., Ikeya, T., Waseda, T., Hibiya, T. & Shigihara, Y. Measuring offshore tsunami currents using ship navigation records. *Prog. Earth Planet. Sci.* **5**, 38 (2018).
58. Sithole, W. W., Naser, M. M. & Guadagno, L. *Indigenous knowledge for disaster risk reduction: documenting community practices in Papua New Guinea*. (International Organization for Migration, 2015).
59. McClanahan, T. r. & Cinner, J. e. A framework for adaptive gear and ecosystem-based management in the artisanal coral reef fishery of Papua New Guinea. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **18**, 493–507 (2008).
60. Silvano, R. A. M. & Valbo-Jørgensen, J. Beyond fishermen's tales: contributions of fishers' local ecological knowledge to fish ecology and fisheries management. *Environ. Dev. Sustain.* **10**, 657–675 (2008).
61. Beckford, C. Climate change resiliency in Caribbean SIDS: building greater synergies between science and local and traditional knowledge. *J. Environ. Stud. Sci.* **8**, 42–50 (2018).
62. IPCC. 2019: Annex I: Glossary. in *IPCC special report on the ocean and cryosphere in a changing climate* (eds. Weyer, N. M. et al.) (2019).
63. Frölicher, T. L., Fischer, E. M. & Gruber, N. Marine heatwaves under global warming. *Nature* **560**, 360–364 (2018).
64. Oliver, E. C. J. *et al.* Marine Heatwaves. *Annu. Rev. Mar. Sci.* **13**, 313–342 (2021).
65. Oliver, E. C. J. *et al.* Longer and more frequent marine heatwaves over the past century. *Nat. Commun.* **9**, 1–12 (2018).
66. Cheung, W. W. L. *et al.* Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Glob. Change Biol.* **16**, 24–35 (2010).
67. Hanich, Q. *et al.* Small-scale fisheries under climate change in the Pacific Islands region. *Mar. Policy* **88**, 279–284 (2018).
68. Sumaila, U. R., Cheung, W. W. L., Lam, V. W. Y., Pauly, D. & Herrick, S. Climate change impacts on the biophysics and economics of world fisheries. *Nat. Clim. Change* **1**, 449–456 (2011).
69. Cheung, W. W. L. Signature of ocean warming in global fisheries catch. *Nature* **497**, 365–368 (2013).
70. Golden, C. D. *et al.* Aquatic foods to nourish nations. *Nature* 1–6 (2021) doi:10.1038/s41586-021-03917-1.
71. Golden, C. D. *et al.* Nutrition: Fall in fish catch threatens human health. *Nature* **534**, 317–320 (2016).
72. Lehodey, P. *et al.* Vulnerability of oceanic fisheries in the tropical Pacific to climate change. in *Vulnerability of tropical pacific fisheries and aquaculture to climate change* (eds. Bell, J. D., Johnson, J. E. & Hobday, A. J.) (Secretariat of the Pacific Community, 2011).
73. Cinner, J. E., Daw, T. & McClanahan, T. R. Socioeconomic Factors that Affect Artisanal Fishers' Readiness to Exit a Declining Fishery. *Conserv. Biol.* **23**, 124–130 (2009).
74. Free, C. M. *et al.* Impacts of historical warming on marine fisheries production. *Science* **363**, 979–983 (2019).
75. Bailey, M., Rashid Sumaila, U. & Lindroos, M. Application of game theory to fisheries over three decades. *Fish. Res.* **102**, 1–8 (2010).
76. Munro, G. R. The optimal management of transboundary renewable resources. *Can. J. Econ.* 355–376 (1979).
77. Pinsky, M. L. *et al.* Preparing ocean governance for species on the move. *Science* **360**, 1189–1191 (2018).
78. Hanich, Q., Campbell, B., Bailey, M. & Molenaar, E. Research into fisheries equity and fairness—addressing conservation burden concerns in transboundary fisheries. *Mar. Policy* **51**, 302–304 (2015).
79. McCauley, D. J. *et al.* Wealthy countries dominate industrial fishing. *Sci. Adv.* **4**, eaau2161 (2018).
80. Palacios-Abrantes, *J. et al. Timing and magnitude of climate driven range shifts in transboundary fish stocks challenge their management*. 2021.08.26.456854 https://www.biorxiv.org/content/10.1101/2021.08.26.456854v1 (2021) doi:10.1101/2021.08.26.456854.
81. Palacios-Abrantes, J., Reygondeau, G., Wabnitz, C. C. C. & Cheung, W. W. L. The transboundary nature of the world's exploited marine species. *Sci. Rep.* **10**, 17668 (2020).
82. Spijkers, J. *et al.* Exploring the future of fishery conflict through narrative scenarios. *One Earth* **0**, (2021).
83. Österblom, H. *et al. Towards Ocean Equity*. 65 (2020).
84. Internal Displacement Monitoring Center. *Global Report on Internal Displacement 2021*. https://www.internal-displacement.org/sites/default/files/publications/documents/grid2021_idmc.pdf (2021).
85. Campbell, J. R., Goldsmith, M. & Koshy, K. *Community relocation as an option for adaptation to the effects of climate change and climate variability in Pacific Island Countries (PICs)*. (Asia-Pacific Network for Global Change Research, 2005).
86. Webber, M. & Barnett, J. *Accommodating migration to promote adaptation to climate change*. (The World Bank, 2010).

87. Barnett, J. & Chamberlain, N. Migration as climate change adaptation: implications for the Pacific. *Clim. Change Migr. S. Pac. Perspect. Wellingt. N. Z. Inst. Policy Stud.* (2010).

88. McLeman, R. Perception of climate migrants. *Nat. Clim. Change* **10**, 600–601 (2020).

89. Suprenant, M. P. *et al. Internal Displacement's Impacts on Health in Yemen.* https://www.internal-displacement.org/sites/default/files/publications/documents/IDMC_ImpactsonHealthinYemen.pdf (2020).

90. Cinner, J. E. *et al.* Building adaptive capacity to climate change in tropical coastal communities. *Nat. Clim. Change* **8**, 117–123 (2018).

91. Petzold, J. & Magnan, A. K. Climate change: thinking small islands beyond Small Island Developing States (SIDS). *Clim. Change* **152**, 145–165 (2019).

92. Robinson, S. Climate change adaptation in SIDS: A systematic review of the literature pre and post the IPCC Fifth Assessment Report. *WIREs Clim. Change* **11**, e653 (2020).

93. Cassels, S., Curran, S. R. & Kramer, R. Do migrants degrade coastal environments? Migration, natural resource extraction and poverty in North Sulawesi, Indonesia. *Hum. Ecol.* **33**, 329–363 (2005).

94. Betzold, C. Adapting to climate change in small island developing states. *Clim. Change* **133**, 481–489 (2015).

95. Remling, E. Migration as climate adaptation? Exploring discourses amongst development actors in the Pacific Island region. *Reg. Environ. Change* **20**, 3 (2020).

96. Wabnitz, C. C., Cisneros-Montemayor, A. M., Hanich, Q. & Ota, Y. Ecotourism, climate change and reef fish consumption in Palau: Benefits, trade-offs and adaptation strategies. *Mar. Policy* **88**, 323–332 (2018).

97. Wabnitz, C. C. C. Adapting tourist seafood consumption practices in Pacific Islands to climate change. in *Predicting Future Oceans* 215–225 (Elsevier, 2019). doi:10.1016/B978-0-12-817945-1.00020-4.

98. UN Environment Programme. SIDS Waste Management Outlook.

99. Verlis, K. M. & Wilson, S. P. Paradise Trashed: Sources and solutions to marine litter in a small island developing state. *Waste Manag.* **103**, 128–136 (2020).

100. World Tourism Organization. *COVID-19 Related Travel Restricitons: A global review for tourism: Ninth Report as of 8 March 2021.* https://webunwto.s3.eu-west-1.amazonaws.com/s3fs-public/2021-03/210309-Travel-Restrictions.pdf (2021).

101. Desai, K., Zutt, J., Maharaj, D., Phelps, J. & Adhikari, R. Debt and Access to Finance for Small Island Developing States in the Era of COVID-19 and Beyond. (2021).

102. Hudson, A. The ocean and COVID-19. *United Nations Development Programme* https://www.undp.org/blogs/ocean-and-covid-19 (2020).

103. Soto, E. H. *et al.* How does the beach ecosystem change without tourists during COVID-19 lockdown? *Biol. Conserv.* **255**, 108972 (2021).

104. Gibbons, D. W. *et al.* The relative importance of COVID-19 pandemic impacts on biodiversity conservation globally. *Conserv. Biol.* (2021) doi:10.1111/cobi.13781.

105. UN ESCAP. *Changing Sails: Accelerating Regional Actions for Sustainable Oceans in Asia and the Pacific.* (UN, 2020). doi:10.18356/b33759c0-en.

106. OHRLLS & FAO. *COVID19 and Impacts on Food Security in LDCs, LLDCs and SIDS.* https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/ohrlls-fao-report_final.pdf (2020).

107. Bennett, N. J. *et al.* The COVID-19 Pandemic, small-scale fisheries and coastal fishing communities. *Coast. Manag.* **48**, 336–347 (2020).

108. Stoll, J. S. *et al.* Alternative Seafood Networks During COVID-19: Implications for resilience and sustainability. *Front. Sustain. Food Syst.* **5**, 614368 (2021).

109. ESMAP. *Going Global: Expanding Offshore Wind to Emerging Markets.* (World Bank, 2019).

110. Tao, J. Y. & Finenko, A. Moving beyond LCOE: impact of various financing methods on PV profitability for SIDS. *Energy Policy* **98**, 749–758 (2016).

111. Genave, A., Blancard, S. & Garabedian, S. An assessment of energy vulnerability in Small Island Developing States. *Ecol. Econ.* **171**, 106595 (2020).

112. Feinstein, C. SIDS – Towards a sustainable energy future. (2014).

113. Tokunaga, K. & Konan, D. E. Home grown or imported? Biofuels life cycle GHG emissions in electricity generation and transportation. *Appl. Energy* **125**, 123–131 (2014).

114. Chase, V. *et al. Independent evaluation of the relevance and effectiveness of the green climate fund's investments in small island developing states.* https://ieu.greenclimate.fund/sites/default/files/document/201123-sids-final-report-top-web_2.pdf (2020).

115. IRENA. *Fostering a blue economy: Offshore renewable energy.* 48 (2020).

116. Lucas, H., Fifita, S., Talab, I., Marschel, C. & Cabeza, L. F. Critical challenges and capacity building needs for renewable energy deployment in Pacific Small Island Developing States (Pacific SIDS). *Renew. Energy* **107**, 42–52 (2017).

117. Low-carbon futures in Least Developed Countries. *World Resources Institute* https://www.wri.org/climate/expert-perspective/low-carbon-futures-least-developed-countries (2019).

118. OECD. The 0.7% ODA/GNI target - a history. https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/the07odagnitarget-ahistory.htm (2016).

119. OECD. *Making development co-operation work for small island developing states.* (OECD Publishing, 2018).

120. Carney, M. Breaking the tragedy of the horizon–climate change and financial stability. (2015).

121. Chenet, H., Ryan-Collins, J. & van Lerven, F. Finance, climate-change and radical uncertainty: Towards a precautionary approach to financial policy. *Ecol. Econ.* **183**, 106957 (2021).

122. Network for greening the financial system. *Annual Report 2020.* https://www.ngfs.net/sites/default/files/medias/documents/ngfs_annual_report_2020.pdf (2021).

123. Dikau, S. & Volz, U. Central bank mandates, sustainability objectives and the promotion of green finance. *Ecol. Econ.* **184**, 107022 (2021).

124. Crain, C. M., Kroeker, K. & Halpern, B. S. Interactive and cumulative effects of multiple human stressors in marine systems. *Ecol. Lett.* **11**, 1304–1315 (2008).

125. Crona, B. *et al.* Sharing the seas: a review and analysis of ocean sector interactions. *Environ. Res. Lett.* **16**, 063005 (2021).

126. Orr, J. A. *et al.* Towards a unified study of multiple stressors: divisions and common goals across research disciplines. *Proc. R. Soc. B Biol. Sci.* **287**, 20200421 (2020).

127. Gissi, E. *et al.* A review of the combined effects of climate change and other local human stressors on the marine environment. *Sci. Total Environ.* **755**, 142564 (2021).

128. Simpson, N. P. *et al.* A framework for complex climate change risk assessment. *One Earth* **4**, 489–501 (2021).

129. Doney, S. C. *et al.* Climate change impacts on marine ecosystems. *Annu. Rev. Mar. Sci.* **4**, 11–37 (2012).

130. Blanc, D. L., Freire, C. & Vierros, M. Mapping the linkages between oceans and other Sustainable Development Goals: A preliminary exploration. *UNDESA Work. Pap.* 34 (2017).

131. He, Q. & Silliman, B. R. Climate change, human impacts, and coastal ecosystems in the anthropocene. *Curr. Biol.* **29**, R1021–R1035 (2019).

132. Schulte to Bühne, H., Tobias, J. A., Durant, S. M. & Pettorelli, N. Improving predictions of climate change–land use change interactions. *Trends Ecol. Evol.* **36**, 29–38 (2021).

133. Pidcock, R. & McSweeney, R. Mapped: How climate change affects extreme weather around the world. *Carbon Brief* https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world (2021).

134. OCHA. Haiti: Flash Appeal - Earthquake (August 2021) - Haiti. *ReliefWeb* https://reliefweb.int/report/haiti/haiti-flash-appeal-earthquake-august-2021 (2021).

135. OCHA Haiti. *Haiti: Earthquake: Situation Report No. 3.* https://reliefweb.int/sites/reliefweb.int/files/resources/2021-08-31_Haiti%20earthquake%20-%20SitRep%233.pdf (2021).

136. Zscheischler, J. *et al.* Future climate risk from compound events. *Nat. Clim. Change* **8**, 469–477 (2018).
137. Reyers, B., Folke, C., Moore, M.-L., Biggs, R. & Galaz, V. Social-ecological systems insights for navigating the dynamics of the anthropocene. *Annu. Rev. Environ. Resour.* **43**, 267–289 (2018).
138. Berkes, F. & Ross, H. Community resilience: Toward an integrated approach. *Soc. Nat. Resour.* **26**, 17 (2013).
139. Biggs, R. *et al.* Toward principles for enhancing the resilience of ecosystem services. *Annu. Rev. Environ. Resour.* **37**, 421–448 (2012).
140. Carpenter, S. R. *et al.* General resilience to cope with extreme events. *Sustainability* **4**, 3248–3259 (2012).
141. Chan, N. "Large Ocean States": Sovereignty, small islands, and marine protected areas in global oceans governance. *Glob. Gov. Rev. Multilateralism Int. Organ.* **24**, 537–555 (2018).
142. Devex & The World Economic Forum. Catalyzing a new future: From small islands to great ocean states. (2021).
143. Hume, A. *et al.* Towards an ocean-based large ocean states country classification. *Mar. Policy* **134**, 104766 (2021).
144. Gattuso, J.-P. *et al.* Ocean solutions to address climate change and its effects on marine ecosystems. *Front. Mar. Sci.* **5**, 337 (2018).
145. Morrison, T. H. *et al.* Advancing coral reef governance into the anthropocene. *One Earth* **2**, 64–74 (2020).
146. Sumaila, U. R. *et al.* Financing a sustainable ocean economy. *Nat. Commun.* **12**, 3259 (2021).
147. Ahmad, R. A., Reed, L. & Zhang, R. *Private equity and venture capital's role in catalyzing sustainable investment.* (International Finance Corporation, Washington, DC, 2018). doi:10.1596/31056.
148. Libes, L. & Eldridge, M. *Who, What, Where and How: 440 Investors.* https://investorflow.org/wp-content/uploads/Investorflow-Report-440-Investors-March-2019.pdf (2019).
149. Friends of Ocean Action. *The ocean finance handbook: Increasing finance for a healthy ocean.* http://www3.weforum.org/docs/WEF_FOA_The_Ocean_Finance_Handbook_April_2020.pdf (2020).
150. Iyer, V., Mathias, K., Meyers, D., Victurine, R. & Walsh, M. Finance tools for coral reef conservation: A guide. https://www.icriforum.org/wp-content/uploads/2019/12/50+Reefs+Finance+Guide.pdf (2018).
151. UNDP. Global Fund for Coral Reefs launches fundraising campaign. *United Nations Development Programme* https://www.undp.org/press-releases/global-fund-coral-reefs-launches-fundraising-campaign (2021).
152. Bayraktarov, E. *et al.* The cost and feasibility of marine coastal restoration. *Ecol. Appl.* **26**, 1055–1074 (2016).
153. Secretariat of the convention on biological diversity. High-level panel on global assessment of resources for implementing the strategic plan for biodiversity 2011-2020.
154. *Global biodiversity outlook 4: a mid-term assessment of progress towards the implementation of the strategic plan for biodiversity 2011-2020.* (Secretariat for the Convention on Biological Diversity, 2014).
155. Cooper, C. Today's conservation challenges are bigger than any one solution – or funder. *Alliance magazine* https://www.alliancemagazine.org/blog/todays-conservation-challenges-are-bigger-than-any-one-solution-or-funder/ (2021).
156. Global Fund for Coral Reefs. How We Work. *Global Funds for Coral Reefs* https://globalfundcoralreefs.org/how-we-work/.
157. Green, K. M. *et al.* How adaptive capacity shapes the adapt, react, cope response to climate impacts: insights from small-scale fisheries. *Clim. Change* **164**, 15 (2021).
158. Zhang, D. & Managi, S. Financial development, natural disasters, and economics of the Pacific small island states. *Econ. Anal. Policy* **66**, 168–181 (2020).
159. Cisneros-Montemayor, A. M. *et al.* Enabling conditions for an equitable and sustainable blue economy. *Nature* **591**, 396–401 (2021).
160. UNFCCC. *National Adaptation Plans 2020.* https://unfccc.int/sites/default/files/resource/NAP-progress-publication-2020.pdf (2021).
161. Green Climate Fund. About GCF. *Green Climate Fund* https://www.greenclimate.fund/about (2021).
162. Green Climate Fund. Approved projects. *Green Climate Fund* https://www.greenclimate.fund/projects (2021).
163. CCRIF SPC. About Us. https://www.ccrif.org/about-us?language_content_entity=en.
164. CCRIF. CCRIF to make US$40 million payout to Haiti following devastating August 14 earthquake - Haiti. *ReliefWeb* https://reliefweb.int/report/haiti/ccrif-make-us40-million-payout-haiti-following-devastating-august-14-earthquake (2021).
165. Sainsbury, N. C., Turner, R. A., Townhill, B. L., Mangi, S. C. & Pinnegar, J. K. The challenges of extending climate risk insurance to fisheries. *Nat. Clim. Change* **9**, 896–897 (2019).
166. The Caribbean Catastrophe Risk Insurance Facility & World Bank Group. The Caribbean Oceans and Aquaculture Sustainability Facility. (2019).
167. Li, H. Experience and enlightenment of the fishery mutual insurance system in asian countries. *Asian Agric. Res.* **5**, 127–130 (2013).
168. Kuruppu, N. & Willie, R. Barriers to reducing climate enhanced disaster risks in least developed country-small islands through anticipatory adaptation. *Weather Clim. Extrem.* **7**, 72–83 (2015).
169. Pelling, M. Urban governance and disaster risk reduction in the Caribbean: the experiences of Oxfam GB. *Environ. Urban.* **23**, 383–400 (2011).
170. Kotchen, M. J. & Costello, C. Maximizing the impact of climate finance: Funding projects or pilot projects? *J. Environ. Econ. Manag.* **92**, 270–281 (2018).
171. Aswani, S. & Hamilton, R. J. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environ. Conserv.* **31**, 69–83 (2004).
172. DeCaro, D. A., Arnold, C. A. (Tony), Frimpong Boamah, E. & Garmestani, A. S. Understanding and applying principles of social cognition and decision making in adaptive environmental governance. *Ecol. Soc.* **22**, (2017).
173. Kuruppu, N. & Liverman, D. Mental preparation for climate adaptation: The role of cognition and culture in enhancing adaptive capacity of water management in Kiribati. *Glob. Environ. Change* **21**, 657–669 (2011).
174. UN Committee for Development Policy Secretariat. Triennial review dataset 2000-2018. https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-data-retrieval.html/ (2018).
175. UNCTAD. Memo items of development status groups and composition. *UNCTADstat - Classifications* https://unctadstat.unctad.org/en/classifications.html (2021).
176. Heck, N., Beck, M. W. & Reguero, B. Storm risk and marine fisheries: a global assessment. *Mar. Policy* **132**, 104698 (2021).
177. Thiault, L. *et al.* Mapping social–ecological vulnerability to inform local decision making. *Conserv. Biol.* **32**, 447–456 (2018).
178. Guillaumont, P. Assessing the economic vulnerability of small island developing states and the least developed countries. *J. Dev. Stud.* **46**, 828–854 (2010).
179. Comte, A., Pendleton, L. H., Bailly, D. & Quillérou, E. Conceptual advances on global scale assessments of vulnerability: Informing investments for coastal populations at risk of climate change. *Mar. Policy* **99**, 391–399 (2019).
180. OECD. Sustainable Development Goals and Evaluation. https://www.oecd.org/dac/evaluation/sustainabledevelopmentgoalsandevaluation.htm.
181. Moltmann, T. *et al.* A Global Ocean Observing System (GOOS), Delivered through enhanced collaboration across regions, communities, and new technologies. *Front. Mar. Sci.* **6**, 291 (2019).
182. Mycoo, M. A. Beyond 1.5 °C: vulnerabilities and adaptation strategies for Caribbean small island developing states. *Reg. Environ. Change* **18**, 2341–2353 (2018).
183. Tanhua, T. *et al.* What we have learned from the framework for ocean observing: evolution of the global ocean observing system. *Front. Mar. Sci.* **6**, 471 (2019).
184. PNA Office. PNA Office Year Book 2019. (2019).

185. Havice, E. The structure of tuna access agreements in the Western and Central Pacific Ocean: Lessons for vessel day scheme planning. *Mar. Policy* **34**, 979–987 (2010).

186. Miller, K. A. Climate variability and tropical tuna: management challenges for highly migratory fish stocks. *Mar. Policy* **31**, 56–70 (2007).

187. Havice, E. Rights-based management in the Western and Central Pacific Ocean tuna fishery: Economic and environmental change under the Vessel Day Scheme. *Mar. Policy* **42**, 259–267 (2013).

188. Yeeting, A. D., Weikard, H. P., Bailey, M., Ram-Bidesi, V. & Bush, S. R. Stabilising cooperation through pragmatic tolerance: the case of the Parties to the Nauru Agreement (PNA) tuna fishery. *Reg. Environ. Change* **18**, 885–897 (2018).

189. Adolf, S., Bush, S. R. & Vellema, S. Reinserting state agency in global value chains: The case of MSC certified skipjack tuna. *Fish. Res.* **182**, 79–87 (2016).

190. Hare, S. R. *et al. The western and central Pacific tuna fishery: 2019 overview and status of stocks.* 55 https://oceanfish.spc.int/en/ofpsection/sam/513-tuna-fisheries-assessment-report-no-20 (2020).

191. Lehodey, P., Senina, I., Calmettes, B., Hampton, J. & Nicol, S. Modelling the impact of climate change on Pacific skipjack tuna population and fisheries. *Clim. Change* **119**, 95–109 (2013).

192. Senina, I. *et al. Impact of climate change on tropical tuna species and tuna fisheries in Pacific Island waters and high seas areas.* http://www.fao.org/fileadmin/user_upload/common_oceans/docs/Final-report-PacificTunaClimateChange.pdf (2018).

193. Bell, J. D. *et al.* Pathways to sustaining tuna-dependent Pacific Island economies during climate change. *Nat. Sustain.* 1–11 (2021) doi:10.1038/s41893-021-00745-z.

194. Bell, J. D. *et al.* Effects of climate change on oceanic fisheries in the tropical Pacific: implications for economic development and food security. *Clim. Change* 1–14 (2012).

195. Clark, S. *et al.* Chapter 12. The Parties to the Nauru Agreement (PNA) 'Vessel Day Scheme': A cooperative fishery management mechanism assisting member countries adapt to climate variability and change. in *Adaptive management of fisheries in response to climate change* (FAO, 2021). doi:10.4060/cb3095en.

196. Priddle, E., Burden, M., Landman, J. & Kleisner, K. *Climate-related impacts on fisheries management and governance in the North East Atlantic.* 37 (2017).

197. Dunn, S., Rodwell, L. & Joseph, G. The Palau Arrangement for the management of the Western Pacific purse seine fishery-management scheme (Vessel Day Scheme). in *Sharing the Fish Conference, Perth* (2006).

198. Pew Charitable Trust. Harvest control rules. *Harvest control rules approaches to effective long-term fisheries management* http://pew.org/2adpw3p (2016).

199. Kritzer, J. P., Costello, C., Mangin, T. & Smith, S. L. Responsive harvest control rules provide inherent resilience to adverse effects of climate change and scientific uncertainty. *ICES J. Mar. Sci.* **76**, 1424–1435 (2019).

200. Farmery, A. K. *et al.* Conceptualising value chain research to integrate multiple food system elements. *Glob. Food Secur.* **28**, 100500 (2021).

201. FAO. *The State of World Fisheries and Aquaculture 2020.* (FAO, 2020). doi:10.4060/ca9229en.

202. Lubchenco, J., Haugan, P. M. & Pangestu, M. E. Five priorities for a sustainable ocean economy. *Nature* **588**, 30–32 (2020).

203. Bell, J. D. *et al.* Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories. *Mar. Policy* **51**, 584–591 (2015).

204. World Bank & United Nations Department of Economic and Social Affairs. *The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marin Resources for Small Island Developing Staets and Coastal Least Developed Countries.* https://openknowledge.worldbank.org/bitstream/handle/10986/26843/115545.pdf?sequence=1&isAllowed=y (2017).

205. Gaines, S. *et al. The Expected impacts of climate change on the ocean economy.* 56 https://oceanpanel.org/blue-papers/expected-impacts-climate-change-ocean-economy (2019).

206. IPCC. 2019: Summary for policymakers. in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (eds. Pörtner, H.-O. et al.) (2019).

207. Golden, C. D. *et al.* Nutrition: Fall in fish catch threatens human health. *Nat. News* **534**, 317 (2016).

208. World Health Organization. *Guidance on mainstreaming biodiversity for nutrition and health.* https://cdn.who.int/media/docs/default-source/climate-change/mainstreaming-biodiversity-for-nutrition-and-health12d76606-f87e-4857-9264-dd2b2924186a.pdf?sfvrsn=afd00782_1&download=true (2020).

209. Maire, E. *et al.* Micronutrient supply from global marine fisheries under climate change and overfishing. *Curr. Biol.* **31**, 4132-4138.e3 (2021).

210. Golden, C. D. *et al.* Social-ecological traps link food systems to nutritional outcomes. *Glob. Food Secur.* **30**, 100561 (2021).

211. IOC. An unprecedented analysis on global harmful algal blooms launched by IOC. https://ioc.unesco.org/news/unprecedented-analysis-global-harmful-algal-blooms-launched-ioc (2021).

212. Visciano, P. *et al.* Marine biotoxins: Occurrence, toxicity, regulatory limits and reference methods. *Front. Microbiol.* **7**, 1051 (2016).

213. AFP. Nineteen die in Madagascar after eating turtle. *CGTN Africa* (2021).

214. Fernandes-Salvador, J. A. *et al.* Current status of forecasting toxic harmful algae for the north-east Atlantic shellfish aquaculture industry. *Front. Mar. Sci.* **8**, 656 (2021).

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