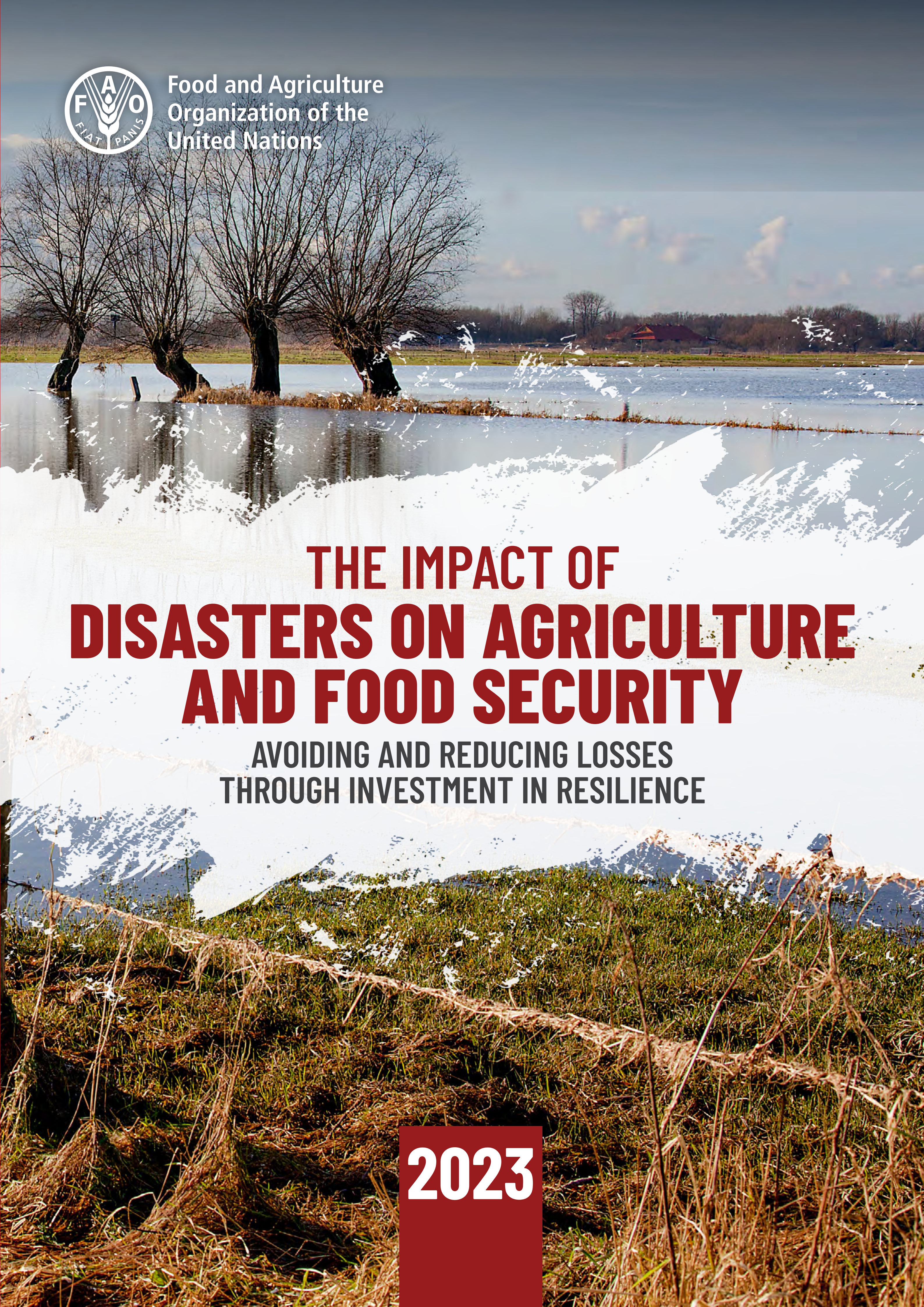

Food and Agriculture
Organization of the
United Nations

THE IMPACT OF DISASTERS ON AGRICULTURE AND FOOD SECURITY

AVOIDING AND REDUCING LOSSES THROUGH INVESTMENT IN RESILIENCE

2023

Required citation:
FAO. 2023. *The Impact of Disasters on Agriculture and Food Security 2023 – Avoiding and reducing losses through investment in resilience.* Rome. https://doi.org/10.4060/cc7900en

ISBN 978-92-5-138194-6

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THE KINGDOM OF THE NETHERLANDS. An average of 12 000 hectares of crops like cotton, corn and walnut were affected by rain and river overflows.

THE IMPACT OF DISASTERS ON AGRICULTURE AND FOOD SECURITY

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Food and Agriculture Organization of the United Nations
Rome, 2023

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FOREWORD

Disasters are causing unprecedented levels of destruction across the globe, demanding new approaches to reducing risk, strengthening response capabilities and building resilience capacities.

The year 2023 has broken all existing records for the highest temperatures recorded on our warming planet and episodes of extreme floods, storms, droughts, wildfires, and pest and disease outbreaks are becoming daily features in global headlines. As the effect of the climate crisis unfolds, the frequency and intensity of climate-related disasters are also increasing, inflicting a heavy toll on communities and livelihoods across the world. Agriculture is one of the most highly exposed and vulnerable sectors in the context of disaster risk, given its profound dependence on natural resources and climate conditions. Recurrent disasters have the potential to erode gains in food security and undermine the sustainability of agrifood systems.

With this report, the Food and Agriculture Organization of the United Nations (FAO) presents groundbreaking evidence on the global impact of disasters on agriculture and food security over the last three decades. It was my decision to elevate this report to the level of a flagship publication, to reflect our commitment to investing in evidence-based disaster risk reduction solutions and promoting more efficient, inclusive, resilient and sustainable agrifood systems for a better future all around the world.

The findings of the report are stark. We have lost an estimated USD 3.8 trillion worth of crops and livestock production due to disaster events over the past three decades. This corresponds to more than 5 percent of annual global agricultural GDP, a figure that would be significantly higher if systematic data on losses in the fisheries and aquaculture and forestry subsectors were available. We urgently need better information on the impact of disasters in all subsectors of agriculture to create data systems that can serve as the foundation upon which effective action can be built and informed, and to meet the monitoring requirements of the Sendai Framework on Disaster Risk Reduction and the 2030 Agenda for Sustainable Development.

In some ways, disaster events represent the tip of the iceberg. There are deeper underlying challenges and vulnerabilities created by social and environmental conditions that generate disastrous outcomes and produce cascading effects across agrifood systems. Poverty, unequal access to resources and governance structures all play a pivotal role in determining the impacts of disasters and crises. Among these, the climate crisis is having a significant effect in amplifying existing risks, but recent pandemics and armed conflicts have also contributed to losses experienced in the agrifood sector. Reducing the impact of disasters will require not only understanding their direct effects, but also necessitates unpacking the overarching conditions that drive risks and the way in which their impacts cascade over sectors, systems and geographical regions.

In a world with limited resources, we need to increase investment in resilience by adopting creative, innovative and scalable solutions that can avoid and reduce losses generated by disasters. Leveraging FAO's technical expertise, this publication showcases opportunities to proactively address risks in agriculture while demonstrating ways to mainstream disaster risk into agricultural practices and policies. It calls for a deep understanding of the context in which these solutions are implemented, as well as strengthened partnerships and collaboration with all relevant partners.

As part of FAO's work to support risk-informed agrifood systems, this report is a valuable addition to the knowledge base required for adopting and scaling up innovative approaches to resilient and sustainable agriculture, thus enabling better production, better nutrition, a better environment and a better life – while leaving no one behind.

Qu Dongyu
FAO Director-General

METHODOLOGY

The Impact of Disasters on Agriculture and Food Security 2023 has been prepared by the Statistics Division (ESS) and the Office of Emergencies and Resilience (OER) of FAO.

Technical inputs were provided by the Office of Climate Change, Biodiversity and Environment (OCB), and the Fisheries and Aquaculture Division (NFI), the Forestry Division (NFO), the Animal Production and Health Division (NSA), and the Plant Production and Protection Division (NSP) of the Natural Resources and Sustainable Production stream.

A coordination team consisting of the management of the collaborating divisions and offices of FAO guided the production of the report. This team decided on the outline of the report and defined its thematic focus. Further, it oversaw the technical writing team composed of experts from the collaborating divisions who contributed to the analysis and technical content of the report.

Background technical papers were prepared to support the research and data analysis undertaken for individual sections of the report. The writing team produced several interim outputs, including an annotated outline, first draft and final draft of the report.

These drafts were reviewed and validated by external experts in two workshops held during the preparation process. The final report underwent a rigorous technical review by senior management, technical experts from various divisions and offices of FAO, as well as independent external reviewers. Finally, the report underwent a process of executive clearance at FAO by the heads of the co-publishing divisions, the Chief Economist, the Deputy Director-General in charge of Emergencies and Resilience, and the office of the Director-General.

ACKNOWLEDGEMENTS

The Impact of Disasters on Agriculture and Food Security 2023 is the outcome of extensive collaboration across several technical divisions and offices within FAO, primarily including the Economic and Social Development Stream, the Office of Emergencies and Resilience (OER), the Office of Climate Change, Biodiversity and Environment (OCB), and the Natural Resources and Sustainable Production stream.

The report was jointly produced by the Statistics Division of FAO (ESS) and OER, with the overall guidance of Laurent Thomas and Maximo Torero Cullen, and under the direction of José Rosero Moncayo and Rein Paulsen. The development of the report was coordinated by a team consisting of Zehra Zaidi, the editor of the publication, and Wirya Khim, Piero Conforti, Stephan Baas, Laurel Hanson and Veronica Boero. Managerial support was provided by Piero Conforti, Shukri Ahmed, Fleur Wouterse and Dunja Dujanovic.

Central to the development of the report were the technical papers and background materials prepared and revised by several FAO experts. Valuable comments and final approval of the report were provided by the executive heads and senior staff of various FAO divisions.

Part 1 of the report was written by Zehra Zaidi and Piero Conforti, with input from Wirya Khim and Laurel Hanson.

Part 2 of the report was coordinated by Zehra Zaidi. **Section 2.1** was written by Zehra Zaidi. Sylvain Ponserre and Vicente Anzellini of the Internal Displacement Monitoring Center developed BOX 2 on displacement, and Giulia Caivano and Priti Rajagopalan produced BOX 3 on gender in **section 2.1**. Zehra Zaidi wrote **section 2.2** with support from Piero Conforti. Rahul Sengupta and Xuan Che of the United Nations Office for Disaster Risk Reduction (UNDRR) provided data and input for the analysis of the C2 Sendai Indicator. **Section 2.3** was written by Piero Conforti, Zehra Zaidi, Veronica Boero, Priti Rajagopalan and Esther Laske. Key inputs were provided by Priti Rajagopalan, Esther Laske and Veronica Boero on the estimation of disaster losses, while support and comments were provided by Antonio Scognamillo, Nidhi Chaudhary and Xinman Liu. **Subsection 2.3.2** on nutrition was produced by Esther Laske, in collaboration with Nancy Aburto, Bridget Holmes and Victoria Padula de Quadro. **Section 2.4** was coordinated by Zehra Zaidi, with key inputs from Esther Laske. Background papers and technical inputs for **section 2.3** and **section 2.4** were provided by Joachim Otte and Dominik Wisser from the Animal Production and Health Division (NSA), Charles Midega (independent consultant), Buyung Hadi and Shawn McGuire on behalf of the Plant Protection and Production Division (NSP), Lara Steil, Shiroma Sathyapala, Peter Moore, William John de Groot, Erik Lindquist and Amy Duchelle as contributing authors for the Forestry Division (NFO), and Stefania Savore, Iris Monnereau, Silke Pietzsch (FAORAP), James McCafferty (independent consultant) and Latu ʻAisea (Ministry of Fisheries, Tonga) on behalf of the Fisheries and Aquaculture Division (NFI).

Part 3 of the report was coordinated by Wirya Khim, Laurel Hanson and Stephan Baas. For **section 3.1**, Wirya Khim, Stephan Baas, Laurel Hanson and Julia Wolf provided overall coordination and guidance with input from Piero Conforti and Zehra Zaidi. The policy developments section was written by Makie Yoshida and Silvia Santato. The attribution and impact study was written by Sabine Undorf (Potsdam Institute for Climate Impacts Research), Bernhard Schauberger (Potsdam Institute for Climate Impact Research/Weihenstephan-Triesdorf University of Applied Science), Lennart Jansen (Potsdam Institute for Climate Impact Research/University of Kassel), Paula Romanovska (Potsdam Institute for Climate Impact Research) and Christoph Gornott (Potsdam Institute for Climate Impact

Research/University of Kassel) with input from Hideki Kanamaru, Wirya Khim, Laurel Hanson and Stephan Baas. **Section 3.2.1** was written by Amandine Poncin, Neil Marsland and Josselin Gauny, with inputs from Wirya Khim and Laurel Hanson. **Section 3.2.2** was written by Damian Tago Pacheco, Bouda Vosough Ahmadi, Andriy Rozstalnyy, Madhur Dhingra and Keith Sumption, with input from Wirya Khim, Laurel Hanson and Stephan Baas. **Section 3.3** was written by Laurel Hanson, Julius Jackson and Neil Marsland with input from Daniele Barelli and Josselin Gauny.

Part 4 of the report was coordinated by Wirya Khim, Stephan Baas and Laurel Hanson. **Section 4.1** was written by Wirya Khim, Tamara Van't Wout and Laurel Hanson with input from Stephan Baas and Niccolò Lombardi. **Section 4.2** was written by Nicholas Bodanac and Niccolò Lombardi with input from Wirya Khim and Laurel Hanson. **Section 4.3** was written by Sergio Innocente, Wirya Khim and Laurel Hanson with input from Keith Cressman, Cyril Ferrand, Shoki Al Dobai, Stephan Baas and Shukri Ahmed.

Part 5 was jointly prepared by Zehra Zaidi and Piero Conforti, with input from Esther Laske, Wirya Khim, Laurel Hanson and Stephan Baas.

Numerous external experts provided comprehensive reviews and valuable technical comments for the report. The entire report was peer reviewed by Julio Serje (former UNDRR staff member).

For **Part 2** of the report, Sepehr Marzi, of the Joint Research Centre of the European Commission (JRC), and Jeremy Pal of the Euro-Mediterranean Center on Climate Change (CMCC) undertook a technical review of the methodology. Specific reviews for **section 2.4** were provided by Yacob Aklilu (Farm-D) for the livestock section, by Kris Wykhuis (FAO), Roger Day (Centre for Agriculture and Bioscience International [CABI]), Anna Szyniszewska (CABI), Bryony Taylor (CABI) and Fazil Dusunceli for the section on fall armyworm, Ane Alencar (the Amazon Environmental Research Institute [IPAM]), Brett Hurley (University of Pretoria), Gary Man, Simon Lawson, Robert Rabaglia (USDA Forest Service), Jesus San-Miguel-Ayanz (JRC) for the section on forestry and Denis Lacroix (Institut Français de Recherche pour l'Exploitation de la Mer [Ifremer]) for the section on fisheries.

Section 3.1 was reviewed by Carlos Dionisio Perez Blanco (University of Salamanca), Elisa Calliari (International Institute for Applied Systems Analysis), Andrea Toretti (JRC), Rupert Stuart-Smith (Oxford University), James Douris (World Meteorological Organization [WMO]), Veronica Grasso (WMO), Sihan Li (University of Sheffield) and Toshichika Iizumi (National Agriculture and Food Research Organization [NARO] – Japan). **Section 3.2.1** on the COVID-19 pandemic was reviewed by Mark Alexander Constas (Cornell University) and John M. Ulimwengu (International Food Policy Research Institute [IFPRI]), while **section 3.2.2** on African swine fever was reviewed by Manon Schuppers (SAFOSO AG) and Karl Rich (Oklahoma State University). **Section 3.3** on the impact of armed conflicts on agriculture was reviewed by Dominique Blariaux (Post Crisis Assessment and Recovery Planning: Support Office of the European Union), Iryna Vysotska (The Quality Food Trade Program) and Igor Kravchenko (The Quality Food Trade Program).

Production support was provided by Olivier Lavagne d'Ortigue and Chiara Gnetti. The FAO Publications and Library Branch of the Office of Communications provided editorial support, design, and layout, as well as production coordination for editions in all six official languages. The FAO Meeting Branch and Language Services Branch of Governing Bodies Servicing Division (CSG) carried out the translations.

ACRONYMS

AA	anticipatory action
ASEAN	Association of Southeast Asian Nations
ASF	African swine fever
BCR	benefit-cost ratio
BFAR	Bureau of Fisheries and Aquatic Resources (the Philippines)
BMI	body mass index
CMIP6	Coupled Model Intercomparison Project Phase 6
COP	Conference of Parties
CRED	Centre for Research on the Epidemiology of Disasters
DAMIP	Detection and Attribution Model Intercomparison Project
DFEE	Department of Forestry, Fisheries and the Environment (South Africa)
DIEM	FAO Data in Emergencies
DINA	The Somalia Drought Impact and Needs Assessment
DLIS	Desert Locust Information Service
DRR	disaster risk reduction
EAR	estimated average requirement
ECS	equilibrium climate sensitivity
EFSA	European Food Safety Authority
EM-DAT	The International Disaster Database
ENSO	El Niño-Southern Oscillation
FAW	fall armyworm
FCT	food composition table
FSNAU	Food Security and Nutrition Analysis Unit (Somalia)
GDP	gross domestic product
GFDRR	Global Facility for Disaster Reduction and Recovery
GSR	green super rice
GWIS	Global Wildfire Information System
HABs	harmful algal blooms
HT-HH	Hunga Tonga-Hunga Ha'apai
IDMC	Internal Displacement Monitoring Centre
IDP	internally displaced people
IFAD	International Fund for Agricultural Development
IFM	integrated fire management

IFRC	International Federation of Red Cross and Red Crescent Societies
IOM	International Organization for Migration
IPC	Integrated Food Security Phase Classification
IPCC	Intergovernmental Panel on Climate Change
MIROC6	Model for Interdisciplinary Research on Climate
MPB	mountain pine beetle
NAP	National Adaptation Plan
NDC	nationally determined contributions
NPV	net present values
IRC	International Rescue Committee
ISC	International Science Council
ISIMIP3	Inter-Sectoral Model Intercomparison Project
MODIS	moderate-resolution imaging spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Co-operation and Development
OIEWG	open-ended intergovernmental expert working group
PAL	physical activity level
PDNA	post disaster needs assessment
PPP	purchasing power parity
RoI	return on investment
SDGs	United Nations Sustainable Development Goals
SIDS	Small Island Developing States
SPB	southern pine beetle
TAD	transboundary animal diseases
TCR	transient climate response
TFP	total factor productivity
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WFP	World Food Programme
WHO	World Health Organization
WIM	Warsaw International Mechanism
WMO	World Meteorological Organization
WWA	World Weather Attribution

KEY MESSAGES

➔ Defined as serious disruptions to the functioning of a community or society, disasters are producing unprecedented levels of damage and loss in agriculture around the world. Their increasing severity and frequency, from 100 per year in the 1970s to around 400 events per year in the past 20 years, affect agrifood systems across multiple dimensions, compromising food security and undermining the sustainability of the agriculture sector.

➔ Data for describing the impact of disasters on agriculture and agrifood systems is partial and inconsistent, especially in the fisheries and aquaculture and forestry subsectors. There is an urgent need for improving data collection tools and systems to support evidence-based policies, practices and solutions for risk reduction and resilience building in agriculture. Despite these limitations, this new flagship report presents the first ever global-level estimation of the impact of disasters on agriculture.

➔ Over the last 30 years, an estimated USD 3.8 trillion worth of crops and livestock production has been lost due to disaster events, corresponding to an average loss of USD 123 billion per year, or 5 percent of annual global agricultural GDP. In relative terms, the total amount of losses over 30 years is approximately equivalent to Brazil's GDP in 2022.

➔ Over the last 30 years, disasters inflicted the highest relative losses on lower- and lower-middle-income countries, ranging between 10 and 15 percent of their total agricultural GDP, respectively. Disasters also had a significant impact on Small Island Developing States (SIDS), causing them to lose nearly 7 percent of their agricultural GDP.

➔ Understanding interconnected and systemic risks and underlying disaster risk drivers is essential to build resilient agrifood systems. Climate change, pandemics, epidemics and armed conflict are all affecting agricultural production, value chains and food security. Therefore, gaining a better understanding of their interactions is essential for developing a comprehensive view of today's risk landscape.

➔ Research aimed at deciphering the impact of climate change on agriculture indicates that climate change is likely to lead to more frequent yield anomalies and a decrease in agricultural production. Global crises such as the COVID-19 pandemic and ongoing armed conflicts have impacted agricultural production as well as input and output markets, resulting in negative effects in the wider agrifood system and for overall food security.

➔ Proactive and timely interventions can build resilience by preventing and reducing risks in agriculture. The available information indicates that there are quantifiable benefits to investing in farm-level disaster risk reduction (DRR) good practices. Anticipatory actions undertaken in several countries through early warning systems, such as combined preventative control against the desert locust outbreak in the Horn of Africa during 2020–2021, demonstrated favourable benefit to cost ratios for investing in disaster prevention and resilience.

➔ Urgent action is needed to prioritize the integration of multisectoral and multihazard disaster risk reduction strategies into agricultural policies and programmes. This can be achieved by enhancing the available evidence, fostering the adoption of available innovations, facilitating the creation of more scalable farm-level risk management solutions, and strengthening early warning systems that lead to anticipatory action.

EXECUTIVE SUMMARY

Not only are disaster events increasing in frequency and intensity, but their impact is expected to worsen, as a warming planet comes to terms with the challenges of an uncertain risk landscape in the context of finite biological and ecological resources. According to the International Disaster Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED), disaster events have increased from 100 per year in the 1970s to around 400 events per year worldwide in the past 20 years.

FAO is launching this new flagship report, *The Impact of Disasters on Agriculture and Food Security*, as part of its ongoing commitment to promote a more inclusive, resilient and sustainable future for agriculture. Building on three prior publications by FAO on this topic, this report aims at organizing and disseminating available knowledge on the impact of disasters on agriculture with a view to promote evidence-based investment in disaster risk reduction.

Disaster risk is composed of a complex interplay between the physical environment (both natural and built), and society (such as behaviour, function, organization and development). Disaster risk is determined probabilistically as a function of hazard, exposure, vulnerability and capacity, while a disaster refers to a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

Agriculture is predominantly affected by meteorological and hydrological hazards, geohazards, environmental hazards and biological hazards, although societal hazards such as armed conflict, and technological and chemical hazards also pose potential threats. The amount of loss and damage produced by a disaster depends on the speed and spatial scale at which a hazard interacts with vulnerability and pre-existing risks, along with the amount of exposed assets or livelihoods.

The impact of disasters is also influenced by the systemic and interconnected nature of today's risk landscape. When hazards manifest, they can have cascading impacts, affecting multiple systems and sectors within and across boundaries. Underlying disaster risk drivers include climate change, poverty and inequality, population growth, health emergencies caused by pandemics, practices such as unsustainable land use and management, armed conflicts and environmental degradation.

IMPACT OF EXTREME EVENTS ON AGRICULTURE

Multifaceted impacts of disasters on agriculture

Agriculture around the world is increasingly at risk of being disrupted due to multiple hazards and threats such as flooding, water scarcity, drought, declining agricultural yields and fisheries resources, loss of biological diversities and environmental degradation. Variations in water supply and extreme temperatures are two of the biggest factors that directly and indirectly impact agricultural production. Floods and heavy precipitation can have both positive and negative impacts on agricultural systems and productivity. Agricultural drought emerges from a combination of rainfall deficits (meteorological drought), soil water deficits, and reduced ground water or water storage levels needed for irrigation (hydrological drought). Extreme temperature events also have negative consequences for agricultural production. In the livestock subsector, heat stress can affect the mortality, liveweight gain, milk yield and fertility of an animal.

There is evidence to show that current warming trends around the globe are already having an impact on agriculture. A recent study found that the severity of heatwave and drought impacts on crop production roughly tripled from 2.2 percent between 1964 and 1990, to 7.3 percent between 1991 and 2015. Disasters also affect livelihoods, food security and nutrition. They cause rural unemployment, a decline in income for farmers and agricultural workers, and reduce the availability of food in local markets.

In extreme cases, disasters result in the displacement and outward migration of rural populations. Pakistan's southern province of Sindh is an illustrative example of how the combination of slow and sudden onset hazards triggered displacement, negatively impacting food systems and increasing food insecurity.

As shown in BOX 3, women are often the most adversely affected by disasters. Resource and structural constraints are the main drivers of gender disparities in disasters. Women face obstacles accessing the information and resources needed to adequately prepare for, respond to and recover from a disaster – including access to early warning systems and safe shelters, as well as access to social and financial protection schemes and alternative employment.

Towards an assessment of global agricultural losses

Understanding the extent and degree to which these weather anomalies and extreme events affect agriculture is the first step to developing disaster risk reduction and climate adaptation strategies. Although several databases record disaster impacts, losses occurring in agriculture and its subsectors are currently not comprehensively assessed or reported as part of total economic losses in existing global, multihazard disaster databases. Missing data and a lack of consistency across existing databases are known limitations of international repositories maintained by EM-DAT, DesInventar, the World Bank, the International Federation of Red Cross and Red Crescent Societies (IFRC), databases maintained by global reinsurance groups, as well as national level databases.

Currently there are two sets of methodologies that are used to collect information on disaster losses in agriculture. The first forms part of post disaster needs assessment (PDNA) surveys, while the second was developed by FAO in coordination with the United Nations Office for Disaster Risk Reduction (UNDRR) to measure indicator C2 of the Sendai Framework Monitor for Disaster Risk Reduction.

Data from PDNAs undertaken from 2007 to 2022 shows that agricultural losses made up an average of 23 percent of the total impact of disasters across all sectors, and that over 65 percent of losses caused by droughts were experienced in the agriculture sector. In disaster events caused by floods, storms, cyclones and volcanic activity, around 20 percent of losses are experienced in the agriculture, thus underscoring the disproportionately high impact of droughts in the sector. Among the subsectors, crops and livestock account for the most losses, but fisheries and aquaculture and forestry may not have received enough attention in these evaluations.

Data from the Sendai Framework for Disaster Risk Reduction 2015–2030 subindicator C2 – which corresponds to direct agricultural losses attributed to disasters – was reported by 82 countries out of the 195, with 38 countries reporting subsectoral data. Total agricultural losses from disasters reported in the Sendai Framework Monitor amount to an average of USD 13 billion per year, mostly from floods (16 percent), fire and wildfire (13 percent) and drought (12 percent). Figures from both PDNAs and the C2 indicator are likely to be significant underestimations, given the limitations and delays of data reporting.

Measurement and evidence on crops and livestock

Data on loss and damage is not being systematically collected. As a means of addressing this gap, data from EM-DAT and FAOSTAT was used to provide a first ever quantification of the impact of disasters on agricultural production at a global scale, focused on crops and livestock. National average productivity reductions by items are compared to a counterfactual scenario in which disaster events did not occur.

Global aggregated losses for the 1991–2021 period amounts to USD 3.8 trillion, corresponding to about USD 123 billion per year. This value is equivalent to 5 percent of global agricultural GDP, and nearly 300 million tonnes of accumulated losses per year, or the real GDP of Brazil in year 2022. Compared to the early 1990s, while overall losses have increased only moderately, they have become more widespread in terms of the countries and products that they affect. The frequency and covariate nature of the extreme events that generate losses in crops and livestock around the world appear to be increasing.

Losses display increasing trends for major agricultural product groups. Losses in cereals amounted to an average of 69 million tonnes per year in the last three decades, corresponding to the entire cereal production of France in 2021, followed by fruits and vegetables and sugar crops, both of which approached an average of 40 million tonnes per year. For fruits and vegetables, losses correspond to the entire production of fruits and vegetables in Japan and Viet Nam in 2021. Meats, dairy products and eggs show an average estimated loss of 16 million tonnes per year – corresponding to the whole production of these products in Mexico and India in 2021.

Global losses mask significant variability across regions, subregions and country groups. Asia experiences by far the largest share of total economic losses, almost equal to losses experienced in Africa, Europe and the Americas put together. However, losses in Asia only account for 4 percent of the agricultural GDP (value added), while in Africa they correspond to nearly 8 percent of the agricultural GDP. In absolute terms, losses are higher in high-income countries, lower-middle-income countries and upper-middle-income countries, but low-income countries (LICs) and SIDS suffered the highest share of losses in agricultural value added. Compared to the estimated counterfactual production, losses appear to be particularly significant in several parts of Africa, primarily eastern, northern and western Africa, and in Micronesia and the Caribbean.

An attribution of losses to specific hazard types cannot be determined with the estimated crop and livestock data, mainly due to the difficulty of disaggregating impacts for multiple disasters occurring in the same year. Results from a mixed effects regression model show that at the global level, extreme temperatures and droughts are the hazards that inflict the largest impact per event, followed by floods, storms and wildfires.

Global losses in crops and livestock are converted to corresponding energy and nine micronutrient values lost for human consumption. Agricultural products lost due to disasters are matched to appropriate nutrient values in the global nutrient conversion table, which provides equivalent nutritional values for major food commodities. It is important to emphasize that the focus is on the availability of nutrients and energy, and not on changes in consumption patterns due to disasters. The estimated losses amount to approximately 147 kilocalories (kcal) per person per day over the past 31 years. To put this into perspective, it is equivalent to the daily dietary requirements of approximately 400 million men or 500 million women. Compared to daily dietary requirements, nutrient losses appear to be particularly prominent for iron, phosphorus, magnesium and thiamine. At a regional level, the estimated nutritional losses linked to production lost due to disasters are around 31 percent in Asia and the Americas, 24 percent in Europe, 11 percent in Africa and 3 percent in Oceania.

Different impacts in different subsectors: fisheries and aquaculture and forestry

For the subsectors of fisheries and aquaculture and forestry, a lack of data does not allow for assessments similar to those conducted for crops and livestock. Insights on disasters impacts in these two subsectors are therefore gathered from existing literature and documented evidence obtained from the analysis of specific cases.

Forests are extremely vulnerable to the impacts of disasters and climate change but also play a key role in risk reduction and mitigation. The two most significant hazards that affect forestry are wildfire and insect infestations. Most hazards affecting the forestry sector are driven by meteorological factors, long-term climate variability and human influence, including land-use change, land management practices and introduction of invasive species. However, in the 2020 edition of the *Global Forest Resources Assessment* (FRA), only 58 countries, representing 38 percent of the global forest area, currently monitor the degradation of forests arising from logging, burning, disease or insect infestation. Obstacles to gathering data on forest impacts include inconsistent approaches to assessing losses and damages, insufficient application of appropriate methodologies, and a lack of comprehensive coverage across the full spectrum of impacts.

Driven by a rising population density in the wildland–urban interface, wildfires are increasingly damaging the environment, wildlife, human health and infrastructure. Every year, about 340 million–370 million hectares (ha) of the Earth's surface are burnt by wildfire, and 25 million ha of forest land were burnt in 2021 alone. According to recent Intergovernmental Panel on Climate Change (IPCC) findings, hotter, drier and windier weather is becoming more frequent in some regions and will continue to increase if countries do not meet and exceed their Paris Agreement commitments. Wildfire data for Africa is notably higher than that of other continents, accounting for roughly 70 percent of all global wildland fires. This is followed by 21 percent in Australia and South America. At the same time, 59 percent of all fires in 2002–2019 occurred in least developed countries, suggesting an association between fire risk, lower income and resource management contexts. Tackling the underlying causes of fires using risk reduction actions can help avoid considerable loss and damage.

Forest damage by invasive species can be economically catastrophic, but determining the thresholds beyond which a tolerable presence of pests transitions into an infestation poses a significant challenge. Current reporting of pest and disease damage is based on land area of damage, volume of tree mortality, or economic impacts — there is no harmonized system for reporting impacts. Overall, data on insect pest and disease outbreaks is limited, especially in developing countries. In high-income countries, reported losses are significant and some studies conclude that the net value of economic impacts associated with pests in New Zealand would be NZD 3.8 billion to NZD 20.3 billion when projected to 2070. Damage by invasive species is estimated to cost the United Kingdom of Great Britain and Northern Ireland's economy more than USD 2.2 billion per year.

Assessing the impact of disasters on forests requires a diverse range of data and indicators, including measurement of direct impacts on productive assets, the consequences on wood production, and the implementation of standardized methodologies for assessing impacts on ecosystem services. An important aspect of assessing timber losses after large-scale disasters in the forestry sector is that a significant portion of damaged timber can usually be salvaged. The number of trees destroyed after a disaster does not automatically result in a drop in timber production. Rather, an increase in timber sales is observed in the immediate aftermath of the event as more timber is put on the market than usual.

FAO has been promoting a specific methodology for data collection and for calculating losses and damages to improve and standardize the estimation of forestry losses from disasters. It offers an assessment of forest resources that differentiates between the value of mature merchantable timber stands (stumpage) and timber stands that have not yet reached their rotation ages at the time of damage.

Wild capture and aquaculture fisheries are vulnerable to multiple sudden and slow onset disasters, including storms, tsunamis, floods, droughts, heatwaves, ocean warming, acidification, deoxygenation, disruption to precipitation and freshwater availability, and salt intrusion in coastal areas. A key ecosystem risk driver for capture fisheries is the increasing intensity and frequency of marine heatwaves, which threaten marine biodiversity and ecosystems, make extreme weather more likely, and negatively impact fisheries and aquaculture. In aquaculture, short-term impacts can include losses of production and infrastructure, increased risks of diseases, parasites and harmful algal blooms (HABs).

Extreme events and climate change directly affect the distribution, abundance and health of wild fish, and the viability of aquaculture processes and stocks. Climate change, variability and extreme weather events are compounding threats to the sustainability of capture fisheries and aquaculture development in marine and freshwater environments. At the same time, the rapid restoration of capture fisheries activities after a disaster can provide nutritious food and employment and can expedite a community's return to normal economic activity.

HABs occur when algae – simple photosynthetic organisms that live in the sea and freshwater – grow out of control, producing toxic or harmful effects on people, fish, shellfish, marine mammals and birds. In March 2021, for instance, South Africa's west coast experienced a 500 tonne "walk out" of west coast rock lobster. Similarly, in needs assessment reports for three typhoons that hit the Philippines in the last five years – Typhoon Kammuri (Tisoy), 2019, Typhoon Goni, 2020, Typhoon Rai (Odette), 2021 – the necessity to better highlight the impacts on the fishing and aquaculture communities is well reflected, including sector specific needs and priorities. One more telling example is that of the Hunga Tonga–Hunga Ha'apai (HT–HH) undersea volcano in Tonga, which erupted on 15 January 2022. The initial disaster assessment report produced in February 2022 by the Ministry of Fisheries in Tonga focused on damage to fisheries assets covering small-scale, tuna and snapper vessels, and their engines and gear. The total estimated damage in the fisheries and aquaculture subsector was USD 4.6 million.

DISASTER RISK DRIVERS AND CASCADING IMPACTS

Risk is omnipresent, and it is growing at a rate that is outstripping our efforts to reduce it. Global risks like climate change, environmental degradation and biodiversity loss are existential in nature and contribute to increasing disaster risk. Beyond the direct impact of disasters, indirect, cascading impacts are also significant, even at the global level. Addressing risk does not just require an assessment of the direct impacts of disasters, but also an understanding of how the impacts of disasters cascade within and across sectors and over geographic areas, the way in which elements of affected systems interact with each other during a hazard event, and the systemic factors driving risks. **Part 3** of the report highlights climate change, the impacts of biological hazards – the COVID-19 pandemic and the African swine fever (ASF) epidemic – and the role of armed conflicts in driving disaster risk and causing substantial damage and loss in agriculture and agrifood systems.

Linking climate change to agricultural production loss

Climate change is contributing to a rise in hazard incidence, leading to increased vulnerability and exposure and diminishing the coping capacity of individuals and systems. Attribution science, defined as evaluating and communicating linkages associated with climate change, offers an entry point for estimating the effect of climate change on crop yields and the degree to which agricultural production is being influenced by extreme and slow onset events. The analysis evaluates how climate change affects yield levels by comparing observed records with estimated counterfactual and factual yield distributions for soy yields in Argentina, wheat yields in Kazakhstan and Morocco, and maize yields in South Africa. An important caveat concerning the results is that there is a significant degree of uncertainty involved in the estimation of such attributions, and although no uncertainty quantification was attempted for this assessment, all results should be treated as approximations.

In Argentina, the model shows that observed variations in high and low temperatures, rainfall intensity and drought explain the higher share of the recorded soy yield variations in the highest-producing provinces of the country. Results suggest that climate change increased average yields during the period of 2000–2019 by less than 0.1 t/ha, amounting to about 3 percent of the average observed yield during that period. Results also indicate that yield anomalies in Argentina that are as low or lower than those in 2018 may have become about half as likely due to climate change, subject to uncertainty. Note, however, that the yield model only captures some of the recorded yield anomaly.

In Kazakhstan, results show that a substantial share of recorded wheat yield variations in the highest-producing oblast[a] can be explained by variations in growing degree days,[b] temperature variability, cold, precipitation variability and drought. In this case, climate change decreased average yields during the period of 2000–2019 by about 0.1 t/ha, which is more than 10 percent of the average observed yield during that period.

The model shows that a significant portion of the recorded wheat yield variability in the highest-producing regions of Morocco can be explained by fluctuations in temperature variability, high temperatures, drought and high precipitation. It suggests that climate change decreased average yields during the period of 2000–2019 by less than 0.1 t/ha and amounted to about 2 percent of the average observed yield during that period.

For South Africa, the model shows that a large share of the recorded maize yield variations in the highest-producing provinces can be explained by variations in growing degree days, temperature variability, cold, drought and high precipitation. Climate change has had a statistically significant adverse effect on maize yields in South Africa. The model suggests that climate change decreased average yields during the period of 2000–2019 by more than 0.2 t/ha, amounting to more than 5 percent of the average observed yield during that period, and that the negative impact of climate change was even stronger in the lowest-yielding years. Collectively, the results suggest that climate change could already be worsening agricultural losses, underscoring the significance of investing in measures aimed at mitigating losses and damages.

a An administrative division, corresponding to a region or province.

b A measure of heat accumulation used to predict crop development rate.

Pandemic and epidemic: the COVID-19 pandemic and African swine fever (ASF)

This subsection presents and analyses the impacts of the recent COVID-19 pandemic and ASF epidemic on agriculture and food security. An initial assessment from the FAO Data In Emergency (DIEM) surveys shows that the COVID-19 pandemic disrupted food systems through labour shortages, impeding seasonal labour movements particularly for labour-intensive production systems. A cross-country analysis conducted in 11 food-insecure nations revealed that the pandemic inflicted a shock on food security and livelihoods comparable to those induced by conflicts or natural hazard induced disasters. Livestock and cash crop producers were among the most severely affected, reporting difficulties in accessing inputs, selling their products, accessing pastures due to movement restrictions and accessing international markets. Additional assessments of pandemic-related lockdowns in various countries confirmed a contraction in the supply of agricultural inputs labour shortages and reduced delivery of veterinary services.

Disruptions in transport and logistics for agricultural products led to a decrease in farm-gate prices. Meanwhile, retail prices increased, affecting farmers' incomes as the cost of living rose. Planted areas were more likely to decrease for cereal and vegetable crops compared to fruit or cash crops. This is particularly true for cash crops, as they are grown primarily for their commercial value rather than for personal consumption by the grower. When the COVID-19 pandemic restrictions were implemented during the main planting season, there was an unambiguous reduction in the area planted. Restrictions on people gathering translated into farmers reporting less or much less area planted, which increases from around 22 percent without gathering restrictions to roughly 50 percent if the gathering restrictions were very stringent. Likewise, gathering restrictions are associated with a 56 percent likelihood of farmers reporting an increase in harvest, compared to places that were not under these restrictions during harvest time. The likelihood of farmers reporting difficulty in accessing agricultural inputs also increased significantly.

In the category of transboundary animal diseases, the ASF outbreak had catastrophic impacts. Since January 2020, ASF has been reported in 35 countries across five continents, with consequences most evident in Asia. Between the first ASF outbreak in China on 3 August 2018, and 1 July 2022, a total of 218 outbreaks were reported to the World Animal Health Information System of the World Organization of Animal Health (WOAH). The culling of 1.2 million pigs as of 2019 led to heavy economic losses. By the end of 2019, the inability to meet the national demand for pork became evident as average pig and pork prices skyrocketed to 161 and 141 percent higher than pre-ASF levels, respectively.

Using findings from the OutCosT tool, it can be estimated that the cost of the ASF outbreaks in Viet Nam's Lao Cai province in 2019 was USD 8.6 million. In the Philippines, ten provinces were affected by ASF in 2019, but by the end of 2020 it had affected 32 provinces. The approximate cost of the ASF outbreaks in 2020 in the Philippines was between USD 194 million and USD 507 million.

The impact of armed conflict on agriculture

Active armed conflicts – comprising situations of civil unrest, regime change, interstate conflicts and civil war – are at their highest level since the Second World War. While the risk of armed conflict is outside the scope of the Sendai Framework for Disaster Risk Reduction 2015–2030, the interplay between conflict and disaster risk is an area that requires further examination, including its relation to damage and loss. The number of national, regional, and sectoral disaster risk reduction strategies and plans that include societal hazards is increasing. Examples include the Central African Republic's draft National Strategy, Iraq's National Disaster Risk Reduction Strategy and Afghanistan's National Strategy on Disaster Risk Reduction.

Conflicts can increase the vulnerability of a society to disasters as infrastructure is destroyed, poverty increases, and long-term investments in disaster risk reduction are no longer considered important or cannot be funded. Unsustainable agricultural practices that lead to increased disaster risk may be driven by disruption and/or loss of livelihoods due to armed conflict. Given that armed conflicts also limit access to land, spur populations to move, and disrupt access to health care and social protection systems, we need to be cognizant of their wider damage and loss implications. Also, the duration of an ongoing conflict can be extended by disaster events, including when they drive resource scarcity.

Highlighting the importance of contextual and local-level differences on how disasters can influence conflict dynamics, a comprehensive study on Africa and Asia found that local drought increased the likelihood of sustained violence for agriculturally dependent groups, as well as politically excluded groups in very poor countries. The broader geopolitical context influences the operation of agrifood systems, as this often affects how armed conflict is shaped at the local level, as well as through more macrolevel impacts on trade flows because of the interconnectivity of global trade. Agrifood systems that are repeatedly put under stress by conflict tend to become unpredictable.

Assessments of the impact of armed conflicts on agriculture include calculations of damage and destruction of equipment and infrastructure, and loss of productive assets such as livestock. However, other impacts on agriculture have longer-term consequences, including forced displacement and the availability of agricultural labour. Tools and guidance have been developed for adapting PDNAs to complex operating environments, including where armed conflict manifests. The guidance provides information on ensuring that post-disaster activities and response operations do not exacerbate conflict dynamics.

Recurrent drought, food insecurity and subsequent risk of famine have become a devastating and increasingly unsustainable cycle in Somalia in recent decades. Between the 2011 famine and the extensive drought experienced in 2016–2017, it was estimated that roughly USD 4.5 billion was expended on emergency responses aimed at saving lives. In 2017, a multisectoral damage and loss assessment conducted under the overall coordination of the United Nations Development Programme (UNDP) indicated that damage and loss in agriculture amounted to a combined total of just under USD 2 billion.

Soon after the initial uprisings in 2011, the Syrian Arab Republic was plunged into a complex set of conflicts. Five years into the crisis, FAO conducted a comprehensive damage and loss assessment. The results indicated that during the first five years of the crisis, total damage in the agricultural sector amounted to USD 16 billion. This was equivalent to one third of the Syrian Arab Republic's GDP in 2016. The largest dollar impact was in terms of losses (USD 9.21 billion), although in this case the level of damages was USD 6.83 billion.

The impact of the war in Ukraine was assessed between September and October 2022 in 22 oblasts. It showed damage and loss of the war experienced by rural households, livestock keepers, and fishers and aquaculture producers to be nearly USD 2.3 billion. On average, 25 percent of the rural population stopped or reduced agricultural production, although along the contact line more than 38 percent of respondents report stopping agricultural production. The overall effects on the aquaculture and fisheries sector in Ukraine for the first eight months of the war in 2022 accounted for damages of USD 4.97 million, and losses (changes in financial flows) of USD 16.6 million, which is 63 percent of the total annual output of the Ukrainian aquaculture sector (USD 34 million).

DISASTER RISK REDUCTION SOLUTIONS IN AGRICULTURE

This part of the report complements the previous three by focusing on the viability of investments in enhanced proactive disaster risk reduction good practices in agrifood systems and in anticipatory action to increase the resilience of livelihoods to disasters. The actions to reduce the potential impacts of disasters and underlying risks are thus analysed in terms of their benefit vis-à-vis the cost of their implementation. Several examples are offered of analysis of the benefits associated with disaster risk reduction practices and anticipatory action that can serve as blueprints for the comparative assessment of scalable investments.

Benefits from farm-level disaster risk reduction good practices

Farmers, particularly smallholders farming under rain-fed conditions, are the most vulnerable stakeholders in the agrifood systems and thus tend to bear the brunt of disaster impacts. There are multiple pathways for farmers, policy makers, and development and humanitarian actors to reduce the vulnerability of smallholders. Among those are preventative farm-level disaster risk reduction good practices and technologies. These technical solutions are scalable and tested under both hazard and non-hazard scenarios, and thus proven to help avoid or reduce agricultural production losses caused by natural or biological hazards.

For instance, in Uganda, to reduce the impact of increasing dry spells, the cultivation of high-yield and drought-tolerant banana varieties was combined with soil and water conservation practices such as mulching, trenches and the use of organic compost. The study demonstrated that in farms impacted by dry spells, the implementation of the good practice package resulted in cumulative net benefits per acre over 11 years that were approximately ten times greater than those achieved through existing local practices. The benefit–cost ratio (BCR)of good practices was 2.15, as compared to 1.16 for the existing local practices.

In the highlands of the Plurinational State of Bolivia, to reduce mortality of the llama camelids from frost, snow, heavy rains and hailstorms, good practices were experimented, entailing the building of semi-roofed livestock shelters (*corralónes*) and the deployment of veterinary pharmacies. The benefit–cost ratio of these practices resulted in 17 percent higher cumulative net benefits than that of the previous local practices over 11 years. The simulation analysis also showed that if the good practices were systematically scaled up, camelid mortality could become 12 times lower than under the previous practices.

In Pakistan, DRR good practices were tested on wheat, cotton, rice, sugar cane, and vegetable and oilseed crops, including okra and sunflower during the two main cropping seasons, namely the dry (*kharif*) season and the wet (*rabi*) season in districts of the Punjab and Sindh provinces, which are highly vulnerable to climate change and among the most vulnerable districts within the Indus Basin. Cost–benefit analyses were conducted over six seasons. Results indicate that every USD 1 invested in this good practice package will generate USD 8.18 and USD 6.78 in benefits under non-hazard and hazard conditions, respectively.

In the Philippines, green super rice (GSR) cultivation in the Bicol region was tested over three successive seasons (the 2015 dry and wet seasons, the 2016 dry season). Results showed clear economic benefits, along with an increased agricultural productivity when adopting the multistress tolerant crop variety compared to the local varieties under both hazard and non-hazard conditions. The benefit–cost ratio of adopting GSR varieties was higher than that of cultivating local varieties in both the wet and dry seasons.

To realize the full potential of the proactive risk reduction measures such as those analysed here, they must be broadly scaled up and replicated. Accordingly, this calls for actions to address challenges and barriers faced by farmers in adopting such measures, including policies that support their uptake. The integration of disaster risk reduction measures and social protection programmes can also offer important opportunities.

Return on investment of anticipatory action interventions

Anticipatory action is defined as acting ahead of predicted hazards to prevent or reduce acute humanitarian impacts before they fully unfold. The window of opportunity for anticipatory action is between an early warning trigger and the moment of impact of the hazard. A trigger system is developed and dedicated funds are pre-allocated to be quickly released when pre-agreed thresholds are reached. The trigger system is developed based on relevant forecasts (for instance, rainfall, temperature, soil moisture, vegetation condition and others in the case of climate-related hazards), along with seasonal observations and vulnerability information.

Anticipatory action is a proven cost-effective measure for mitigating the impact of disasters with significant resilience dividends. By delivering support before a crisis has occurred, efficient and timely anticipatory action can curb food insecurity, reduce humanitarian needs and ease pressure on strained humanitarian resources. Triggered by context specific early warning systems, anticipatory actions are short-term interventions that aim at protecting DRR and resilience gains from the immediate impact of forecast shocks. Results of the BCR for anticipatory action for the ten interventions analysed in this section are mostly positive, ranging from 0.46 to 7.1.

Anticipatory actions to protect livestock ahead of forecast hazards have proven particularly effective in reducing animal mortality, maintaining animal body condition and productivity, as well as the reproductive capacity of herds. Positive results were also recorded for anticipatory action interventions centred on crops. Depending on the context, these may include stress-tolerant seeds, early harvesting, plant protection from hazard-induced pests and diseases, short-cycle crop seeds and small irrigation equipment, among other interventions.

Anecdotal evidence suggests that anticipatory action interventions can also reduce existing risk, protecting livelihoods well past the effects of the initial hazard. Training conducted during anticipatory action interventions provides an opportunity to raise awareness and build skills for disaster risk reduction. Also, effective early warning systems can lead to timely interventions, and further incorporating anticipatory action within disaster risk reduction policies, plans and financial frameworks, as well as within humanitarian and development frameworks, will allow countries to strengthen resilience and reduce disaster risks.

Combining preventative control and anticipatory action – the case of desert locusts in the Horn of Africa

The desert locust upsurge that occurred in the greater Horn of Africa in 2020 and 2021 was one of the most severe crises of its kind ever recorded in the region. It was an unprecedented threat to food security and livelihoods, with the potential to cause widespread suffering, displacement and conflict. Based on previous experience of implementing the desert locust control operation in 2020–2021, a new living methodology was developed to calculate the return on investment of FAO's risk-informed intervention. Reports from the field provided details about the nature of the control operation (air and ground) as well as the ratio of hoppers to swarms. The timely and accurate early warning and forecasting information provided by FAO's Desert Locust Information Service (DLIS) throughout the upsurge allowed the risk-informed strategies to be deployed. As a result, the 2.3 million ha affected area were treated in the Horn of Africa and Yemen. The commercial value of the overall averted cereal and milk losses was estimated at USD 1.77 billion. At scale and risk-informed desert locust control interventions provide a return on investment of 1:15. This means that every USD 1 invested in the intervention averted an estimated USD 15 of losses in the greater Horn of Africa. These collective efforts by FAO and partners averted 4.5 million tonnes of crop losses, saved 900 million litres of milk production and secured food for nearly 42 million people.

It is worth recalling also that the upsurge in desert locusts was not the only disaster affecting the Horn of Africa in 2020–2021. Farmers in the Horn of Africa were already suffering from other disasters such as floods, droughts and storms, along with the COVID-19 related restrictions that limited access to agricultural inputs and decreased planted areas. Without the preventative control of a desert locust upsurge, the maize and sorghum production in 2020 and 2021 might have been even lower. This has also called for a multihazard disaster risk reduction approach to ensure that the interventions implemented on the ground address the interconnected nature of disaster risks and their cascading impacts.

The overall lesson learned is that risk-informed action in the case of the locust upsurge has limited considerably the potential negative impact of the shock on agrifood systems and the associated livelihoods. It resulted in reduced damage to crops and rangelands, reduced pesticide sprays that have negative impacts on human health and the environment, and lowered financial costs.

CONCLUSIONS

The **need for improved data and information on the impacts of disasters in agriculture is the first key theme** running across all sections of the report. Investment in enhanced data monitoring, reporting, and collection methodologies and tools is an essential first step in building national capacities to understand and reduce disaster risks in agriculture and wider agrifood systems. This report has advanced the knowledge base by providing the first ever global estimate of the impact of disasters on crops and livestock production.

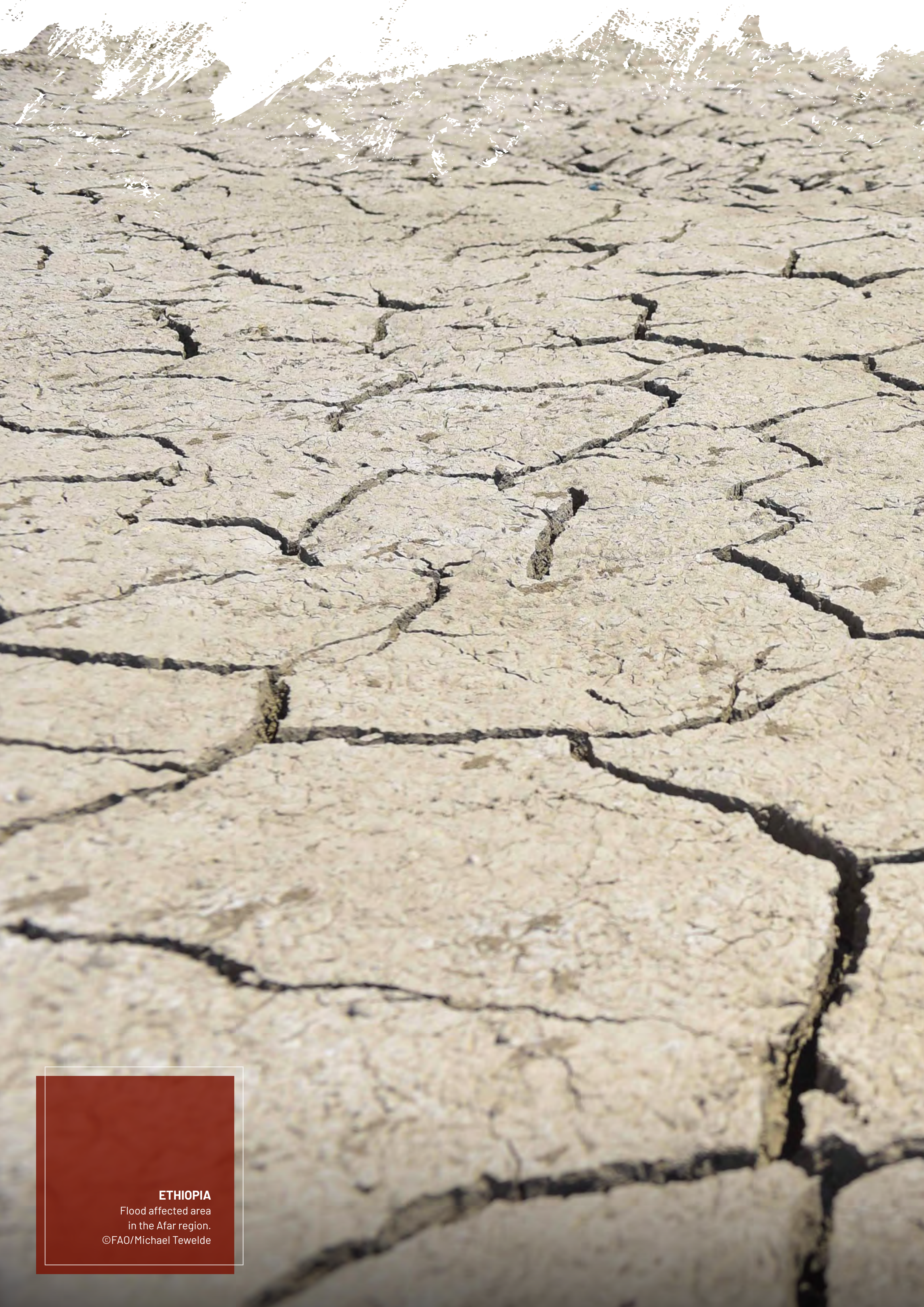
Sector-specific approaches for assessing vulnerability, evaluating impacts and reducing risks are essential. Even in subsectors with better information access, there is a need to develop standardized tools for measuring the impact of disasters to assess loss and damage, build capacity at various levels, support coordination mechanisms for prevention and response, and scale up these loss estimations to a national or global scale. In particular, the forestry and fisheries subsectors suffer from a lack of comprehensive information on their production, assets, activities and livelihoods, and are frequently overlooked in post-disaster impact evaluations and needs assessments. Emerging technologies and advances in remote sensing applications offer new avenues towards improving information on disaster impacts in agriculture. At a policy level, promoting and strengthening data reporting for the Sendai Framework C2 indicator on direct economic losses in agriculture, corresponding to indicator 1.5.2 of the United Nations Sustainable Development Goals (SDGs), will also provide a systematic and comprehensive database for disaster losses in agriculture.

A second key conclusion of this report is the **need to develop and mainstream multisectoral and multihazard disaster risk reduction approaches into policy and decision making**. Disaster impacts are worsened by multiple drivers and overlapping crises that produce cascading and compounding effects and worsen the exposure and vulnerability of people, ecosystems and economies. As described in this report, factors such as climate change, the COVID-19 pandemic, the African swine fever epidemic and armed conflicts, all result in the amplification of disaster risk and impacts in agrifood systems. In the case of climate change, the use of attribution science methodologies provides new information on the degree to which climate change is exacerbating losses in agriculture.

Effective strategies for reducing disaster and climate risk must adopt a holistic, systemwide view of the different drivers and impact pathways that produce losses in agrifood systems. This is particularly relevant in countries that have a large number of vulnerable people or communities, have less developed capacities or resources to prepare for or respond to disasters, or where fluctuations in agricultural production can easily threaten food security. Gaining a better understanding of the benefits of disaster risk reduction actions in the agriculture sector and across agrifood systems is of utmost importance. It is crucial to establish a strong evidence base for interventions and measures that can be expanded and promoted on a larger scale.

The third main conclusion of the report is the **need for investments in resilience that provide benefits in reducing disaster risk in agrifood systems** and improve agricultural production and livelihoods. Context and location specific farm-level disaster risk reduction good practices are cost effective solutions that enhance the resilience of livelihoods and agrifood systems against natural and biological hazards. The case studies presented in this part demonstrate that not only do good practices reduce disaster risks, but they also display significant additional benefits. This calls for urgent action to foster the adoption of available innovations, promoting the generation of more scalable risk management solutions, and enhancing early warning and anticipatory actions.

Though not yet comprehensive, the available evidence suggests a set of actions that can be undertaken to improve disaster impact assessments and to step up disaster risk reduction policies. National, sectoral and local disaster risk reduction strategies are a cornerstone for achieving inclusive and resilient agrifood systems, and the United Nations system can be an important collaborator in mainstreaming disaster risk reduction in national and sectoral policies, programmes and funding mechanisms. However, there is a need to expand the knowledge base of studies that can guide evidence-based policies and decision making to promote resilience in agriculture and agrifood systems at large. This is a fundamental first step for successful integration of multihazard disaster risk reduction into agricultural policies and extension services, as well as national and local disaster risk reduction strategies.



ETHIOPIA
Flood affected area
in the Afar region.
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PART 1
INTRODUCTION

In contrast to international development ambitions, 2023 came at the end of the warmest decade on record, marked by unprecedented extreme weather events and large-scale disasters whose impacts have been exacerbated by ongoing conflicts and the effects of the COVID-19 pandemic. The global community has experienced widespread human, economic and infrastructure losses, disruptions to supply chains, and the degradation of vital environmental and ecological systems in recent years. The occurrence and intensity of disaster events, defined by the United Nations General Assembly (UNGA) as "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts,"[1] is increasing and is expected to worsen as a warming planet faces up to the challenges of an uncertain risk landscape in the context of finite biological and ecological resources.

The year 2023 offers a good opportunity to assess the impact of disasters on agriculture as the international community approaches important global milestones in measuring progress towards a more sustainable future. The 2023 SDG Summit on the implementation of the 2030 Agenda for Sustainable Development and the midterm review of the Sendai Framework for Disaster Risk Reduction 2015–2030 have provided an important platform for reviewing progress made in reducing risks, building resilience and promoting a more sustainable world. Looking forward, the Global Stocktake of the Paris Agreement on Climate Change at the end of 2023 and the Summit of the Future in 2024 will present further opportunities to continue the assessment of global development gains.

According to the EM-DAT database of the Centre for Research on the Epidemiology of Disasters (CRED),[c] which contains the most extensive records of extreme events, disasters caused nearly 31 000 deaths and an estimated USD 223.8 billion in economic losses in 2022 alone, affecting more than 185 million people.[2] The frequency of disaster events has increased from 100 per year in the 1970s to around 400 events per year worldwide in the past 20 years (FIGURE 1).[d]

In general, risks affecting agriculture are omnipresent and growing at a rate that is outstripping efforts to reduce them. Increasing the resilience (broadly defined here as the ability to deal with disturbances or the effect of adverse events) and coping capacities of a community or a socioecological system requires significant changes to existing practices and improved access to and mobilization of resources. Developing better impact and risk information that is consistent and appropriately combined at all scales will allow agricultural communities at local and national scales to determine the best possible strategies for mitigating or reducing the impact of future events. Simultaneously, efforts to prevent the creation of new risks and reduce existing risks before a disaster event takes place, build capacities to cope during a disaster, and develop post-event response measures must become widespread if we are to achieve the goals of the 2030 Agenda for Sustainable Development, the Paris Agreement and the Sendai Framework. This requires a cross sectoral paradigm shift in agricultural activities, plans, policies and

c See The International Disaster Database (EM-DAT) https://public.emdat.be/

d "Other" hazard category includes biological, extraterrestrial, and complex hazards. Also, some of the increases in numbers of disasters reflect improvements in data reporting, but much of the rise can be attributed to a greater number of disasters caused by weather and climate related hazards (e.g. flood, drought and extreme temperatures). In contrast, the number of geophysical events such as earthquakes, volcanic eruptions and mass movements have stayed relatively stable over time. While the overall number of events has levelled off in recent decades, they are projected to increase as atmospheric greenhouse gases continue to accumulate.

financing to cultivate a culture of proactive prevention and risk reduction.

FAO is launching this new flagship report, *The Impact of Disasters on Agriculture and Food Security*, as part of its ongoing commitment to promote a more inclusive, resilient and sustainable future for agriculture. Building on three prior FAO publications on this topic,[e] this report aims at organizing and disseminating available knowledge on the impact of disasters on agriculture with a view to promote evidence-based investment in disaster risk reduction. It aims at demonstrating methodologies for improved data collection and research on risks affecting agriculture and the associated impacts, and directing international attention and political and economic support and commitment to disaster risk reduction.

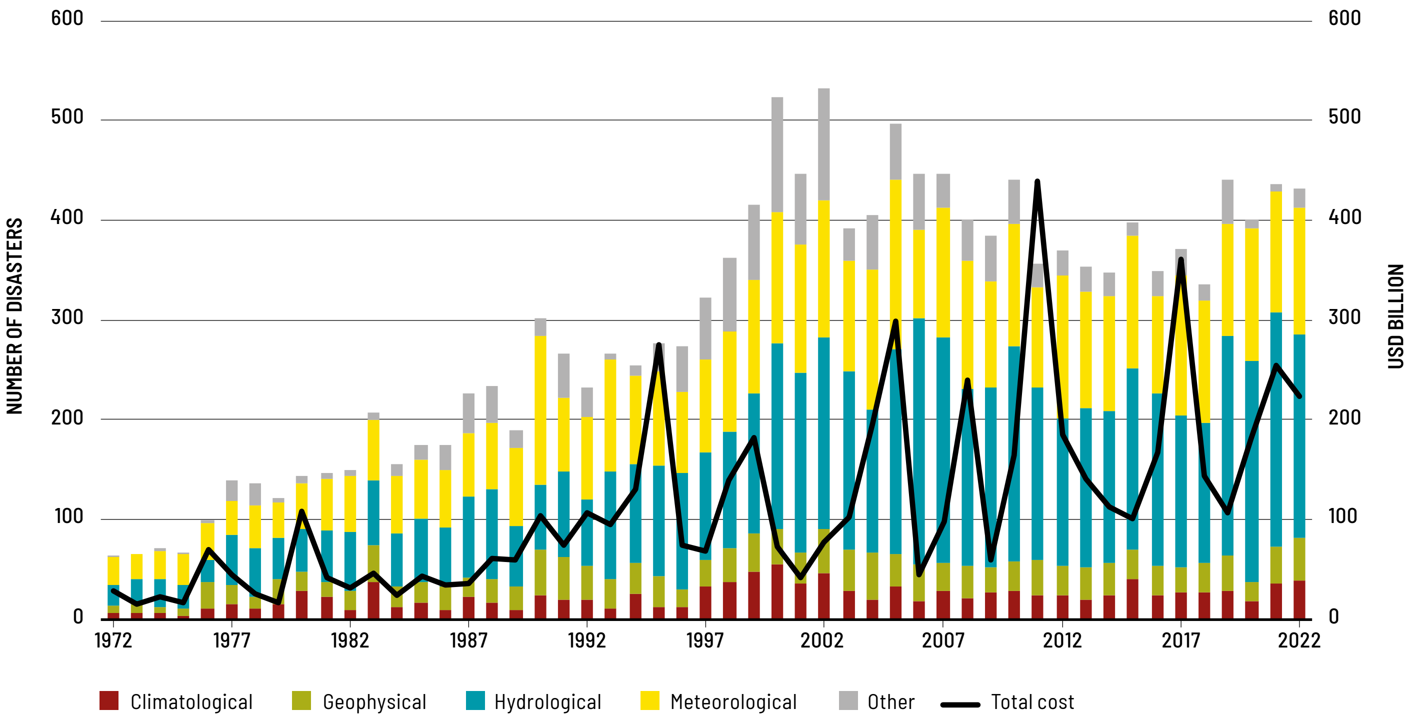
e Previous publications issued in 2015, 2017 and 2021.

Given the urgent need to understand and address the effects of disasters on agriculture, this report consolidates existing knowledge and provides new data on the subject in two main ways: first, by gathering and summarizing available evidence on the impact of disasters on agriculture using a variety of tools and approaches to unpack and quantify, where possible, the losses experienced in agriculture as a result of disasters; and second, by analysing the potential benefits of investing in disaster risk reduction solutions, such as proactive farm-level DRR good practices and anticipatory action interventions as a means of increasing the resilience of agricultural livelihoods.

The framework presented below connects the key concepts of disaster risk reduction in agriculture to the contents of the different parts of the report.

FIGURE 1

NUMBER OF DISASTERS BY EM-DAT HAZARD GROUPING AND TOTAL ECONOMIC LOSSES (1972–2022)



Source: EM-DAT. 2023. EM-DAT Public. In: *EM-DAT*. Brussels. [Cited January 2023]. https://public.emdat.be/

1.1 A CONCEPTUAL FRAMEWORK OF DISASTER RISKS AND THE ORGANIZATION OF THIS REPORT

Through the work of the Open-Ended Intergovernmental Working Group on Terminology and Indicators Related to Disaster Risk Reduction (OIEWG) established by the UNGA in A/RES/69/284, several definitions and concepts explored in this paper were elaborated. These definitions were then intergovernmentally endorsed by the UNGA in A/RES/71/276. As defined in this body of work, disaster risk is "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity."

The term hazard is used to describe "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" in a given area and over a period of time.[1] The International Science Council and UNDRR have developed an international reference set of 302 hazards clustered into eight groups: meteorological and hydrological hazards, extraterrestrial hazards, geohazards, environmental hazards, chemical hazards, biological hazards, technological hazards, and societal hazards, which can be further disaggregated or adapted to specific disaster contexts.[3] Agriculture is predominantly affected by meteorological and hydrological hazards, geohazards, environmental hazards and biological hazards, although societal hazards such as armed conflict and technological and chemical hazards can also pose potential threats (TABLE 1).

Exposure describes the "situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas".[1] In agriculture, exposed items can include crops, livestock, fisheries and aquaculture, and forestry products, as well as assets such as production and transport infrastructure, or resources such as land, water and other ecological resources that support agricultural production and the associated livelihoods. Vulnerability, however, refers to "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards".[1] This includes the economic, social and environmental characteristics inherent to the society or system that can be affected. The final dimension of the definition of disaster risk endorsed is capacity, defined as "the combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience."[1]

FIGURE 2 provides a conceptual framework for the report by describing the interplay of disaster risks in agriculture and linking it to the organization of the report and its different parts. Components of disaster risk such as vulnerability, exposure and coping capacity occur in a continuum and change over time. The amount of loss and damage produced by a disaster depends on the speed and spatial

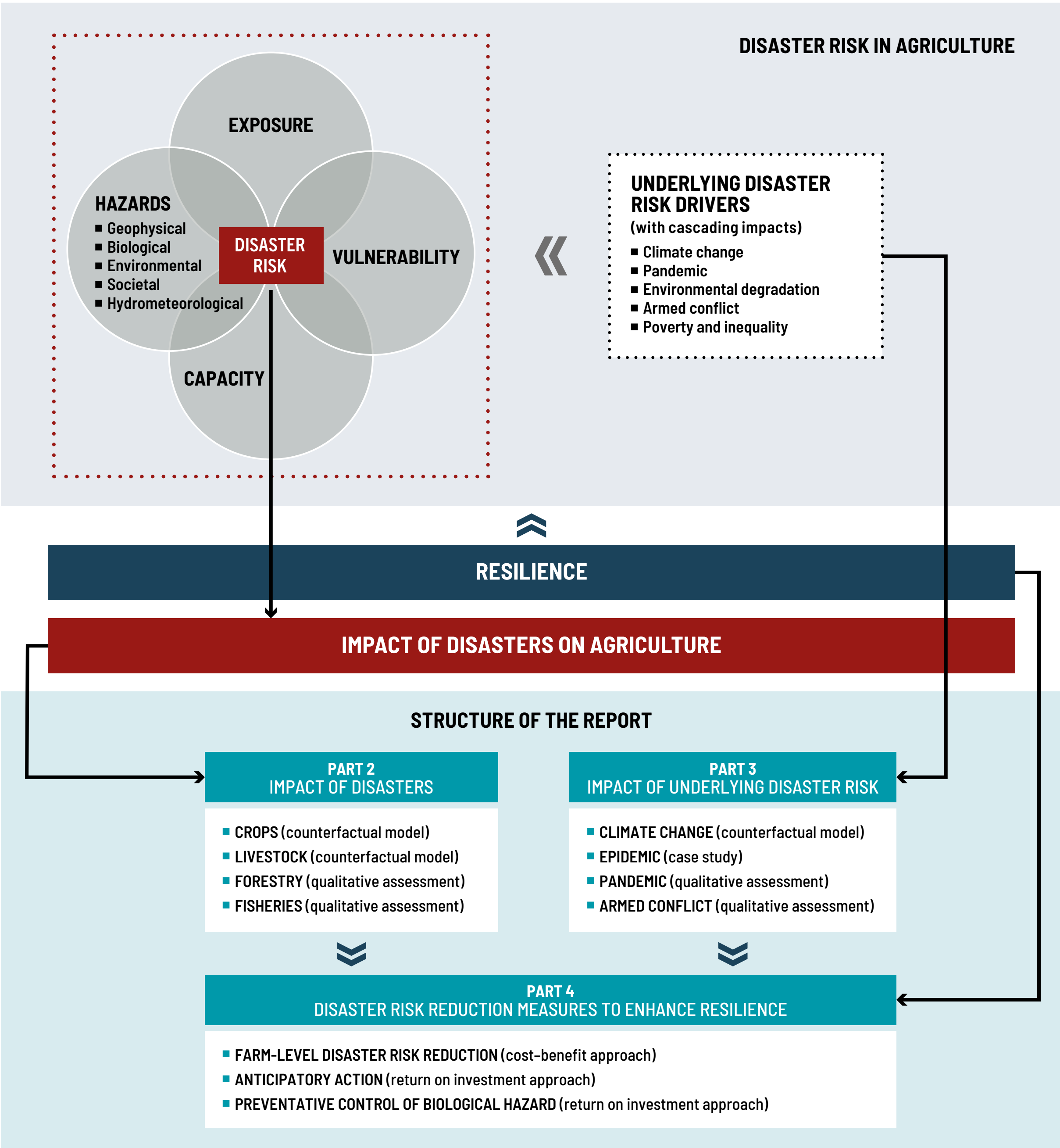
TABLE 1
HAZARD TYPES ADDRESSED IN THIS REPORT

HYDROMETEOROLOGICAL	GEOPHYSICAL	BIOLOGICAL	ENVIRONMENTAL	SOCIETAL
Flood, drought, cyclone, storms, extreme temperatures	Earthquake, volcanic activity, tsunami, landslide	Plant and animal pest and disease (African swine fever), insect infestation (desert locust, fall armyworm [FAW]), harmful algal blooms	Wildfire and forest fire	Armed conflict

Source: Authors' own elaboration.

scale at which a hazard interacts with the components of disaster risk. In agriculture, as with other sectors, both hazards and the resulting disaster event can unfold at different temporal and spatial scales. Hazards such as heatwaves, drought or pest infestations, as well as their resulting impacts, extend over longer timeframes and are commonly referred to as slow-onset events. Storms, floods, and earthquakes are sudden-onset events whose impacts are relatively restricted on a temporal and spatial scale, making it easier to measure the resulting loss and damage they produce. The initial destruction to physical or structural assets amounts to direct damage, and direct economic losses refer to the monetary value of these destroyed assets. Disasters also produce secondary or indirect losses that

FIGURE 2
CONCEPTUAL FRAMEWORK FOR THE REPORT



Source: Authors' own elaboration.

represent a decline in economic value added as a result of direct economic loss and human and environmental impacts.[4]

The dynamic interaction between hazards and other components of disaster risk is also influenced, as shown in FIGURE 2, by underlying risks drivers and shocks that have cascading impacts, affecting multiple systems and sectors within and across boundaries. These disaster risk drivers, defined as "processes or conditions, often development-related, that influence the level of disaster risk by increasing levels of exposure and vulnerability or reducing capacity"[4] include climate change, poverty and inequality, population growth, but also the occurrence of pandemics, practices such as unsustainable land use and management, armed conflicts and environmental degradation. Perhaps the most pressing risk for agriculture, which depends on climate conditions and the health of environmental and ecological resources, is the growing threat of climate change. As the process of climate change intensifies, the effects of a wider range of climate extremes will become increasingly important. Climate change causes changes in the frequency, intensity, spatial extent and duration of weather and climate related hazards.[2] According to the IPCC, high levels of vulnerability combined with more severe and frequent weather and climate extremes may result in some parts of the world becoming increasingly difficult places in which to live and grow food.[5]

Based on the interplay of risks, exposure, vulnerability, capacity and hazard described in FIGURE 2, **Part 2** of this report quantifies the impact of disasters on agriculture and its subsectors – crops, livestock, fisheries and aquaculture, and forestry.

Historical loss data are essential for quantifying and validating estimates of disaster impacts. Depending on the hazard context, assessment object or subject, needs of institutions and stakeholders, and the social, physical and temporal dimension of the impact evaluation, there are multiple approaches and methodologies that could be adopted for measuring disaster loss and damage. Above all, the availability of relevant and reliable data is the single biggest factor in determining impact evaluation approaches.

Currently, there is no specialized repository for documenting the repercussions of disasters in agrifood systems. Moreover, the data within existing international disaster databases either lack comprehensive sectoral coverage or do not provide information that can be easily disaggregated to identify and evaluate the various risks and consequences associated with agrifood systems. The complex challenge of recording disaster losses in agriculture, described in **section 2.1**, is in part due to the diversity represented within agricultural subsectors, which encompasses a diverse group of products, assets, activities and livelihoods that can be affected by multiple hazardous events. Standardizing common definitions, data indicators and measurement methodologies is imperative as part of a long-term strategy aimed at enhancing disaster risk reduction through improved information gathering.

FAO has been working towards improving coverage and standardizing data collection techniques to assess the impacts of extreme events in agriculture, and towards establishing tools and methodologies for regular monitoring and reporting at the country and subnational level.[6] It has provided support in developing a standardized methodology and definitions for the Sendai Framework for Disaster Risk Reduction's C2 indicator: Direct agricultural loss attributed to disasters (described in **section 2.2** of this report), which records data on loss and damage in agriculture and its subsectors by member states of the United Nations (corresponding to SDG indicator 1.5.2). However, data contained under the C2 indicator needs to be further strengthened as countries are lagging in data collection and reporting. In the context of insufficient data availability, evidence on the relative share of losses borne by this sector versus other productive sectors needs to be derived from alternative sources, such as post disaster needs assessments.

In the absence of data, different approaches have been proposed to be able to estimate the impact of a disaster on agriculture. One approach to estimating the global impact of disasters on agriculture is the use of probabilistic and statistical models, built upon the relationship between historical disaster events and agricultural production data. **Section 2.3** of this report undertakes such an exercise, providing the first ever assessment of global agricultural losses in crops and livestock resulting from disaster events over the past three decades. Information on hazard frequency is obtained from EM-DAT, whereas information on production, prices and area harvested are used to calculate fluctuations in yields as a reflection of exposure and vulnerability in agriculture. This analysis utilizes a counterfactual scenario to compare a world with and without disasters, revealing insights into the annual magnitude, scale, and variable loss burden experienced across different regions and hazard types.

When data production and reporting is of an advanced standard, for example in the crop and livestock subsectors, assessments can provide detailed, ground-level loss estimates for production and related agricultural activities. The assessment of crop losses due to the fall armyworm invasion in East Africa and the impact evaluation of drought on livestock in Somalia are able to drill down to a local level and employ indicators, methodologies, and approaches that are tailored to take into account the specific effects of different hazards and risks on agricultural production. They highlight how data availability affects accurate assessments of disaster impacts and propose strategies and methodologies that can be employed to address the specific needs for impact evaluations in different contexts.

In contrast, a lack of standardized indicators and data for measuring impacts in the fisheries and aquaculture and forestry subsectors restricts both micro and macro level analysis of disaster impacts. In **section 2.4**, an overview of the challenges of assessing the impacts of disasters in these two subsectors is presented. Certain hazards and disaster events highlight the limitations of data availability and underscore the significance of impact evaluation exercises for the forestry, fisheries and aquaculture sectors.

Part 3 of the report takes a more holistic approach, considering how the main underlying risk drivers – climate change, pandemics, environmental degradation and armed conflicts – impact agriculture. It builds on the analysis presented in **Part 2** by providing insights into some underlying disaster risk drivers and their cascading impacts that affect agriculture (see FIGURE 2). First, this section presents a new application of climate change impact attribution science to demonstrate the extent to which climate change is affecting crop productivity in four different country contexts. Second, case studies on the COVID-19 pandemic and African swine fever outbreaks are discussed to highlight the impact of pandemics and epidemics on the agriculture sector, including cascading impacts on global markets. Finally, this part also explores the effect of armed conflicts on agriculture and the interaction and amplification of underlying risk drivers in crisis contexts.

Finally, **Part 4** uses available evidence to analyse the benefits of preventing hazards and disaster risks from triggering full-blown disasters through the application of farm-level DRR good practices, and how mitigating disaster risks through anticipatory actions and investment in multirisk resilience can limit or reduce damages and losses in agriculture. The proactive development of disaster risk reduction measures, support for good practices and technologies at the farm level, and the adoption of increased disaster and climate finance for food insecure and vulnerable populations have demonstrable benefits for reducing the brunt of disaster impacts for both men and women. Not only do these good practices provide better economic returns, but they also produce broader socioeconomic and environmental co-benefits for strengthening rural livelihoods and increasing the resilience capacities of farmers and people engaged in agriculture. The case studies showcased in this part of the report provide examples of cost–benefit analysis of farm-level DRR good practices, technologies and risk informed anticipatory action when a hazard is forecasted, which is a proven cost-effective solution for saving lives and livelihoods. Lastly, it looks at a suite of solutions deployed to curb the spread of the desert locust outbreak and protect agricultural livelihoods in the Horn of Africa. ■

UNITED REPUBLIC OF TANZANIA
Man-made fire burning a forest. FAO is developing training modules to increase the sustainable management of forests across the world.
©FAO/Luis Tato

PART 2

IMPACT OF DISASTERS IN AGRICULTURE

KEY MESSAGES

➔ Over the last 30 years, an estimated USD 3.8 trillion worth of crops and livestock production has been lost as a result of disaster events, corresponding to an average loss of USD 123 billion per year or 5 percent of annual global agricultural GDP. This total value of losses over 30 years is approximately equivalent to Brazil's GDP in 2022.

➔ Average losses over 30 years have increased across all the main agricultural product groups, with an average of 69 million tonnes of cereals, 40 million tonnes of fruits and vegetables and 16 million tonnes of meat, dairy products and eggs lost annually due to extreme events. These amounts are significant: they correspond to little more than the entire 2021 production of cereals in France, of fruits and vegetables in Japan and Viet Nam, and of meats, dairy products and eggs in Mexico and India.

➔ Data from post disaster needs assessments shows that nearly 23 percent of total economic losses due to disasters were sustained by the agriculture sector.

➔ Lower-income and lower-middle-income countries sustained the highest losses due to extreme events, up to 10 percent of their agricultural GDP. Losses in SIDS account for about 7 percent of their agricultural GDP.

➔ Extreme temperatures, droughts, floods and storms are the leading hazards for creating losses in agriculture across the world.

➔ Agricultural production losses translate into significantly reduced nutrient availability, with a loss of dietary energy estimated at 147 kcal per person per day at the global level from 1991 to 2021. This is equivalent to the average requirement of around 400 million men or 500 million women during one year.

➔ Data for describing the impact of disasters on agriculture is partial and inconsistent, especially in the fisheries and aquaculture and forestry subsectors. There is an urgent need for improving data collection to support evidence-based policies, practices and solutions for risk reduction and resilience building in agriculture.

In the globalized context of modern societies, the impacts of extreme events are multidimensional, interconnected and cascading. Located at the intersection of human, social and environmental systems, agriculture is highly susceptible to the effects of major disruptions and shocks. To reduce the negative impact of these shocks and improve the resilience of this sector by developing and implementing risk reduction and resilience strategies, it is necessary to first identify and measure the way in which agricultural activities are impacted by disasters.

Part 2 advances the narrative on how disasters impact agriculture. The first and second section of **Part 2** outline the potential impact trajectories of extreme events on agriculture and highlight the current status of data production and collection for recording these impacts. These effects can be caused by a range of hazards and can manifest as negative physical, economic and social outcomes. These sections also outline two aspects of social impacts produced by disasters in agriculture, namely their effect on female farmers and on displacement and migration.

The third section of **Part 2** describes the results of a global assessment of historical agricultural losses, revealing the variable loss burden across years, regions and event types experienced in the two subsectors of crops and livestock over the past three decades. Losses are presented both as lost units of agricultural products (tonnes), as well as their total economic value. Production losses are then converted into nutrients and energy to highlight the lost potential for healthy diets. Boxes offer a field perspective on livestock losses after the 2016/17 drought in Somalia and the impacts of the fall armyworm infestation for crops.

The fourth section of **Part 2** zooms in on the effects of disasters experienced in the other two agricultural subsectors of fisheries and aquaculture and forestry. Detailed accounts of sector-specific hazards or impacts are presented through two assessments covering the effects of wildfires and insect infestations in forestry, and the diverse impacts in fisheries and aquaculture resulting from different disasters in three country locations. The section underscores the complexity of calculating disaster losses in fisheries and aquaculture and forestry, and provides insights into better systems for data collection and impact assessment. ■

2.1 MULTIFACETED IMPACTS OF DISASTERS IN AGRICULTURE

Agricultural activities and livelihoods – and the agrifood production systems they support – are heavily dependent on environmental conditions, natural resources and ecosystems. Climate conditions and weather-related events directly affect the sustainability of crops, livestock, fisheries and forestry.[7] Agriculture around the world is increasingly at risk of being disrupted due to multiple hazards and threats, such as flooding, water scarcity, drought, declining agricultural yields and fisheries resources, loss of biological diversities and environmental degradation. Geophysical hazards such as earthquakes, volcanic eruptions and mass movements damage infrastructure and cause widespread disruption to the services and networks (such as transport and market access) on which agriculture is reliant.

Variations in water supply and extreme temperatures are two of the biggest factors that directly and indirectly impact agricultural production. Floods and heavy precipitation can have both positive and negative impacts on agricultural systems and productivity.

For example, heavy rainfall and flooding of fields can delay spring planting, increase soil compaction, and cause crop losses due to oxygen deprivation and root diseases. Conversely, a flood can also have a positive effect on the following season's crops. In addition, intense rainfall associated with monsoons and cyclones can be of great benefit to ecosystems, helping to restore water levels in reservoirs, support seasonal agriculture and alleviate summer drought in arid areas. Nonetheless, rainfall variability is one of the leading causes of most crop losses. In Pakistan, exceptional monsoon rainfalls and subsequent flooding in 2022 caused nearly USD 4 billion in damages to the agricultural sector.[8]

The United States of America's National Oceanic and Atmospheric Administration (NOAA) estimates that over USD 21.4 billion in crop and rangeland losses were caused by major weather and climate events in the United States of America in 2022 alone.[9] Drought and wildfires accounted for over USD 20.4 billion in total crop losses, with the remaining USD 1.08 billion linked to hurricanes, hail, flooding and other severe weather events. Drought can lead to water shortages and crop failures, and it can ultimately trigger famine in vulnerable contexts. In Honduras, the combined effects of drought and the 2020 storms halved agricultural production and heightened food insecurity, forcing many to flee internally and across borders.[10,11,12]

Agricultural drought emerges from a combination of rainfall deficits (meteorological drought), soil water deficits and reduced ground water or water storage levels needed for irrigation (hydrological drought). During the growing season especially, drought can result in a lack of precipitation that affects crop production or ecosystem function. Soil moisture deficits and soil degradation impact other productive systems in addition to agriculture, particularly on other natural or managed ecosystems, including forests and rangelands. For instance, there is a strong correlation between droughts, high temperatures and the incidence of bark beetle infestations in spruce pine forests in northern Europe.[13]

Extreme temperature events also have negative consequences for agricultural production. In the livestock subsector, heat stress can affect the mortality, liveweight gain, milk yield and fertility of an animal.[14] Animal welfare may also be negatively affected by temperatures higher than an animal's thermoneutral zone, thereby increasing susceptibility to some diseases. Some breeds and species of cattle can experience thermal stress at temperatures higher than 20 °C, which has knock-on effects on the economic performance of dairy and beef production systems.[15] Many crops are particularly sensitive to extreme heat, which can reduce yields of cereal crops such as corn and increase stress on livestock. Rice yields can be reduced by up to 90 percent when night temperatures increase from 27 °C to 32 °C,[16] and temperatures above 30 °C are deemed to be harmful to maize production.[17] High temperatures during grain development of wheat can alter the protein content of the grain, and high temperatures during grain filling have been identified as one of the most important factors affecting both yield and flour quality of wheat.[18]

Extreme events after a crop is grown can also impact production. For example, wildfires destroyed more than 10 million ha in south-eastern Australia during the 2019/20 fire season, around one-quarter of which was agricultural land.[19] Moreover, frequent hot days are also likely to increase heat stress for farm workers, animals and plants. In some regions of western Europe, despite the wide application of farm technologies in large-scale agricultural production and food processing, severe drought in 2022 caused crop yields to fall by up to 45 percent, while wheat and rice yields dropped 30 percent.[20]

There is evidence to show that current warming trends around the globe are already having an impact on agriculture. Warming ocean temperatures are causing an increase in the incidence of marine heatwaves, threatening marine ecosystems and negatively impacting fisheries and aquaculture. Crop yields in some areas have already begun to decline due to warmer conditions compared to expected yields without warming. A recent study found that the severity of heatwave and drought impacts on crop production roughly tripled from 2.2 percent between 1964 and 1990, to 7.3 percent between 1991 and 2015.[21] Overall, historical droughts and heatwaves reduced European cereal yields on average by 9 percent and 7.3 percent respectively, and non-cereal yields declined by 3.8 percent and 3.1 percent during the same period. Cold waves led to cereal and non-cereal yield declines by 1.3 percent and 2.6 percent, respectively.

These increasing trends are a cause for concern. Agriculture plays a vital role in securing the availability of food for healthy diets, and is an important driver in creating employment, food security and reducing poverty. Over half of Asia's 4.75 billion population resides in rural areas and relies on agricultural activities.[27]

Similarly, the livelihoods of almost 50 percent of the population in Africa are linked to agriculture, which accounts for 35 percent of the region's GDP.[28] The potential vulnerability of this sector to disasters is alarming, especially in the context of the rising global population and increasing demand for food.

In addition to direct impacts on agricultural production and stocks, disasters affect livelihoods, food security and nutrition. They cause rural unemployment, a decline in income for farmers and agricultural workers, and reduce the availability of food in local markets. Secondary effects on food supply and nutrition, such as spiking food prices, less money to buy food through loss of livelihoods or »

BOX 1

RECENT EVENTS AFFECTING AGRICULTURE

- Tropical Cyclone Idai made landfall in Malawi, Mozambique and Zimbabwe in 2019. Labelled as the deadliest cyclone in southern Africa, the storm displaced 95 388 people, killed 598 people, and destroyed 715 000 ha of crops in Mozambique, worsening the food security situation in the country.[22]
- Over 800 000 ha were destroyed by wildfires in the European Union in the summer of 2022. The fires are estimated to have caused over EUR 2 billion in damages, affecting Portugal, Romania and Spain the worst.[23]
- The outbreak of African swine fever in China, which started in 2018, seriously affected the country's swine industry. The epidemic led to an estimated USD 111.2 billion in losses, amounting to 0.78 percent of China's GDP.[24]
- In 2022, the United States of America experienced 18 weather and climate disasters, each causing damages exceeding USD 1 billion. According to NOAA, 2022 surpassed 2021 as the third costliest year for disaster events in history, causing 470 deaths and an estimated USD 165 billion in total economic losses, of which nearly USD 22 billion were in crop losses alone.[9]
- Following heavier than average monsoon rains, Pakistan experienced one of the world's deadliest floods in 2022. Affecting over 33 million people, the floods resulted in USD 30 billion in economic losses. Agriculture, one of the hardest-hit economic sectors, suffered substantial losses in cotton, date, sugarcane and rice crops, resulting in the deaths of approximately 1.2 million livestock animals. As a result, an estimated additional 7.6 million people are facing food insecurity in the country.[25]
- Devastating earthquakes struck southern Türkiye in February 2023. The affected region, known as Türkiye's fertile crescent, accounts for nearly 15 percent of agricultural GDP and contributes to almost 20 percent of the country's agrifood exports. The earthquake severely impacted 11 key agricultural provinces, affecting 15.73 million people and more than 20 percent of the country's food production. Initial assessments by FAO indicate significant impacts on agriculture, with preliminary estimates of USD 1.3 billion in damage and USD 5.1 billion in losses to the sector.[26]

Source: Authors' own elaboration.

BOX 2

DISASTER DISPLACEMENT AND ITS EFFECTS ON AGRICULTURE AND FOOD SECURITY

Assessing the impacts of disaster-induced displacement in the agricultural sector remains challenging. Nevertheless, evidence from around the world confirms that displacement stands out as one of the most conspicuous consequences of disasters, carrying both short and long-term implications for food security and the sustainability of food systems.

Sudden-onset hazards trigger mass displacement every year, and slow-onset hazards also render entire areas unsuitable for agriculture and force communities to move. When both types of disaster combine, their impacts can be devastating, and displacement may become prolonged. The latest data from the Internal Displacement Monitoring Centre shows that disasters triggered 376 million internal displacements between 2008 and 2022 and left 8.7 million people displaced as of the end of 2022.

As rural communities are displaced, not only do they abandon their land and livelihoods, but their departure means that food production is reduced too, which has a cascading effect on the sustainability of food systems. From Colombia to Ethiopia and Somalia, floods and droughts have forced many rural communities to move, sometimes indefinitely, to urban areas. In some instances, the impacts of disasters have compounded with those brought on by conflict and violence, which means that displaced communities that rely on agricultural production and trade to sustain their livelihoods are unable to produce and sell food, while movement restrictions and other impacts of the conflict further heighten their food insecurity.

Pakistan's southern province of Sindh serves as an illustrative example of how the interplay between slow and sudden onset hazards has led to displacement, severely affecting food systems and exacerbating food insecurity. The province, which is key to the country's agricultural production, suffered severe drought in 2021 and early 2022. The situation prompted the government to issue alerts as water scarcity became a major threat to the production of crops such as cotton and wheat, undermining the livelihoods of millions of farmers.[30,31] The monsoon floods of August 2022 left 18 percent of the province under water, triggering mass displacement and severely damaging crops.[32] National losses to the agricultural sector amounted to USD 9.2 billion, 72 percent of which were recorded in Sindh.[33]

Numerous warnings about the floods potentially triggering a food crisis proved to be an accurate prediction.[34,35] Almost 6 million people faced Integrated Food Security Phase Classification (IPC) phase 3+ levels of food insecurity across Pakistan at the height of the monsoon in July and August. More than half of them were in Sindh, which together with Balochistan, were the provinces where most flood displacement was recorded.[36] The 2022 monsoon season brought record-breaking rainfall over Pakistan that triggered 8.2 million movements, making it the world's largest disaster displacement event in the last ten years.[37]

Similarly, displacement and agricultural losses have been significant in Honduras after back-to-back disasters. Hurricanes Eta and Iota triggered 918 000 internal displacements in two weeks in November 2020. Many farmers were affected, with widespread implications for the agricultural sector across 16 departments. Crops such as coffee and bananas, which account for a significant proportion of the country's exports and GDP, were damaged.[38]

Honduras sits in Central America's dry corridor and drought has also played a role in recent years in reducing harvests and undermining farmers' resilience. The combined effects of drought and the 2020 storms halved agricultural production and heightened food insecurity, forcing many to flee internally and across borders.[10,39,40]

These examples show that the impacts of disaster displacement on agriculture should not be overlooked. On the contrary, more data are needed to fully assess the scope and scale of this phenomenon, also considering how the food and agriculture sector can support durable solutions to displacement.[37]

Source: Authors' own elaboration.

BOX 3

UNVEILING GENDER VULNERABILITY: IMPACT OF DISASTERS ON FEMALE EMPLOYMENT IN AGRICULTURE IN PAKISTAN

Existing gender inequalities increase disaster risk for women in all sectors of society, and weaken the resilience of communities as a whole. It is possible to observe a differential economic impact of disasters on men and women in the agriculture sector in Pakistan.

Agriculture forms the biggest sector of Pakistan's economy. It represents 24 percent of GDP[44] and employs 37 percent of the total workforce (FIGURE 3).[45] Women represent more than 70 percent of workers in agriculture in the country. Their contribution has remained stable since the 1990s due to social, economic and cultural factors that continue to impede female employment in non-agricultural sectors. In contrast, men have transitioned to the manufacturing and service sectors to a greater degree, intensifying pre-existing gender disparities within the economy.

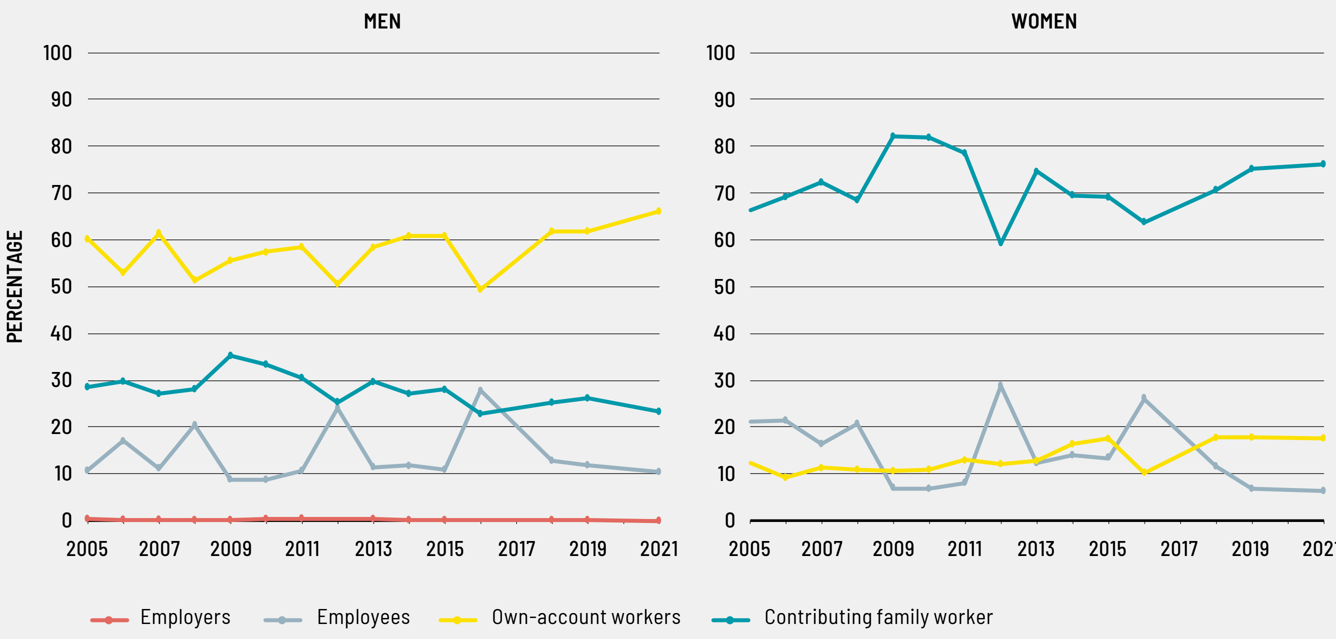
The data analysis for Pakistan suggests that floods had an impact on agricultural employment and, overall, workers experienced a reduction in paid employment in the sector after disaster events. Different coping strategies were adopted by workers to adapt to this change, with gender playing a role in the alternative employment options available (FIGURE 3). While men transitioned to operating their own enterprises or farms, women who lost their employment were more likely to work within the household without pay. This trend is evident in the aftermath of the floods in 2007, 2011, 2018 and 2019.

After a major flood event, the number of male wage workers employed in agriculture is seen to decrease as men shift to self-employed forms of agricultural activities. On the other hand, the number of females in paid work decreases and the number of women contributing to unpaid family-based agricultural activities increases. This suggests that flood damage affects the employment conditions and wage security of women more negatively than men in the long run.[46] Overall, the findings suggest that floods have a gendered impact on agricultural employment in Pakistan, where women are disproportionately affected after such disasters in terms of reduced economic opportunities and increased dependence on family-based work arrangements.

Source: Authors' own elaboration.

FIGURE 3

STATUS OF EMPLOYMENT IN AGRICULTURE FOR MEN AND WOMEN IN PAKISTAN



Source: ILO. 2023. ILO modelled estimates database. In: *ILOSTAT*. [Cited May 2023]. https://ilostat.ilo.org/data/

» destruction of assets, interrupted access to food through displacement or disrupted markets and infrastructure, disruption of social assistance programmes, and a lack of clean water and sanitation, can also reduce food access for communities directly affected by disasters. Such stresses can reduce household purchasing power, increase debt, drive up poverty and exacerbate gender inequalities. In extreme cases, they can result in the displacement and outward migration of rural populations (see BOX 2). Ultimately, the quantity and quality of food consumption is reduced, and food insecurity and malnutrition increases, especially among the most vulnerable households. In a global context, it is estimated that between 691 and 783 million people in the world faced chronic hunger in 2022 – about 735 million, considering the mid-range.[29]

These impacts are most acutely experienced at the local and household levels within disaster-affected areas, with women often bearing the brunt of the adverse effects. Although a greater number of men are employed in agriculture than women at a global scale, agriculture is the most important economic sector for female employment in low- to middle-income countries, and it generally employs a larger share of women than men.[41] Economically, disasters have varying impacts on men and women within the agricultural sector, and this discrepancy is particularly pronounced in developing countries, where female farmers often face greater vulnerability to disasters compared to their male counterparts.[42] Resource and structural constraints are the main drivers of gender disparities in disaster impacts. Women have difficulty accessing the information and resources needed to adequately prepare for, respond to and recover from a disaster – including access to early warning systems and safe shelters, as well as access to social and financial protection schemes and alternative employment (see BOX 3).

In addition to social and economic impacts, disasters cause negative consequences throughout agrifood value chains, including disruptions to the flow of agricultural inputs such as seeds and fertilizer, and downstream activities such as food processing and distribution. They disrupt food supplies, market access and trade, and can also lead to a decline in exports and revenues. This negatively impacts the balance of payments and affects long-term growth in the agricultural sector, as well as national GDP.[43]

In the context of a changing climate, the effects of extreme events on agriculture will in turn affect the sustainability of agriculture in both high- and low-income countries. In southern Australia, for example, climate change may lead to changes in land use, as crop and livestock production in arid marginal areas could become non-viable if rainfall decreases, even if yield increases due to increased CO_2 might partially offset this effect. But the impacts of increasingly frequent disasters will be even more pronounced in those low-income countries that host the highest number of vulnerable populations with limited coping capacities and limited access to resources for reducing risk and adapting to changes in climate and environmental conditions.

Small island developing countries, particularly atoll countries, will be increasingly vulnerable to climate change, with erosion, flooding, and saline intrusion already resulting in reduced agricultural productivity.[47] Some sub-Saharan African countries, already experiencing high levels of fragility and food insecurity, are also projected to undergo increased vulnerability to climate extremes.[48] Namibia, for instance, is projected to experience annual losses of 1 to 6 percent of GDP due to climate impacts on natural resources, resulting in significant economic losses in livestock, small-scale farming and fisheries. Cameroon, which is highly dependent on rain-fed agriculture, is projected to experience significant economic losses due to a 14 percent decrease in rainfall.[49] ■

2.2 TOWARDS AN ASSESSMENT OF GLOBAL AGRICULTURAL LOSSES

Understanding the extent and degree to which these weather anomalies and extreme events affect agriculture is the first step to developing disaster risk reduction and climate adaptation strategies. Although several databases record losses and damage associated with disaster events, losses occurring in agriculture and its subsectors are currently not comprehensively assessed or reported as part of total economic losses in existing global, multihazard disaster databases. Where agricultural losses are included in economic loss estimations, there is often little to no breakdown of monetary losses in relation to other economic sectors, or information on the types of agricultural losses that occurred after specific events. The impact of disasters in agriculture is rarely disaggregated down to the subnational level, and little to no information is provided on land use and total agricultural area affected.

Missing data and a lack of consistency in definitions and typologies of hazards and data indicators across these data systems is an ongoing challenge, and acts as a limitation for international repositories such as the EM-DAT,[f] DesInventar,[g] the World Bank,[h] the IFRC,[i] databases maintained by global reinsurance groups,[j] as well as national level databases.[50]

Monitoring and measuring progress towards the goals and targets of the SDGs, the Sendai Framework and the Paris Agreement will require addressing the significant data gaps at the global, regional, national and subnational levels. FAO has been working towards improving coverage and standardizing data collection techniques to assess the impacts of extreme events in agriculture, and towards establishing regular monitoring and reporting at the country and subnational levels. Currently, there are two sets of methodologies that are used to collect information on disaster losses in agriculture. The first forms part of post disaster needs assessment surveys, which are undertaken by governments and international agencies in the aftermath of disasters to assess the monetary value and replacement costs of loss and damage for all major affected sectors. The second methodology was developed by FAO in coordination with UNDRR to measure direct economic losses in agriculture attributed to disasters for indicator C2 of the Sendai Framework Monitor for Disaster Risk Reduction. Data from these two sources were utilized to estimate losses in agriculture relative to other productive sectors.

f https://www.emdat.be/

g https://www.desinventar.net/

h https://www.gfdrr.org/en/disaster-risk-analytics

i https://www.ifrc.org/document/world-disasters-report-2022

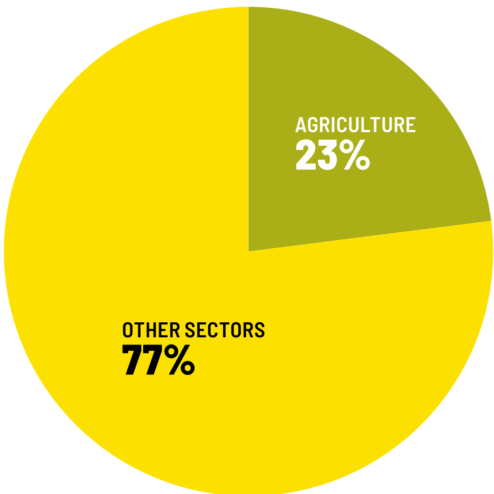
j https://www.swissre.com/institute/research/sigma-research/data-explorer.html; https://www.munichre.com/en/solutions/for-industry-clients/natcatservice.html

2.2.1
POST DISASTER NEEDS ASSESSMENTS

Post disaster needs assessment (PDNA) surveys typically include information about the impact of disasters on the productive sectors of agriculture, commerce, industry, trade, tourism and livelihoods; social sectors such as education, health, housing, culture and nutrition; and infrastructure such as transport and telecommunications, water and sanitation, and energy and electricity. The information included in PDNAs is detailed, but, at the same time, limited in scope, given that these exercises are conducted after a limited number of events and in countries with relatively less capacity to cope. As such, data derived from PDNAs must be used with caution due to their limitation.

Data are currently available from 88 PDNAs undertaken during the 2007–2022 period in 60 countries (see **Technical annex 1**). Findings show that agricultural losses made up an average of 23 percent of the total impact of disasters across all sectors (FIGURE 4).

FIGURE 4
SHARE OF SECTORAL LOSSES



Note: See **Technical annex 1**.
Source: Authors' own elaboration based on data derived from PDNAs.

The data, however, are limited by the number of available PDNAs, which were conducted only in low-income countries and after the most damaging extreme events. A more general and comprehensive estimate with a reliable quantification of the extent of global economic losses from all economic sectors is not available to date.

Data from PDNAs can also be utilized to assess the degree to which different hazards affect agriculture. However, this information needs to be considered with care as losses in agriculture can vary by the type of hazard, its magnitude, geographic location and ecosystems. The period in which a hazard hits relative to the agricultural production calendar, the type of activities taking place and other details of production processes are also important. Altogether, PDNAs show that over 65 percent of losses caused by droughts were experienced in the agriculture sector. Floods, storms, cyclones and volcanic activities account for around 20 percent each, thus underscoring the disproportionately high impact of droughts in the sector (FIGURE 5).

Although the sample size is limited, PDNAs provide information on subsectoral losses in agriculture. This information is available for 50 out of the total 80 PDNAs (FIGURE 6). Crops and livestock account for most of the losses suffered, both around 50 percent. The significantly higher share of crop and livestock loss is also due to the fact that fisheries and aquaculture and forestry do not receive enough attention in these evaluations.

2.2.2 SENDAI FRAMEWORK MONITOR INDICATOR C2

The Sendai Framework for Disaster Risk Reduction 2015–2030 was the first major agreement of the post-2015 development agenda that monitors the actions of the United Nations Member Countries to protect development gains from the risk of disasters. The overarching goal of the framework is to prevent new risks and reduce existing ones while increasing resilience. The framework is guided by four priorities for action and seven global targets, labelled A to G, to support the assessment of global progress in achieving the Sendai Framework. Following the adoption of the Sendai Framework, the United Nations General Assembly established an open-ended intergovernmental expert working group (OIEWG) aimed at developing a set of indicators to measure progress against the Sendai Framework's seven global targets, and to establish agreed terminology related to DRR.[51] The report of the OIEWG on terminology and indicators related to DRR recommended 38 indicators to evaluate progress against the seven targets of the Sendai Framework, which were subsequently endorsed by the United Nations General Assembly.[k]

Within global target C of the Sendai Framework, subindicator C2 corresponds to direct agricultural losses attributed to disasters. These include losses in crops, livestock, fisheries, apiculture, aquaculture and forest subsectors, as well as their associated facilities and infrastructure. Following a request by the United Nations General Assembly, FAO has supported the development of a methodology to measure subindicator C2. As with all other indicators of the framework, reporting is voluntary, and Member Countries can choose to adapt the recommended methodology based on national or other systems of measurement and calculation. Data are compiled in the online Sendai Framework Monitor, which allows for the inclusion of all agricultural subsectors and further disaggregation by commodity types.

Since reporting began under the Sendai Framework, 82 countries out of the 195 reporting to the Sendai Framework Monitor have reported on indicator C2 at least once. The highest number of reports by countries was in 2019 (FIGURE 7). Of these 82 countries, 38 have included subsectoral data, with 31 reporting agricultural loss by crops and 24 reporting agricultural loss by livestock. It is important to note that the decline observed in 2020 and 2021 stems from a drop in reporting by Member Countries and should not be interpreted as an actual decrease of events in 2020 and 2021. A more complete picture of agricultural losses is expected to emerge as countries scale up data reporting, including disaggregation by agricultural subsectors at the national

k See United Nations General Assembly Resolution A/RES/71/276.

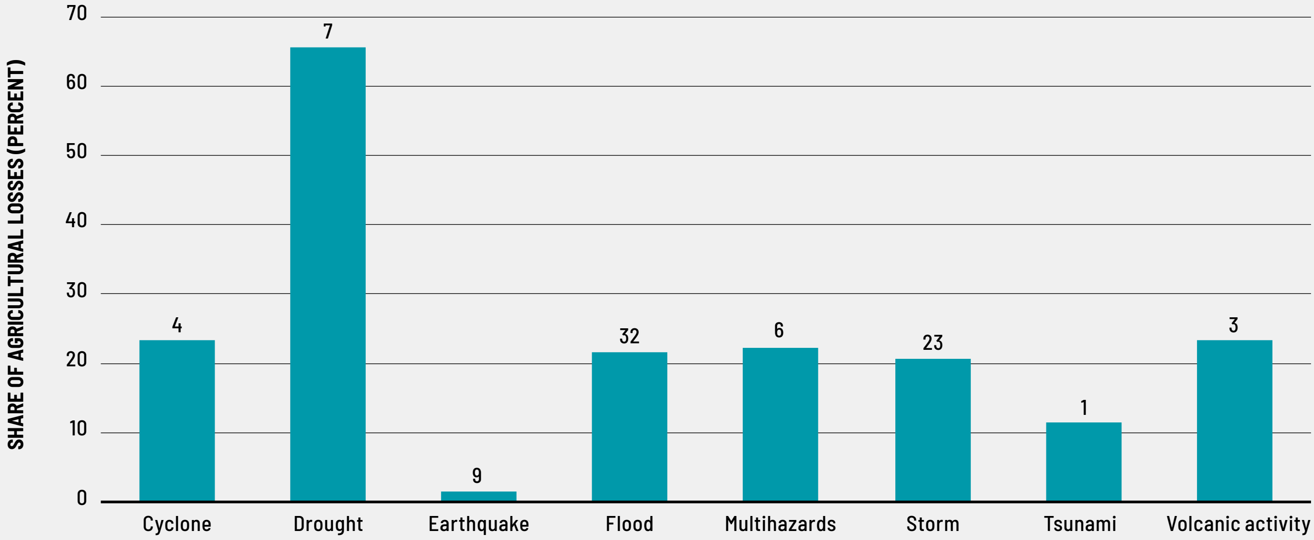
and subnational levels. Since subsector and commodity type data reporting is optional, there is still a critical information gap for understanding granular level impacts that disasters produce in agriculture, livelihoods and food security.

Total agricultural losses from disasters reported in the Sendai Framework Monitor amount to an average of USD 13 billion per year. The most prevalent disaster types as reported by 31 countries providing hazard disaggregated information on agricultural losses were floods (16 percent), fire and wildfire (13 percent) and drought (12 percent). In contrast, nearly half of all agricultural losses reported in this data subset were caused by droughts, once again underscoring the significant effect of this hazard on agriculture (FIGURE 8).

These figures are likely to be a significant underestimation of agricultural losses due to »

FIGURE 5

SHARE OF (PERCENTAGE) LOSS IN AGRICULTURE BY HAZARD TYPE



Note: Figure on top of bar corresponds to total number of events. See **Technical annex 1**.
Source: Authors' own elaboration based on data derived from PDNAs.

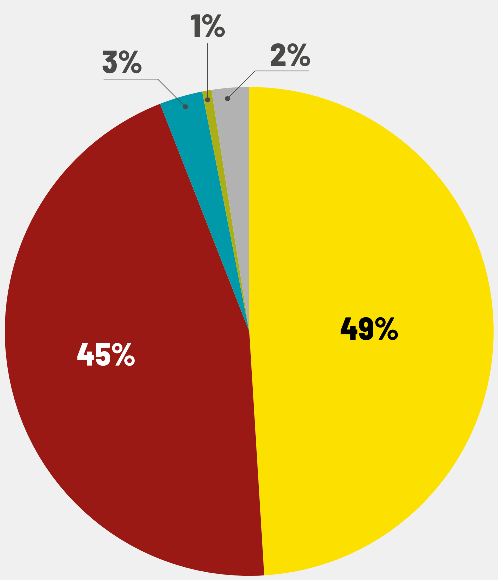


FIGURE 6

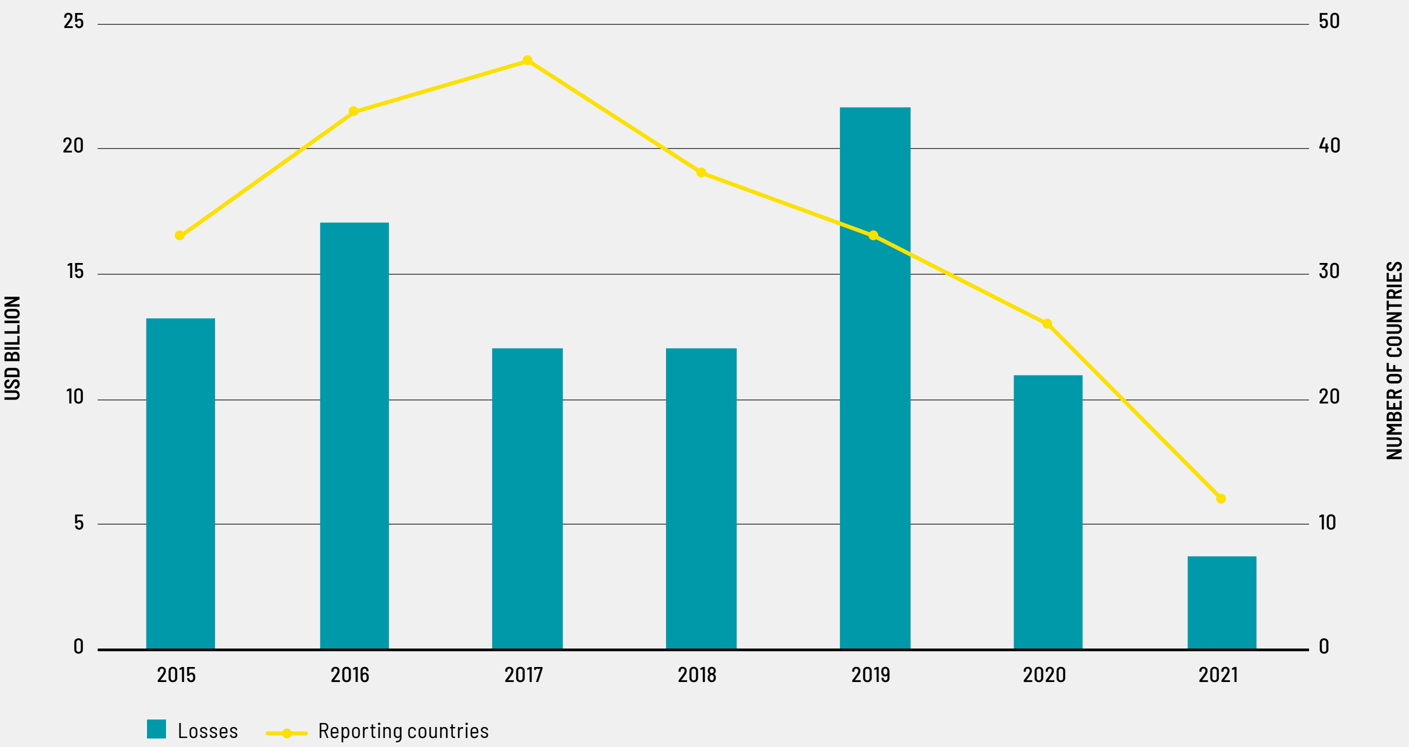
BREAKDOWN OF LOSSES IN AGRICULTURE BY SUBSECTORS (2007-2022)

Crops | Livestock | Fisheries and aquaculture | Forestry | Other

Note: See **Technical annex 1**.
Source: Authors' own elaboration based on data derived from PDNAs.

FIGURE 7

AGRICULTURAL LOSSES DECLARED UNDER SENDAI FRAMEWORK INDICATOR C2 (2015–2021)



Source: Authors' own elaboration based on UNDRR Sendai indicator C2 data.

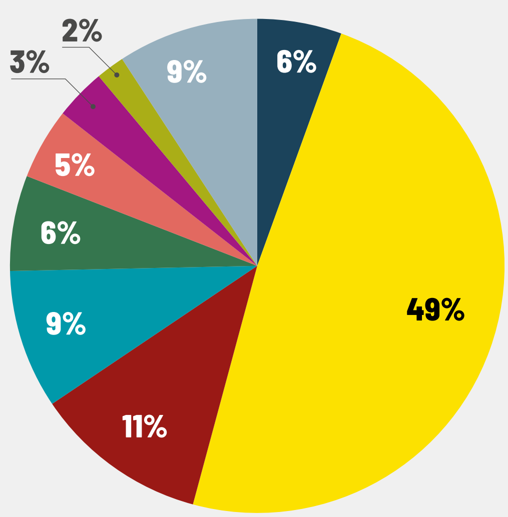


FIGURE 8

SHARE OF IMPACT BY HAZARD TYPE DECLARED UNDER SENDAI FRAMEWORK INDICATOR C2 (2015-2022)

Animal disease · Drought · Earthquake · Flood · Storm · Forest fire and wildfire · Plant disease · Locust and pest · Other

Source: Authors' own elaboration based on UNDRR Sendai indicator C2 data.

» the limited number of countries reporting and delays in reporting caused by the COVID-19 pandemic. More timely data are necessary to predict and mitigate disasters that may likely affect agriculture and determine the best risk-informed practices.

Improved information on disaster losses can enhance the understanding of how the agriculture sector is affected and to address the ways in which it is affected. It will also inform the development and adoption of policies, programmes and financial mechanisms that help protect the sector's development from shocks and crises, thus strengthening its resilience. To address the gap created by the absence of relevant and granular data to describe the precise impacts of disasters on agriculture and food security, this report adopts a macro level approach for estimating losses in agriculture using national level data on agricultural production and the occurrence of disasters. The following section outlines an innovative and novel methodology for estimating global losses in agriculture resulting from extreme events spanning from 1991 to 2021. This assessment, for the first time, provides a global overview of losses in agriculture resulting from small-, medium- and large-scale disasters in all countries of the world over the past 31 years. ■

2.3 MEASUREMENT AND EVIDENCE ON CROPS AND LIVESTOCK

Disaster risk reduction and climate change adaptation polices are key to ensuring sustainable development. However, the ability to make accurate and effective decisions requires first and foremost a reliable knowledge framework. Despite the urgent need to understand the full extent of disaster impacts on production in agriculture, data on loss and damage are not being systematically collected or reported and remain limited in scope. As a means of addressing this gap, the following sections draw on secondary data, notably EM-DAT and FAOSTAT production data, to provide a quantification of the impact of disasters on agricultural production, focused on crops and livestock production.

EM-DAT provides the most comprehensive coverage of historical disaster events, including storm, flood, drought, extreme temperature, insect infestation, wildfire, earthquake, landslide, mass movement and volcanic activity. These hazard types form the basis of the assessment.[I] Direct losses due to these disasters are estimated using agricultural production data available from FAOSTAT for 192 crops and livestock items over the period 1991–2021. National average productivity reductions by items are compared to a counterfactual scenario in which disaster events did not occur, estimated on the basis of total factor productivity (TFP) growth (see **Technical annex 2** for details). Losses are aggregated across different products using prices deflated with 2017 purchasing power parity (PPP) USD. To estimate losses associated with each hazard type, weights are calculated using the parameters of a mixed effects regression model, in the absence of reliable information on their differential potential impact.

Among the assumptions of this exercise, it is important to note that in the absence of more granular data, productivity reductions in comparison to the counterfactual are attributed to disasters. Additionally, when disasters strike, they produce negative outcomes in combination with pre-existing climate conditions, socioeconomic factors and institutional contexts. The impacts also result from, and simultaneously produce, a dynamic interaction between the subsectors of crops and livestock. For example, droughts can result in water scarcity, affecting both crop growth and livestock hydration. Floods can cause crop damage, soil erosion and destruction of livestock infrastructure. Similarly, wildfires can destroy crops, pastureland and livestock feed, posing risks to both crop production and livestock well-being.[52] However, the impact of disasters on crops and livestock production are treated as independent and instantaneous occurrences in this estimation, without considering the dynamic nature of their interdependency.

I EM-DAT also includes data on other disasters, which are not considered here. See **Technical annex 2** for details.

2.3.1 GLOBAL LOSSES IN CROPS AND LIVESTOCK PRODUCTS

Findings reveal that estimated losses in the crops and livestock subsectors of agriculture have been following a slowly increasing trend over the last three decades. When aggregating losses from extreme events that occurred worldwide over the past 31 years, the estimated total loss amounts to USD 3.8 trillion, equivalent to an annual average of approximately USD 123 billion (FIGURE 9). This value is equivalent to 5 percent of global agricultural GDP. In relative terms, the total amount of USD losses over 31 years is approximately equivalent to Brazil's GDP in 2022.

Major spikes approximately equivalent to USD 150 billion appear in the years 1993, 2002, 2004, 2010, 2012 and 2020. As the estimates presented here aggregate negative impacts from all recorded events of varying intensities, it is difficult to correlate these high losses with specific disaster events. However, correlations with certain recorded disaster events are observable. For example, spiking losses levels reflect the massive floods that affected cereals and soybean production in northern America in 1993; the large scale droughts that occurred in southern Asia and Africa in 2002; major droughts that affected China and caused extensive famine in the Sahel in 2010, at the same time as the Russian Federation experienced heatwaves; the disrupted monsoons that affected southern Asia in 2012; and the floods and cyclones that hit China and India respectively, at the same time as the record breaking Atlantic hurricane season that plagued northern America in 2020.

Aggregated global losses mask the considerable variability of impacts experienced at the national level. In this respect, the size of the standard deviation bars in FIGURE 9 makes it possible to assess the extent to which losses arose from a few localized events, or from many events taking place in several different countries. The standard deviation bars appear generally smaller in more recent years compared to the earlier periods. For instance, while the average variability around the central value was around ±35 percent in the years 1991 to 1993, that same average is down to ±17 percent in the last three years. Conversely, the years 1991 to 1993 saw on average 156 disasters reported around the world, whereas in the period of 2019 to 2021, »

BOX 4

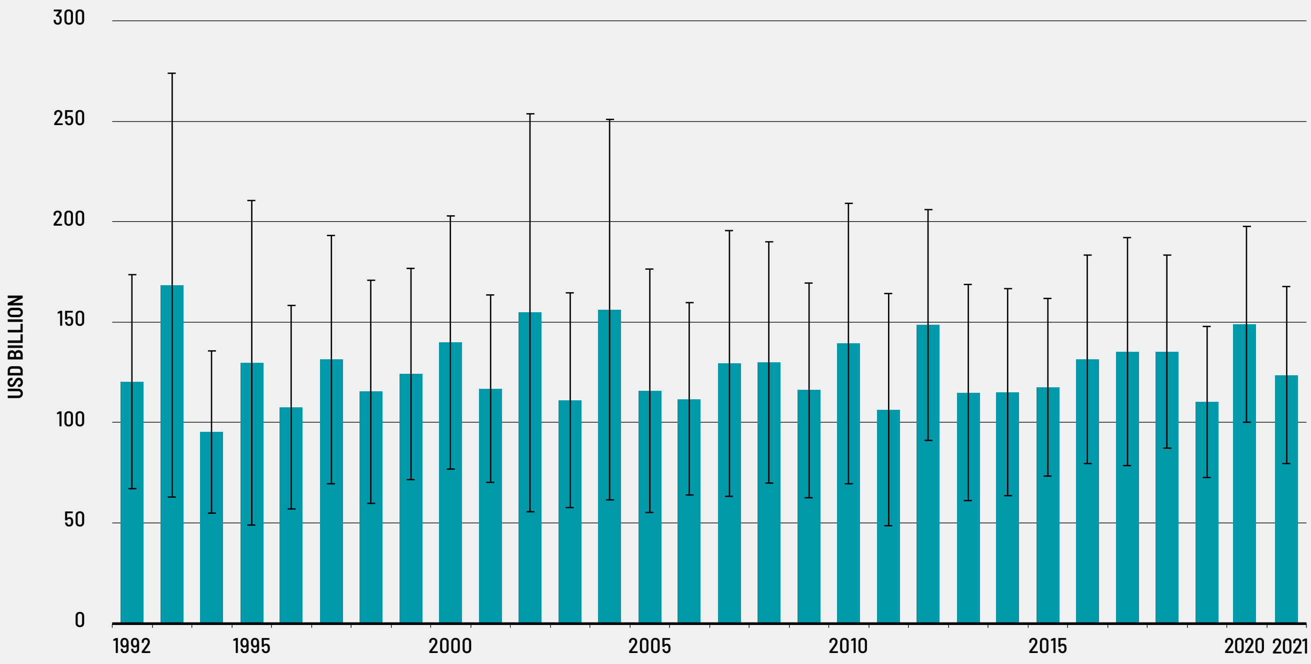
METHODOLOGY FOR ESTIMATING DISASTER-INDUCED CROP AND LIVESTOCK LOSSES AT THE GLOBAL SCALE

To estimate disaster losses in agriculture on a global scale over 1991–2021, counterfactual yields are estimated for disaster years for 186 items and 197 countries/territories (see **Technical annex 2**). The differences between the estimated counterfactual yields and the actual yields correspond to disaster-induced yield losses, after filtering by significance levels. Using the yield losses estimated for a particular item at the country level, production losses in tonnes and monetary losses in 2017 USD are calculated.

Disaster data are drawn from EM-DAT, production and prices data from FAOSTAT, and some agricultural TFP data from the United States Department of Agriculture (USDA). Three counterfactual estimation methods are used depending on the country and item time series: a structural model with Kalman Filter (58 percent), a statistical method based on TFP clustering (39 percent), and a regression method based on TFP data (3 percent). Once the differences between counterfactual yields and actual yields are imputed, the estimation is repeated 1 000 times, including random disaster events, to create a null distribution that determines significance levels and filters for significant yield losses.

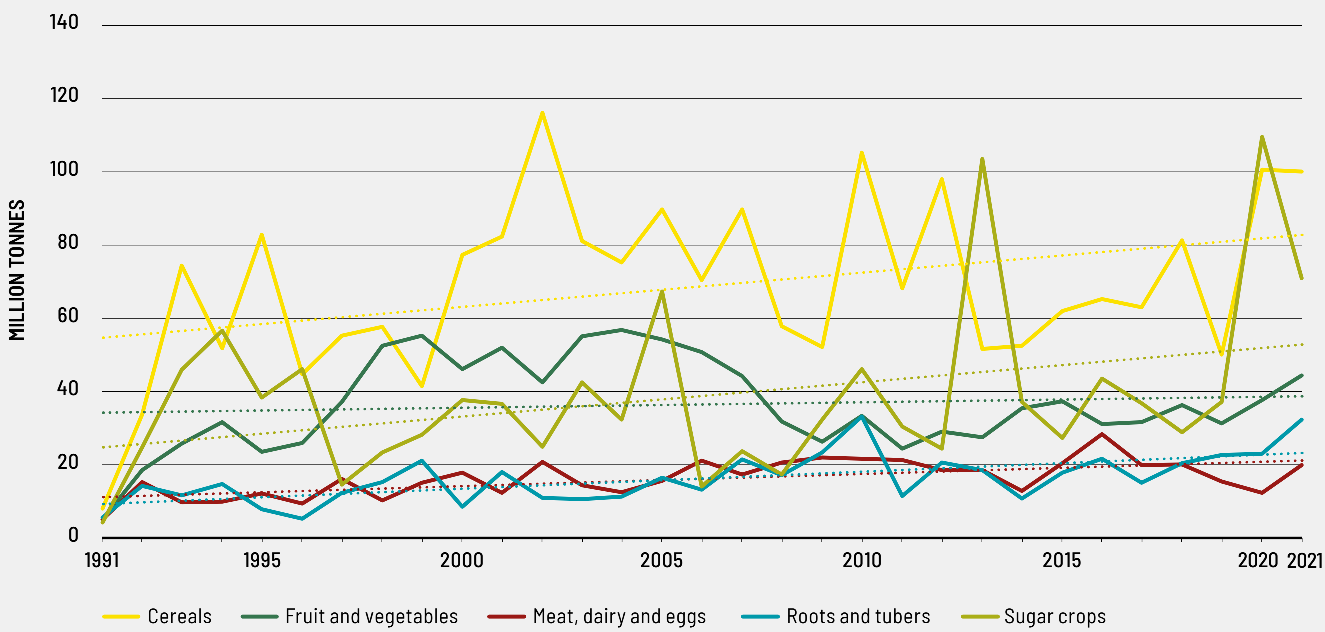
Source: Authors' own elaboration.

FIGURE 9
TOTAL ESTIMATED AGRICULTURAL PRODUCTION LOSSES



Source: Authors' own elaboration based on FAO and EM-DAT data.

FIGURE 10
ESTIMATED LOSSES IN MAIN PRODUCT GROUPS (1991–2021)



Source: Authors' own elaboration based on FAO and EM-DAT data.

» this number was as high as 397.[m] This suggests that, over time, the concentration of losses has decreased as extreme events contributing to the total estimated annual losses become progressively more widespread across countries and products. Therefore, compared to the early 1990s, while overall losses (in value terms) have increased only moderately, they have become more widespread in terms of the countries and products that they affect. The covariate nature of the extreme events that generate losses in crops and livestock around the world seems to be increasing, as is its frequency.

Losses for all major crop and livestock product groups display increasing trends (FIGURE 10). Estimated losses in cereals added up to an average of 69 million tonnes per year in the last three decades, followed by fruits and vegetables and sugar crops, which both approached an average of 40 million tonnes per year. Meats, dairy products and eggs show an average estimated loss of 16 million tonnes per year, along with roots and tubers; both these product groups present a markedly increasing trend. These amounts are significant: they correspond to little more than the entire 2021 production of cereals in France, of fruits and vegetables in Japan and Viet Nam, and of meats, dairy products and eggs in Mexico and India.

In order to estimate losses in crops and livestock relative to other sectors, we look at Post-Disaster Needs Assessment (PDNAs). As seen in **section 2.2**, agriculture appears to account for 23 percent of total economic losses, but these data are limited in providing an assessment of total losses. The World Meteorological Organization (WMO) recently published an estimate of USD 4.3 trillion in economic losses between 1970 and 2021,[53] which was computed using 3 612 hydrometeorological disaster events from EM-DAT. These events represent a small subset of disasters for which information on economic losses is available, corresponding to only 35 percent of the 10 000 plus disasters considered in the estimate of losses for crops and livestock presented in this section.

Although information on total economic losses is available in EM-DAT, the database is missing loss values for more than 40 percent of its recorded disaster events.[54] According to a joint report from the Centre for Research on the Epidemiology of Disasters (CRED) and the UNDRR, their findings indicate a significant disparity in disaster reporting. Specifically, during the period from 1998 to 2017, high-income countries reported losses in 53 percent of cases, while low-income countries only reported losses in 13 percent of disaster incidents. Notably, the report highlights that there is an absence of loss data for approximately 87 percent of disasters in low-income countries.[55] In a recent report by UNDRR, it was noted that the economic loss figures recorded in EM-DAT are prone to underestimation due to data gaps in many countries, as well as the omission of medium- and long-term economic losses from the tracking mechanism.[56]

Evidence available at country level corroborates the fact that estimates of total economic losses obtained from the EM-DAT dataset are underestimated. For instance, extreme events occurring in the United States of America produced economic losses of over USD 122 billion per year during 2018–2022, and USD 149 billion per year during 2000–2022 according to NOAA, and these figures have been increasing systematically since the 1980s.[9] Similarly, estimates of loss and damage resulting solely from the 2019 African swine fever outbreak in China range from USD 60 billion to USD 297 billion.[24]

While the absolute total of economic losses from extreme events remains unknown, the order of magnitude of the estimated losses in crops and livestock estimated here appears consistent with these examples and the amount obtained through the PDNAs, as illustrated in **section 2.2**.

Losses around the world

The estimation of global agricultural losses masks significant variability across regions, subregions and country groups. Disasters affect different regions and countries differently, both due to pre-existing social and environmental conditions and the vulnerability

m A caveat, developments in reporting mechanisms affect these figures. More events are now reported in EM-DAT, compared to the early 1990s, resulting in a slight reporting bias in the total numbers.

or resilience of agriculture and agricultural communities in dealing with disaster risk. The varying capacities for adaptation, resilience, risk reduction and recovery result in asymmetries in the degree to which a country is affected by a disaster event. While economic losses may be greater in high-income countries and regions – where agriculture produces higher-value goods and assets, and infrastructure is more widespread and developed – social consequences may be lower given the relatively higher ability of farmers and other affected stakeholders to cope with losses or obtain access to social protection. In lower-income countries, agriculture tends to be associated with lower-value commodities, assets and infrastructure, which makes the net economic value of losses relatively low. However, the ability to recover from shocks generally tends to be lower in such contexts, resulting in knock-on effects on vulnerability and disruptions to livelihoods that generate serious long-term consequences for poverty and food insecurity.

Somewhat predictably, the distribution of total losses across regions for the entire 1991–2021 period reflects the overall geographic size of the region (FIGURE 11). Asia experienced by far the largest share of total economic losses. Africa, Europe and the Americas together display a similar order of magnitude despite the large differences in land use and agricultural practices in these regions. As the smallest region, Oceania accounts for the lowest total losses.

To put these losses in perspective, it is useful to consider their value relative to total agricultural value added in each region (FIGURE 12), as losses in production have a different bearing in each region's economy, depending on the importance of the agricultural sector and relative values lost. While Asia shows the largest share of absolute global losses (45 percent), it shows the smallest share (4 percent) relative to agricultural GDP. In contrast, the total losses in Africa are about one-quarter of Asia's losses, which corresponds to nearly 8 percent of the agricultural value added, or double that of Asia. Losses in Europe and the Americas represent around 7.5 percent and around 5 percent in Oceania.

At the subregional level, the relative importance of losses in economic terms reveals an even more nuanced picture (FIGURE 13). The prominence of eastern Africa, with almost 15 percent of value added in agriculture lost due to extreme events affecting crops and livestock, relates to the disruptive power of the large-scale droughts that have occurred in the Horn of Africa during the 2010s and in more recent years.

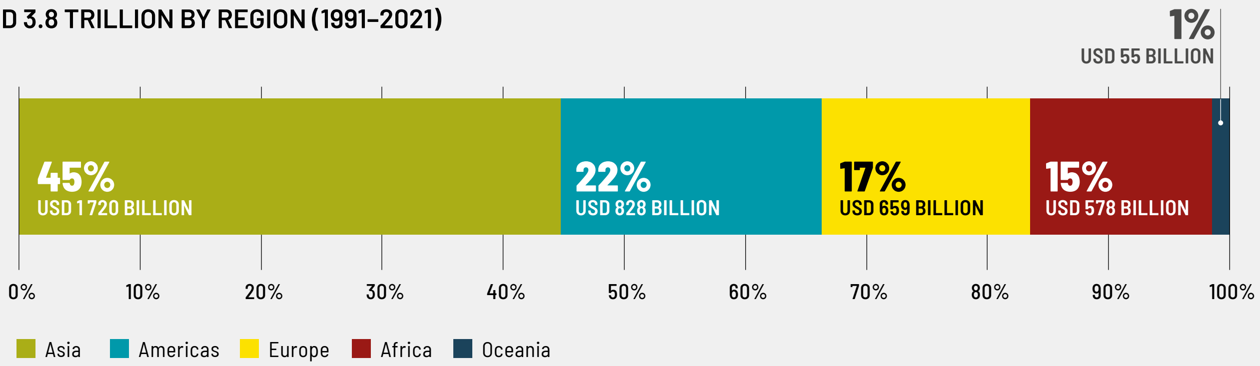
Similarly, in Latin America and the Caribbean, albeit for different reasons, losses from extreme events are substantial, with values reaching close to 10 percent. Asian subregions, on the contrary, appear to undergo significant losses that account for a smaller share of the agricultural value added, notwithstanding the significant extreme experienced, such as the several floods experienced in the southern region, or the extent of occurrences such as the outbreak of African swine fever in China. It is also noteworthy that northern America has witnessed substantial losses from floods, hurricanes and other disasters occurring over the past three decades. (FIGURE 13).

Further insights can be gained by looking beyond the regions and towards country groups defined by per capita income levels. In this report, special consideration is assigned to SIDS, which are particularly exposed and vulnerable to disruptive extreme events. As expected, in absolute terms, losses are higher in high-income countries, lower-middle-income countries and upper-middle-income countries (FIGURE 14, upper panel). On the contrary, low-income countries, and SIDS, show very low levels of absolute losses. These relative positions reflect a combination of the small physical size of the countries in each group and the low unit price of the products involved. The small physical size is the reason for the low value reported by SIDS. The low level reported by low-income countries, instead, stems mostly from low unit values of crops and livestock products.

The picture changes significantly when the distribution of losses across these groups is considered in relative terms as a share of agricultural value added (FIGURE 14, bottom panel). Expressed in this way, it becomes evident that the extent of the losses suffered »

FIGURE 11

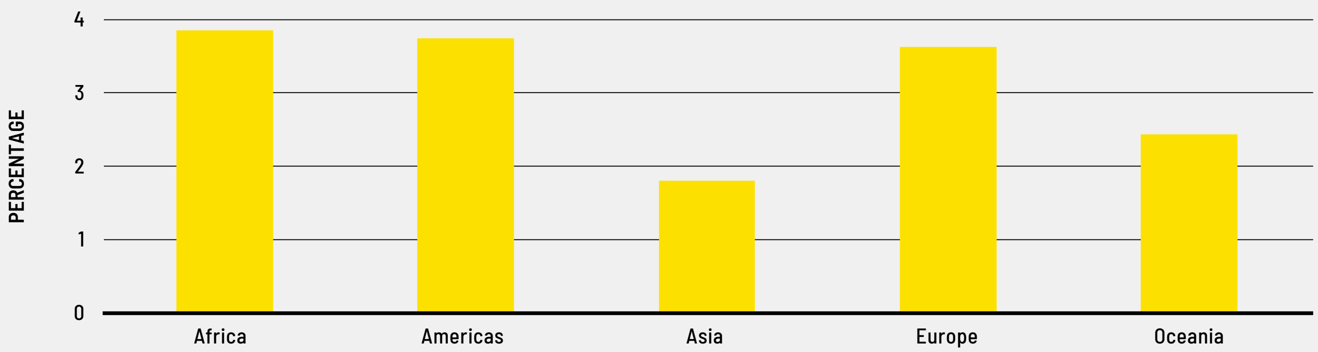
DISTRIBUTION OF TOTAL ESTIMATED LOSSES OF USD 3.8 TRILLION BY REGION (1991–2021)



Source: Authors' own elaboration based on FAO and EM-DAT data.

FIGURE 12

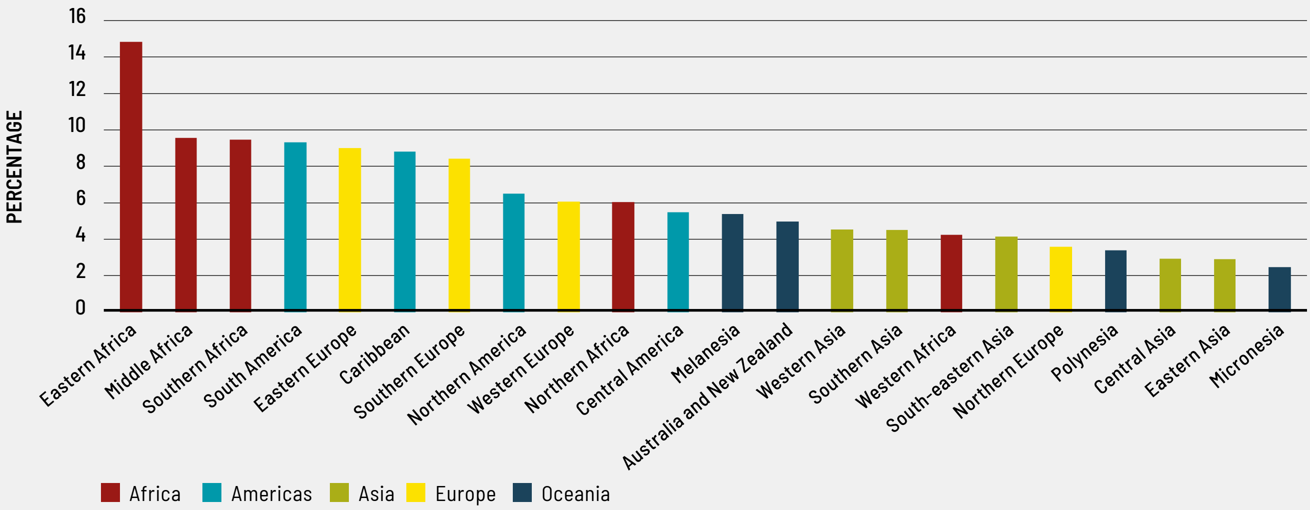
LOSSES AS SHARE OF AGRICULTURAL GROSS DOMESTIC PRODUCT (1991-2021)



Note: Loss as a share of agricultural GDP is a ratio of regional aggregate losses by regional aggregate agricultural GDP over 30 years.
Source: Authors' own elaboration based on FAO and EM-DAT data.

FIGURE 13

TOTAL AGRICULTURAL LOSSES AS A SHARE OF AGRICULTURAL GROSS DOMESTIC PRODUCT BY SUBREGION (1991-2021)



Note: Loss as a share of agricultural GDP is a ratio of subregional aggregate losses by subregional aggregate agricultural GDP over 30 years.
Source: Authors' own elaboration based on FAO and EM-DAT data.

» by low-income countries is, on average, more than double that of the losses experienced by upper-middle-income countries. Something similar can be seen in SIDS where losses are quite extensive due to the small agricultural production basis. High-income and lower-middle-income countries appear in an intermediate position, following the different combination of an extensive agricultural production basis with a significant number of extreme events recorded.

It is also worth considering losses in the crops and livestock subsectors compared to production. For each main product group, the losses estimated are reported on the amount of production estimated in the counterfactual scenario where no reported extreme event would occur (see **Technical annex 2** for details). Considering the data in this manner provides information on the lost potential production in each of the main product groups due to the occurrence of disasters, and qualifies this potential in the world regions and different economic country groupings.

The losses compared to the counterfactual production can be observed for all crops and livestock products as a whole by using prices deflated with PPP 2017 USD[n] (FIGURE 15). In these terms, results emphasize the importance of losses in several parts of Africa, primarily the eastern, northern and western parts. The impact of extreme events appears less prominent in eastern, southern and south-eastern Asia, despite their absolute magnitude. This is due to the large scale of production in these regions, which absorbs the frequent occurrence of disasters.

Notwithstanding considerable year-to-year variability, extreme events seem to cause losses ranging around 10 percent of the counterfactual production at the global level. Moreover, examining individual product groups in these physical terms provides an interesting perspective on their behaviour (FIGURE 16).[o] This is the case of most product groups, with the exception of meats, which report slightly lower shares. Losses in cereals seem to be on the rise in the past few years, while those of fruits and vegetables seem to have decreased in the last decade. Losses in roots and tubers, however, seem to have increased consistently since the mid-2010s.

Also in these terms, the global figures mask significant differences among regions and subregions. In low-income countries (FIGURE 16), estimated losses of cereals in the past three decades range between 10 and 20 percent of the counterfactual production; that is, they appear to be double those computed at the global level. In general, the variability appears to be wider for all product groups, and particularly for roots and tubers, which are food staples. In the case of the SIDS (FIGURE 16), shares of losses in the counterfactual production appear to be extremely variable as well as large. Cereal losses range up to above 20 percent in almost every other year, especially during the 1990s, but also in the following decades. Fruits and vegetables, too, display highly frequent spikes in losses.

Impact of specific hazards in agriculture

An attribution of losses to specific hazard types cannot be determined by the methodology for assessing losses described in the earlier section due the difficulty of disaggregating impacts for multiple disasters occurring in one year. Despite their limited coverage, the PDNAs reviewed in **section 2.2** provide a better source for understanding the distribution of losses in agriculture across different hazard types. Despite differences in the scope and parameters of each dataset, findings on the distribution of losses across hazard type from both the PDNAs and EM-DAT point in a similar direction.

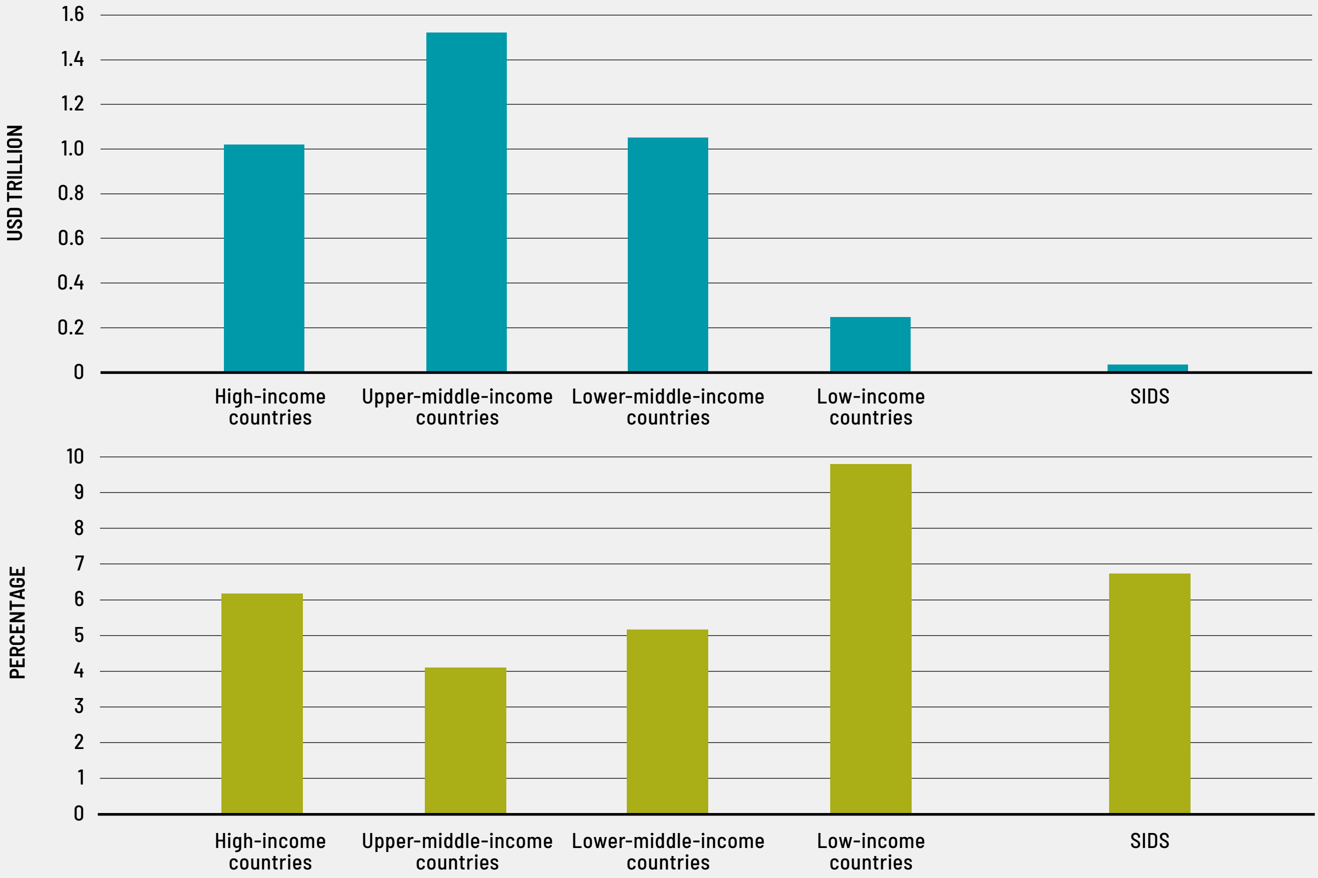
According to data reported in the PDNAs, droughts appear to be the most significant hazard type causing damage in agriculture »

n It is worth noting that, in this case, the indicator is a ratio of two sets of physical quantities (expressed in tonnes) multiplied by the same price. This means that the ratio captures exclusively a quantity effect. The only function of the price is to aggregate quantities that would otherwise not be comparable.

o In this case, ratios of losses to counterfactual production are built directly on tonnes, under the hypothesis that quantities produced are homogeneous enough to be aggregated.

FIGURE 14

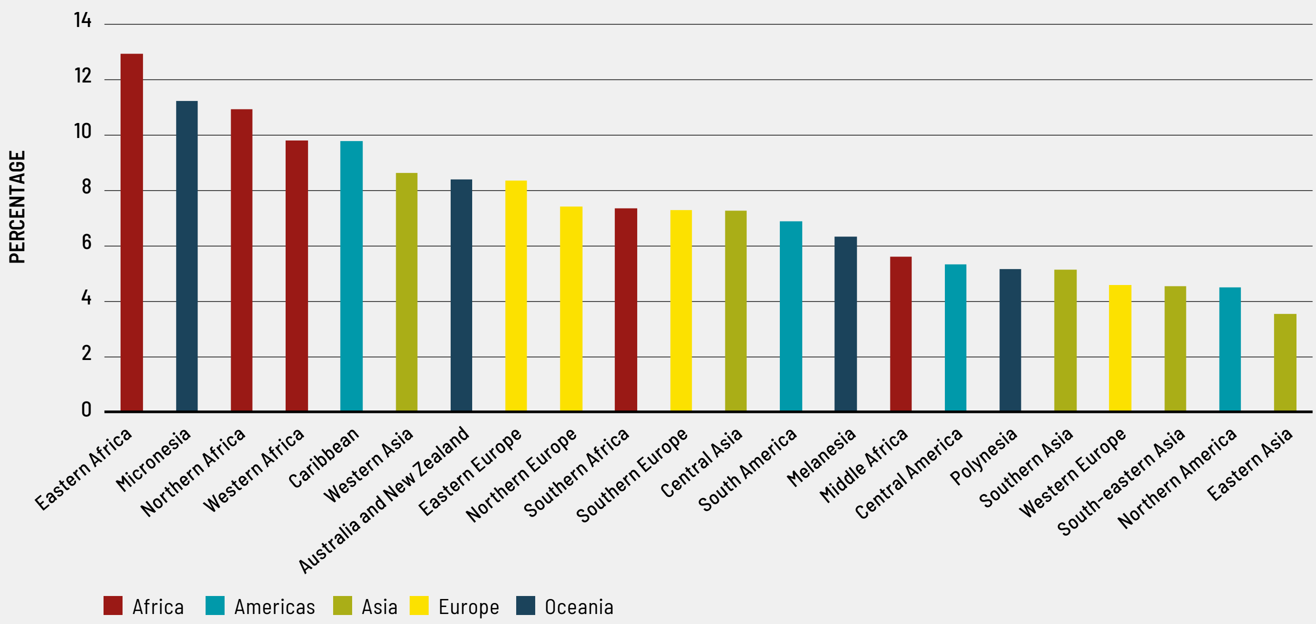
TOTAL AGRICULTURAL LOSSES (TOP) AND TOTAL AGRICULTURAL LOSSES AS A SHARE OF AGRICULTURAL GROSS DOMESTIC PRODUCT (BOTTOM) BY COUNTRY GROUPS (1991-2021)



Source: Authors' own elaboration based on FAO and EM-DAT data.

FIGURE 15

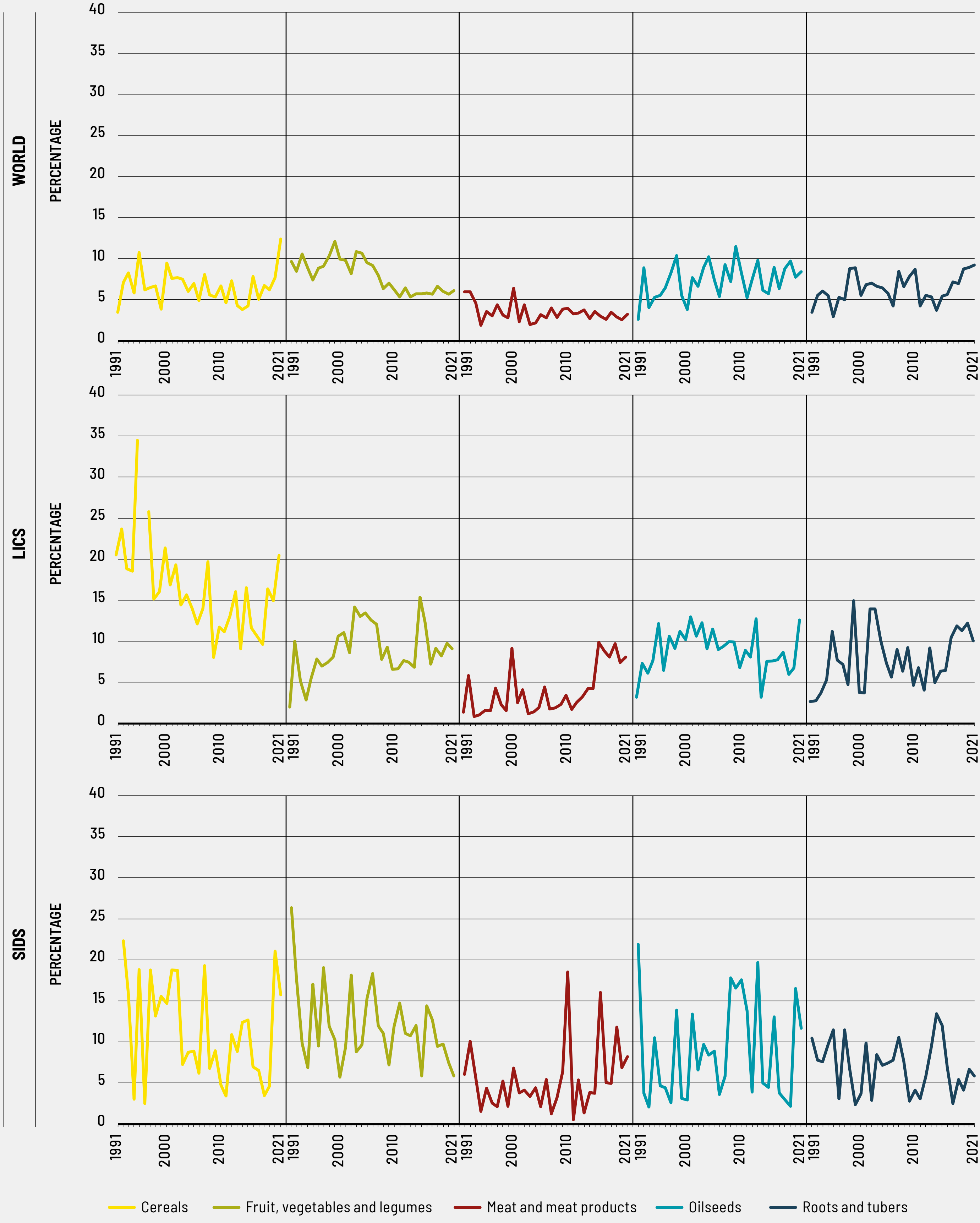
TOTAL AGRICULTURAL LOSSES AS A PERCENTAGE OF ESTIMATED COUNTERFACTUAL PRODUCTION BY SUBREGION (1991-2021)



Source: Authors' own elaboration based on FAO and EM-DAT data.

FIGURE 16

TOTAL AGRICULTURAL LOSSES AS A PERCENTAGE OF ESTIMATED COUNTERFACTUAL PRODUCTION BY COMMODITY GROUP WORLDWIDE IN LOW-INCOME COUNTRIES AND IN SMALL ISLAND DEVELOPING STATES (1991–2021)



Source: Authors' own elaboration based on FAO and EM-DAT data.

» during the 2006–2022 period, followed by cyclones and floods. While droughts constituted over 80 percent of the estimated losses in agriculture in 2017,[57] it is floods, in conjunction with storms and cyclones, that generate the most substantial losses. As the risk of climate change increases, the frequency and intensity of meteorological hazards such as floods and storms, along with drought and extreme temperatures, are expected to increase.[56,5]

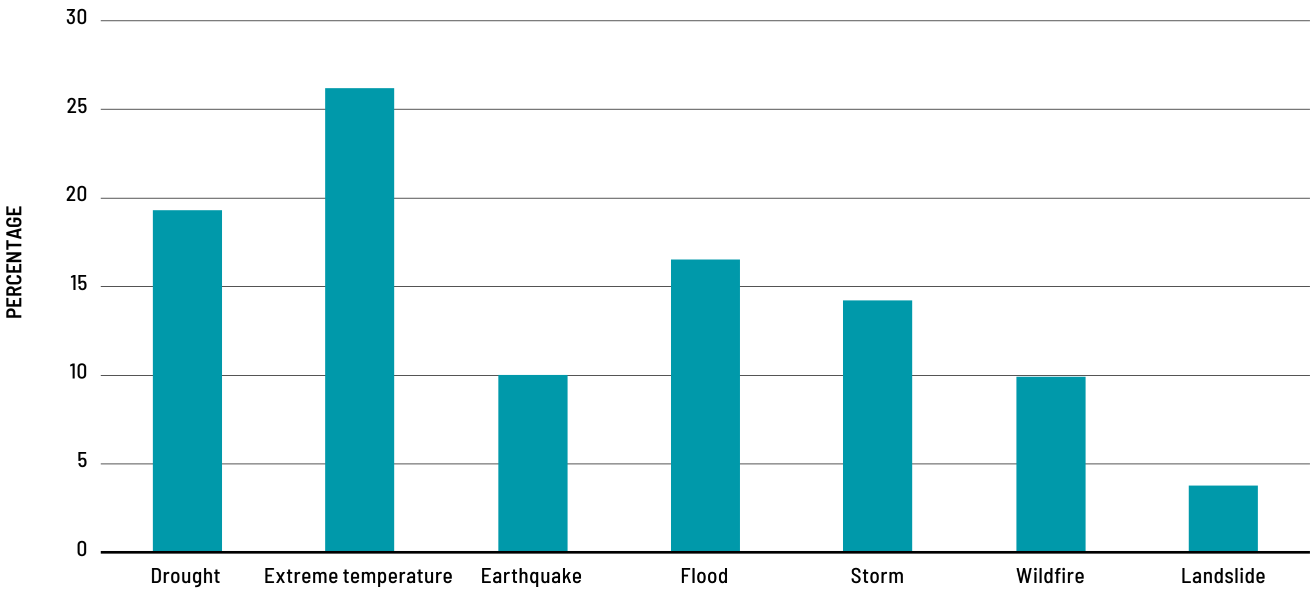
To elaborate on the degree to which different hazard types impact agriculture, a further exercise was conducted to assess the average amount of production lost for every hazard type during the 1991–2021 period. This was done by fitting a mixed effects regression model, in which losses in tonnes for a specific product in a given country during a given year were regressed against the number of events reported for each type of disaster in that same country and year. The results were estimated at a global level, and various parameters are used to compute weights and unit losses per hazard type in each region. Details of this analysis are in **Technical annex 2a**.

Results are presented as a percentage of the average total losses that each hazard type produces in agriculture (FIGURE 17). On a global scale, extreme temperatures and droughts are the hazards that exert the most significant impact per event, followed by floods, storms and wildfires.

As mentioned above, the estimates presented in this section on losses due to disasters were generated through probabilistic modelling using secondary data. In an ideal setup, this information may be collected though questionnaires, yielding harmonized information on disaster losses at the national and subnational levels. There are however some successful experiences of this type of assessments (see BOX 5 and 6). While there are no standardized protocols, the case studies presented in the following boxes are meant to provide information that can be used to develop protocols.

FIGURE 17

PRODUCTION LOSS PER EVENT BY HAZARD TYPE IN CROPS AND LIVESTOCK (1991-2021)



Source: Authors' own elaboration based on FAO data.

BOX 5

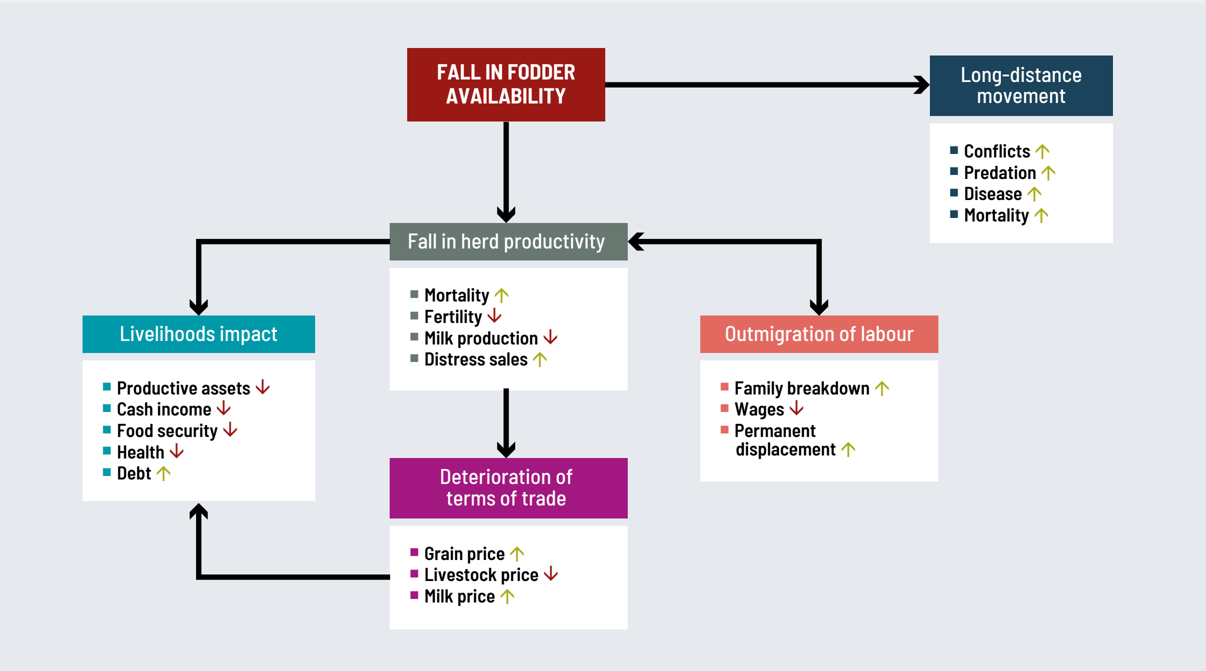
ANIMAL HEALTH: IMPACT OF THE 2016–2017 DROUGHT ON SOMALI LIVESTOCK KEEPERS

Ethiopia, Kenya and Somalia are currently grappling with severe water shortages and degraded rangelands due to below-average rainfall and high temperatures, affecting nearly 23 million people. Compounded by food inflation and other economic shocks, this situation echoes past droughts in 2011, 2016/17, and 2020/21. In Somalia, a national disaster was declared in 2017 after three consecutive seasons of insufficient rainfall. With limited precipitation, pastoralism serves as the primary land use, contributing 60 percent to GDP in 2013–2016.[58] Livestock plays a vital role, providing milk, meat, employment and livelihoods, and constituting 80 percent of export earnings. Somalia heavily relies on food aid and imports as local grain production covers only 22 percent of cereal needs on average, even in favourable years. During droughts, herders are compelled to sell livestock to afford food and care for the remaining animals, leading to a surge in livestock sales, causing price depression. To cope, some pastoralists send family members elsewhere to reduce reliance on the family herd, while others migrate to towns for income (FIGURE 18). The impact of drought varies based on wealth and resource access, often exacerbating wealth disparities, with larger herd owners more likely to maintain breeding herds, while smaller ones may struggle to survive.

In comparison to the baseline scenario without drought, the impact of drought led to a substantial reduction in livestock numbers (FIGURE 19). The pre-drought count of 52.9 million animals decreased to 36.1 million by the end of the drought year, representing a 32 percent drop. This decline affected all livestock categories, with sheep and goats experiencing over a 30 percent decrease and camels and cattle seeing reductions of under 20 percent. The decline resulted from both increased drought-induced mortality and reduced reproductive performance, particularly in small ruminants. Although 4 million animals died in the drought year, the deficit of 14.8 million births, primarily in goats (10.5 million) and sheep (4 million), was more significant. In contrast, excess mortality was the main factor behind the decline in camel and cattle numbers during the drought year, with reduced fertility rates mainly evident in the post-drought year. The combined effect of excess deaths and birth deficits (18.8 million animals) was exacerbated by an estimated reduction in

FIGURE 18

DROUGHT IMPACT ON LIVESTOCK KEEPERS



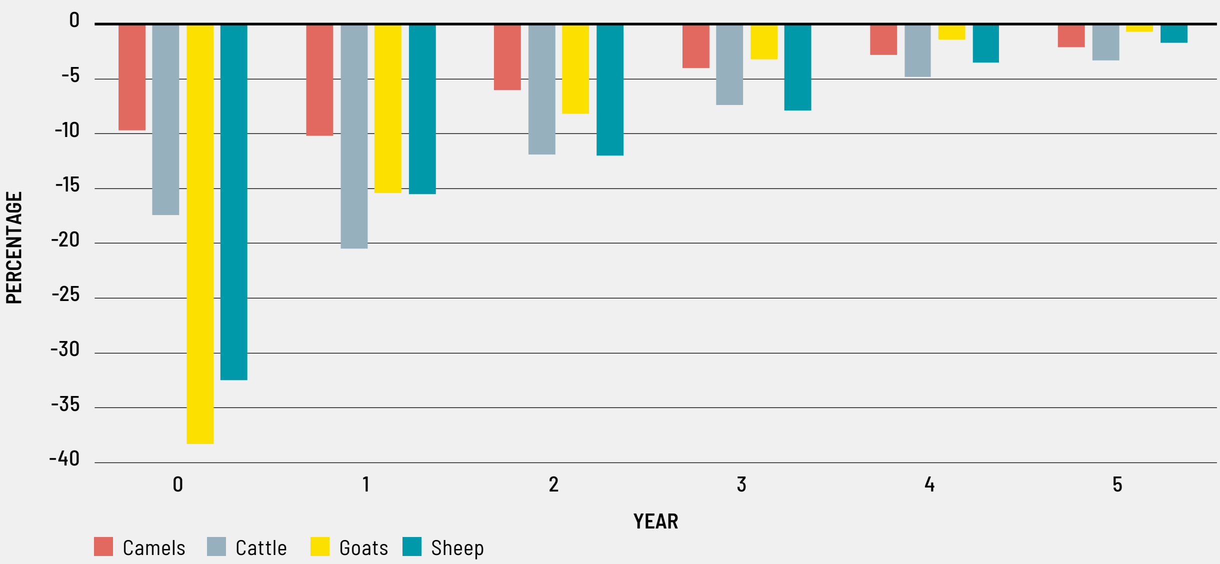
Source: Adapted from Toulmin, C. 1985. *Livestock losses and post-drought rehabilitation in sub-Saharan Africa*. Livestock Policy Unit Working Paper. 9. International Livestock Centre for Africa. https://cgspace.cgiar.org/handle/10568/4452

BOX 5
(CONTINUED)

animal offtake of about 2 million heads. None of the four species fully recovered to pre-drought numbers within the modelled timeframe, with cattle numbers remaining 0.1 million heads (3 percent) below the baseline.

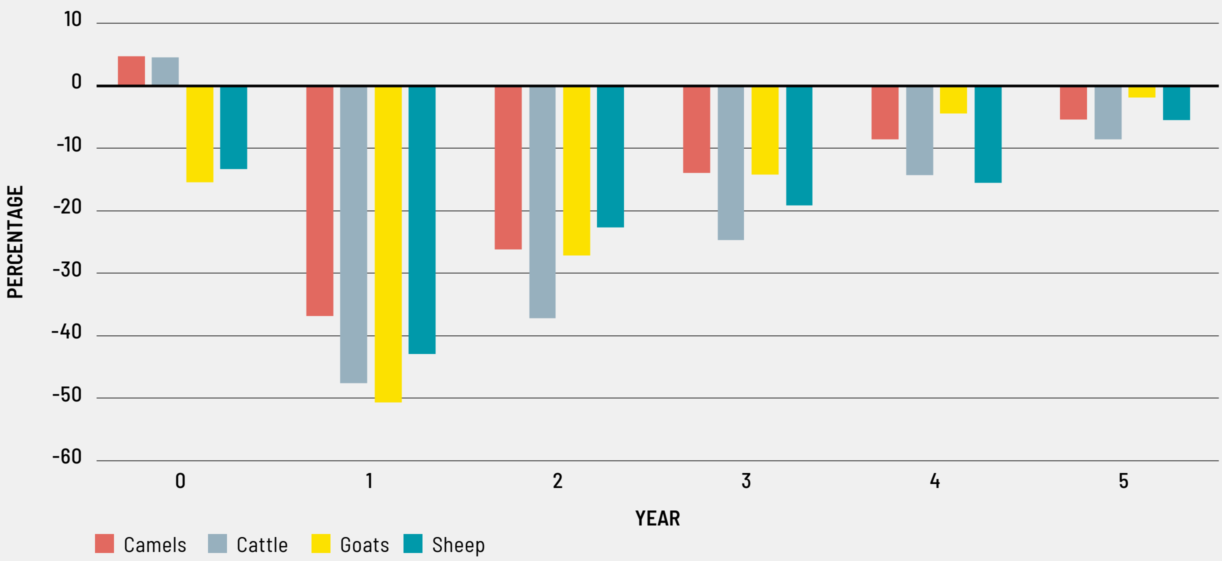
In the post-drought year, live animal offtake dropped significantly to 8.2 million heads from 15.7 million heads in the pre-drought year (FIGURE 20). This sharp decline is mainly due to the previous year's birth deficit among

FIGURE 19
RELATIVE DIFFERENCE IN LIVESTOCK POPULATION COMPARED TO PRE-DROUGHT YEAR



Source: Authors' own elaboration based on FAO data.

FIGURE 20
RELATIVE DIFFERENCE IN LIVESTOCK OFFTAKE COMPARED TO PRE-DROUGHT YEAR



Source: Authors' own elaboration based on FAO data.

BOX 5
(CONTINUED)

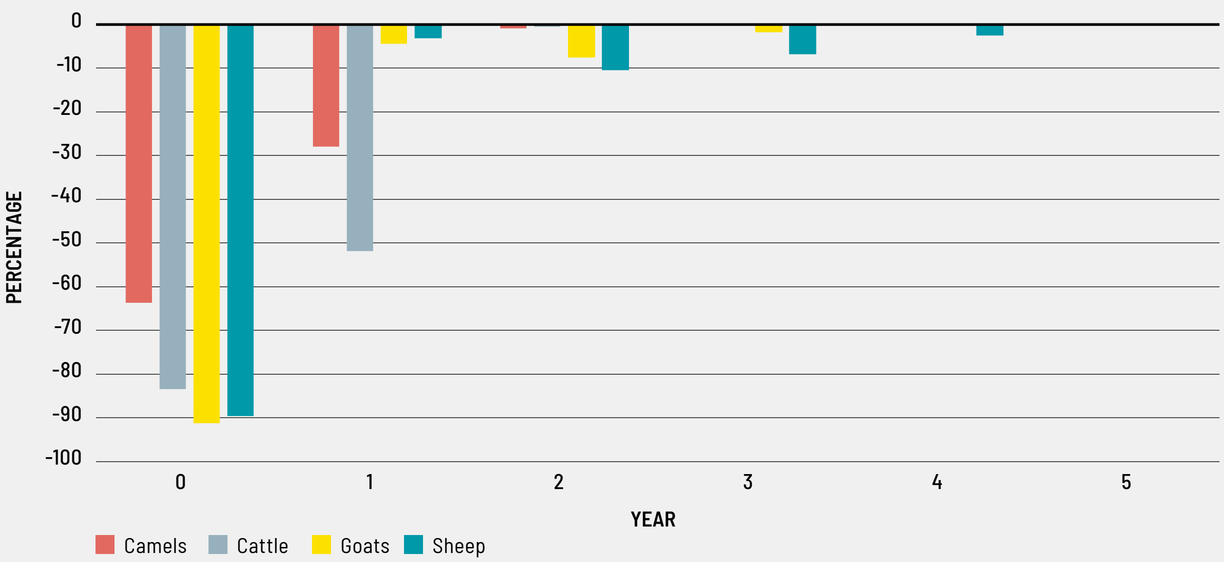
small ruminants. Camels and cattle also saw notable reductions in offtake, primarily driven by increased mortality during the drought year. Efforts to rebuild herds further contributed to the decreased offtake. As livestock populations have not fully recovered to pre-drought levels even after five years, animal offtake is expected to remain slightly below pre-drought levels.

During the drought year, milk offtake plunges by roughly 1.75 million tonnes, a 75 percent decrease compared to the 2.4 million tonnes in the pre-drought year (FIGURE 21). In the post-drought year, milk offtake remains at around 1.7 million tonnes, 30 percent below pre-drought levels. Small ruminants' milk production bounces back due to improved feed availability, while cattle and camels continue to have milk deficits due to reduced calving rates. Despite drought-tolerant camels forming a significant part of Somalia's milking herd, milk losses make up nearly 90 percent of lost income in the drought year. In the post-drought year, most losses stem from reduced live animal offtake, driven by the sharp decline in small ruminants' birth rate during the drought year and the need to rebuild herds. Rebuilding takes time, and even five years after a drought, livestock numbers remain nearly 5 percent below the baseline.

In FIGURE 22, rural market prices and terms of trade for local-quality grain, goat and camel milk are depicted in the pre-drought, drought and post-drought years, illustrating drought-induced price fluctuations. According to the Food Security and Nutrition Analysis Unit (FSNAU), live cattle prices did not significantly decrease in the drought year, while prices for camels, goats and sheep dropped by 10 to 15 percent. Conversely, milk prices saw a 20 to 25 percent increase in the drought year. Small ruminant prices rebounded in the post-drought year, rising over 10 percent above the baseline, while camel and cattle prices remained stable. The rise in small ruminant prices after a drought is due to their demand as "seed" animals for herd repopulation and their affordability for average consumers. Despite milk production more than doubling in the post-drought year, milk prices still experienced a slight increase.

Fluctuations in the terms of trade of livestock compared to grain were more pronounced than the changes in livestock prices – the amount of grain exchanged for livestock decreased by 20 to 40 percent or more in the drought year and increased by 15 to 20 percent for goats and sheep in the post-drought year.

FIGURE 21
RELATIVE DIFFERENCE IN MILK OFFTAKE COMPARED TO PRE-DROUGHT YEAR



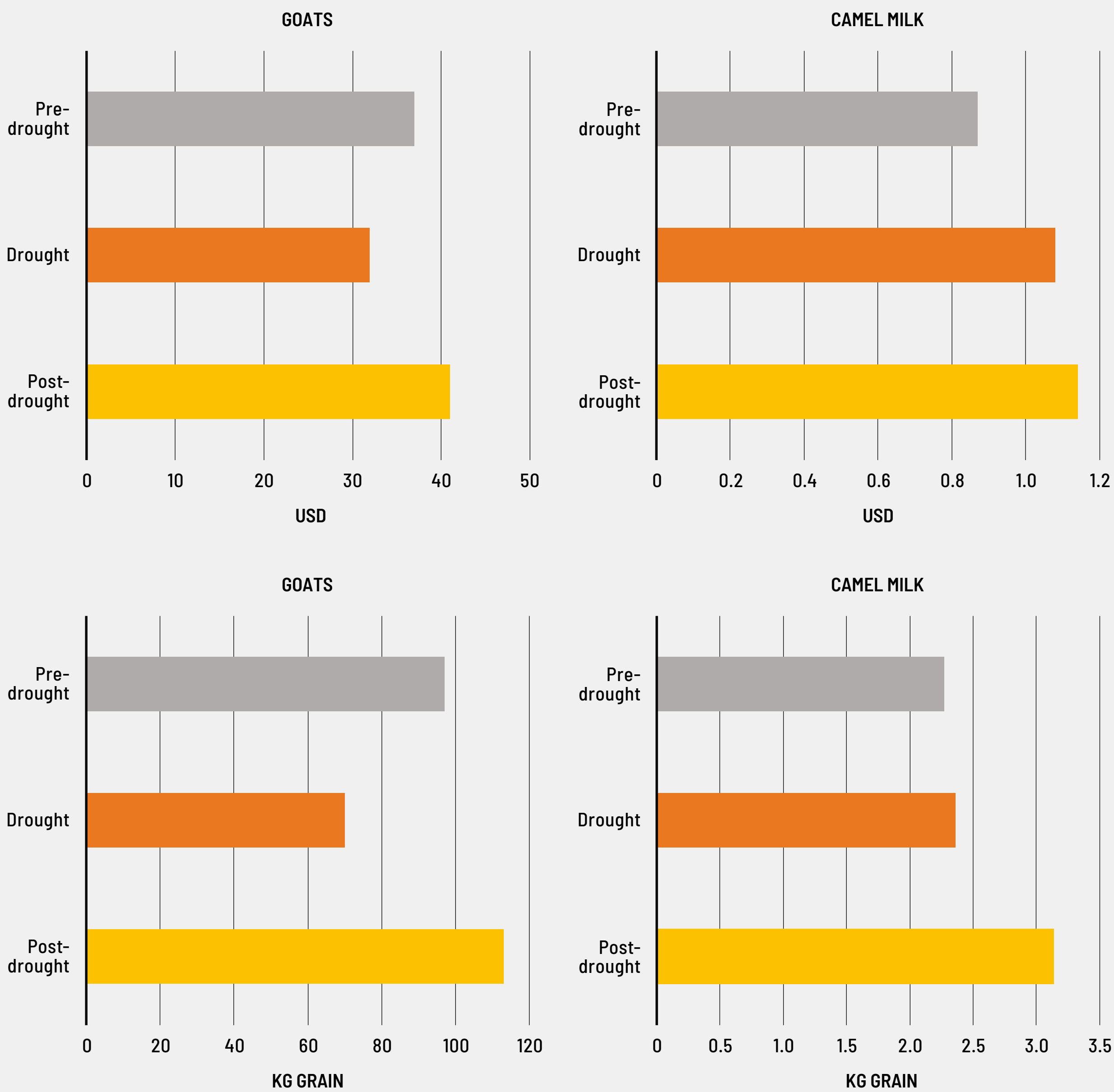
Source: Authors' own elaboration based on FAO data.

BOX 5
(CONTINUED)

In the case of milk, the drought-year price increase was similar to the average price increase in grain, leaving the milk-grain terms of trade relatively unaffected. However, milk prices continued to rise while grain prices declined in the post-drought year. This caused the milk-grain terms of trade to shift heavily in favour of pastoralists capable of supplying milk to the market. This reflects a typical drought/post-drought scenario and its impact on income distribution.

Using prevailing rural market prices, the value of animal and milk offtake dropped from USD 3 billion

FIGURE 22
AVERAGE LOCAL MARKET PRICES (USD) FOR LOCAL QUALITY GOAT AND CAMEL MILK (TOP ROW) AND TERMS OF TRADE IN THE PRE-DROUGHT, DROUGHT AND POST-DROUGHT YEARS (BOTTOM ROW)



Source: Authors' own elaboration based on FAO data.

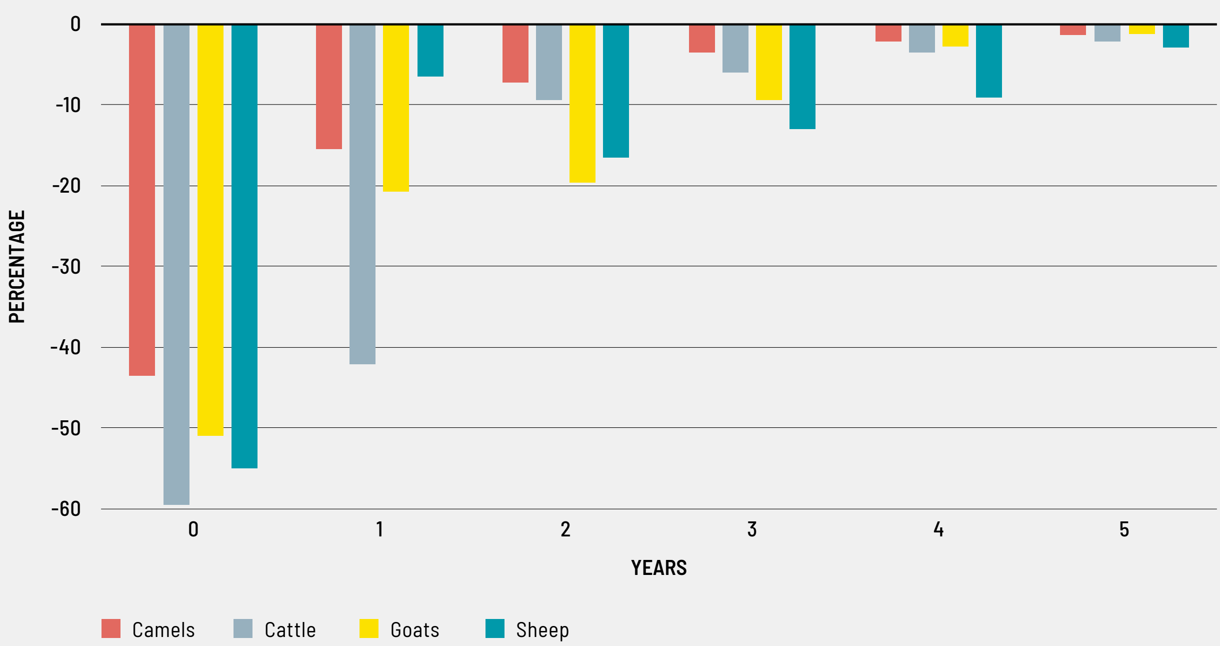
BOX 5
(CONTINUED)

in the year preceding the drought to USD 1.5 billion in the drought year. Revenue from cattle was the most affected, dropping by around 70 percent due to the high loss in milk revenue (FIGURE 23). This was followed by small ruminant revenue falling by around 50 percent and camel revenue falling by around 40 percent. Revenue from cattle was still more than 40 percent below the pre-drought level in the year following the drought, while the revenue losses of other species were only 20 percent or lower compared to pre-drought; they were assisted by price increases of small ruminants and milk in the post-drought year. It was only in post-drought year 4 that the estimated revenue losses fell below 10 percent for all species. The deterioration of the livestock-grain terms of trade in the drought year augments revenue losses by an additional 10 percent when expressed in kilogram-grain equivalent.

In summary, it is estimated that around 4 million excess animal deaths, mainly those of small ruminants, occurred in the drought year, inflicting damage of approximately USD 290 million. Estimated losses incurred in the drought year amounted to nearly USD 1 300 million from foregone milk production and USD 160 million from reduced quantity and value of animal offtake. In the post-drought year, the value of milk losses dropped to USD 150 million while the losses from reduced animal offtake rose to USD 460 million, mainly due to the reduced kid and lamb crop in the drought year. Further losses of USD 640 million accrued in post-drought years 2 to 5 as livestock populations remained below pre-drought levels and animal offtake did not reach pre-drought values.

Source: Authors' own elaboration.

FIGURE 23
RELATIVE DIFFERENCE IN THE ESTIMATED VALUE OF ANIMAL AND MILK OFFTAKE COMPARED TO PRE-DROUGHT YEAR



Source: Authors' own elaboration based on FAO data.

BOX 6

CROP LOSSES ON THE GROUND: THE CASE OF THE FALL ARMYWORM INFESTATION

Transboundary pest infestations are slow-onset disasters that generate increasingly significant agricultural losses in many parts of the world. This challenge may likely worsen in the coming years, as trade and tourism expand and environmental stressors like climate change and biodiversity loss become more severe.[59]

The fall armyworm (FAW) (*Spodoptera frugiperda*, J.E. Smith), is native to tropical and subtropical America and has been a major crop pest in the region for many decades. Its first appearance outside the Americas occurred in January 2016, when a severe outbreak was reported in western Africa.[60] FAW's presence has now been confirmed in most of sub-Saharan Africa. It is invasive, highly mobile and destructive, and causes severe losses to agriculture globally, with countries now having to deal with it as a major threat to their agricultural development efforts. The first report of FAW in Asia was confirmed in Karnataka, India in 2018. More recently, FAW was reported in Australia, the Canary Islands and New Caledonia (FIGURE 24).[61]

The rapid spread of FAW, especially in Africa, has been driven by several factors, including its ability to utilize various perennial host plants, which, together with warm and conducive climatic conditions, favour its multiplication. Although FAW can feed on various crops and eats more than 350 plant species,[62] it prefers maize (*Zea mays L.*), Africa's major cereal crop and Asia's second most important one.

FAW causes losses through reduced harvestable yields and the increased production cost from additional pest control investments. Estimates indicate that Brazil spent USD 600 million to control FAW in 2009. In Africa, maize yield losses in Ghana and Zambia were estimated at USD 284 million and USD 198 million, respectively, with an extrapolated loss estimate of USD 2.5 billion to 6.3 billion across 12 African countries in 2017.[63] As FAW spread, losses for maize, rice, sorghum and sugarcane were estimated to be USD 13 billion per annum across sub-Saharan Africa.[64]

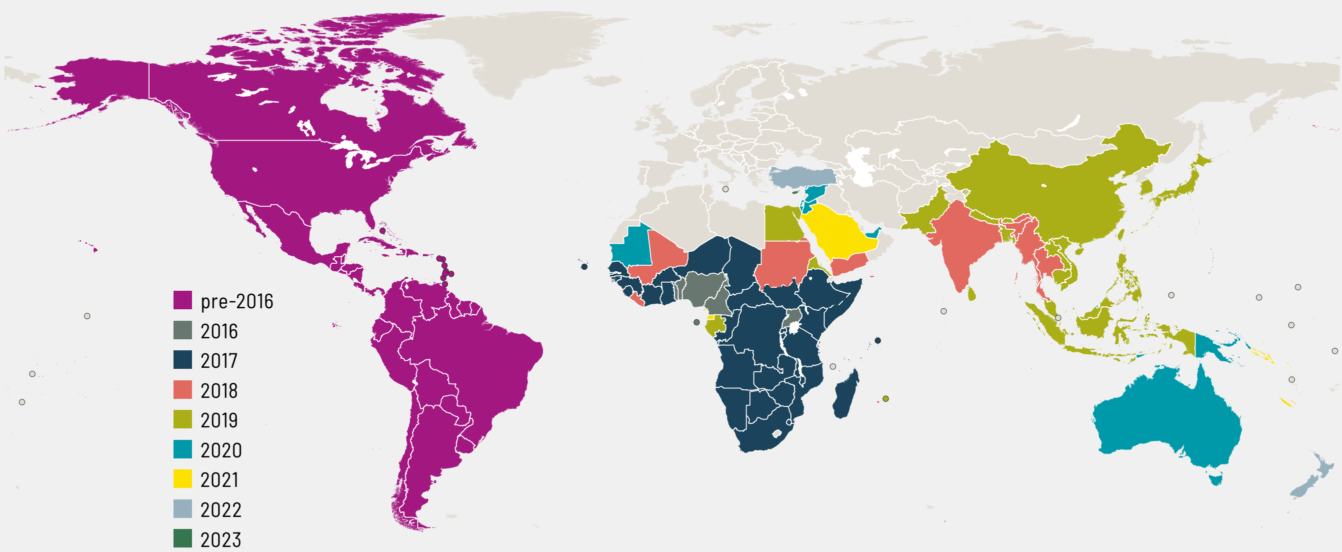
Measuring FAW infestation and crop damage

Attributing crop loss and damage to FAW is challenging, due to the diversity of crop species, varieties, growth cycles, pest life stages and other confounding factors like weather, soil health and the ecological forces affecting FAW. A review of published literature, institutional reports and other data sources reveals an increasing number of assessments on FAW's impact in Africa and Asia, with diverse measurements of their effects on maize. These are primarily plot-level assessments, with synthetic reviews or models only starting to be conducted.

An analysis of data in the literature indicates that direct FAW-induced yield loss in maize ranges from 0.4 to 94.8 percent. Regarding country-to-country variations, the average yield loss in the analysis ranged between 15.7 percent in Ecuador and 45.7 percent in India. Notably, these losses do

FIGURE 24

GLOBAL MAP OF FAW INVASION



Source: Authors' own elaboration based on FAO data and UN Geospatial. 2020. Map geodata [shapefiles]. New York, USA, UN.

not include quality reductions and are based on field (plot)-level measurements at various scales and with variable numbers of observations in the different countries. Different methods produce different yield loss estimates. For example, in Zimbabwe, maize yield loss in 2017 was estimated at 58 percent through farmer perceptions[65] and 12 percent from a rigorous analysis of field data in 2018.[66] This implies that farmers' perceptions might overestimate yield losses.[67] However, a pairwise comparison of such estimates in the same space and time is not available. Additionally, it is challenging to estimate national FAW-induced yield loss estimates from plot-level data due to high variability at various scales, making extrapolation difficult. There is a clear need to develop and apply standardized methodologies, incorporate more variables, target sampling across scales and create appropriate crop models to support effective interventions against FAW.

Measured through a damage rating scale, results show that maize grain yield loss tends to increase with the rise in the severity of plant damage, with one unit increase in damage rating score being associated with approximately 10 percent increase in yield loss (FIGURE 25). A much stronger and statistically significant relationship is observed in studies that reported damage as the proportion of plants with a damage rating greater than three (FIGURE 26).[68] This implies that a significant impact on yields is likely to materialize once plant damage reaches a certain level. Additionally, yield loss seemed to be influenced by pest infestation level, measured as the number of FAW larvae per plant. Although based on plot-level data, these results imply that regardless of scale, measurements of the impact of FAW on yield losses should incorporate crop damage measures and, where possible, pest population levels.

Modelling fall armyworm impacts to estimate the potential for direct economic yield loss

To correctly estimate the economic loss potential from the FAW invasion, it is essential to consider all main crops that can be attacked by FAW, and include both quality and quantity losses, along with lost trade opportunities.[63,69]

Below is a proposed accounting framework to estimate FAW's direct economic loss potential in the field without management.[67]

$$ELP_{(FAW)} = YL_{\sum(Cr1,\ Cr2,\ldots Crn)} + FC_{\sum Cr1+\sum Cr2\ldots+\sum Crn} + QL_{\sum(Cr1,\ Cr2,\ldots Crn)}$$

ELP = economic loss potential from FAW invasion
YL = monetary value of yield loss attributed to FAW for crops (Cr) 1, 2…n
FC = the cost of FAW control in crops *(Cr) 1, 2…n*, accounting for the costs of the various control options applied to each crop
QL = quality loss attributed to FAW for crops *(Cr) 1, 2…n*, accounting for the economic value of the crop, the quality of which is either reduced or lost to FAW

The model computes losses to FAW invasions by estimating the monetary value of yield losses in different crops, the cost of enacting control measures, and the value corresponding to a decline in crop quality.

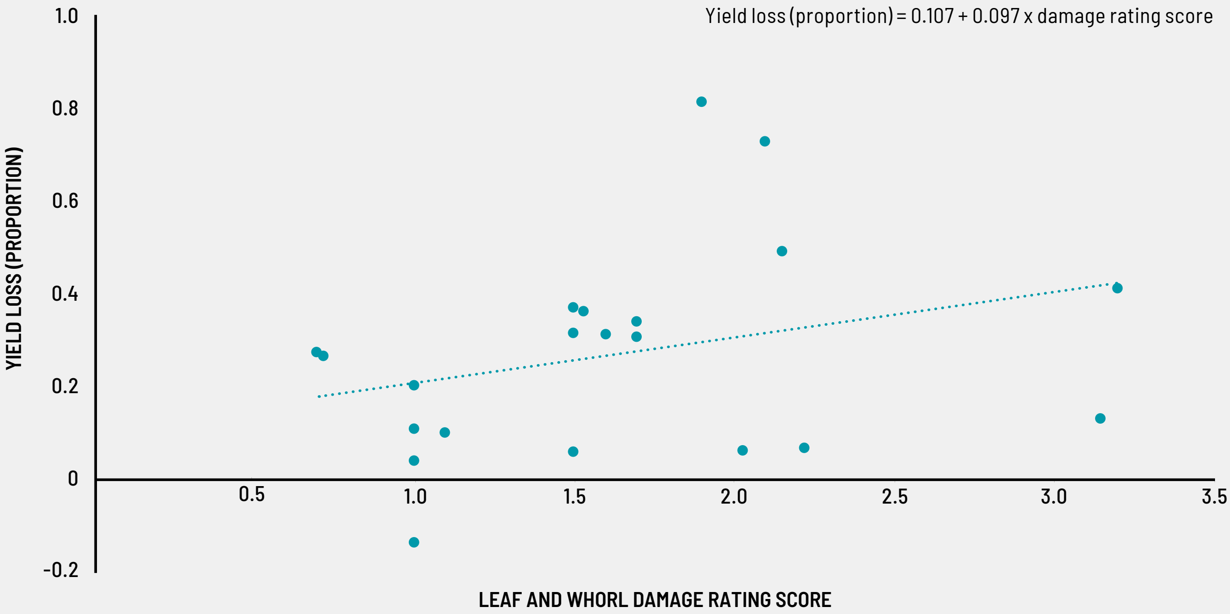
In fact, FAW invasions have continued to negatively affect productivity, especially in smallholder farming systems, thereby worsening the vulnerability of millions of African and Asian smallholder farmers. FAW has an indirect negative impact on human health, although this has not been measured in any systematic way. Other invasion impacts include an increased use of synthetic pesticide, increased pest management costs, reduced crop yields and farm-level income, and aggravated environmental and welfare impacts.

Climate projections suggest that FAW may progressively and severely impact agriculture over the next several decades.[70,71] This highlights the need to put in place effective and well-coordinated management systems, including surveillance, monitoring and response systems. The use of synthetic insecticide remains the most mentioned and practised approach for FAW control in Africa and Asia.[72,73] The dangers posed by synthetic pesticides suggest a need for control strategies that effectively suppress the pest without compromising human health, the resilience of agrifood production systems and the natural environment. Some of these include nature-based solutions within the Integrated Pest Management framework, such as biological control of FAW.

Source: Authors' own elaboration.

FIGURE 25

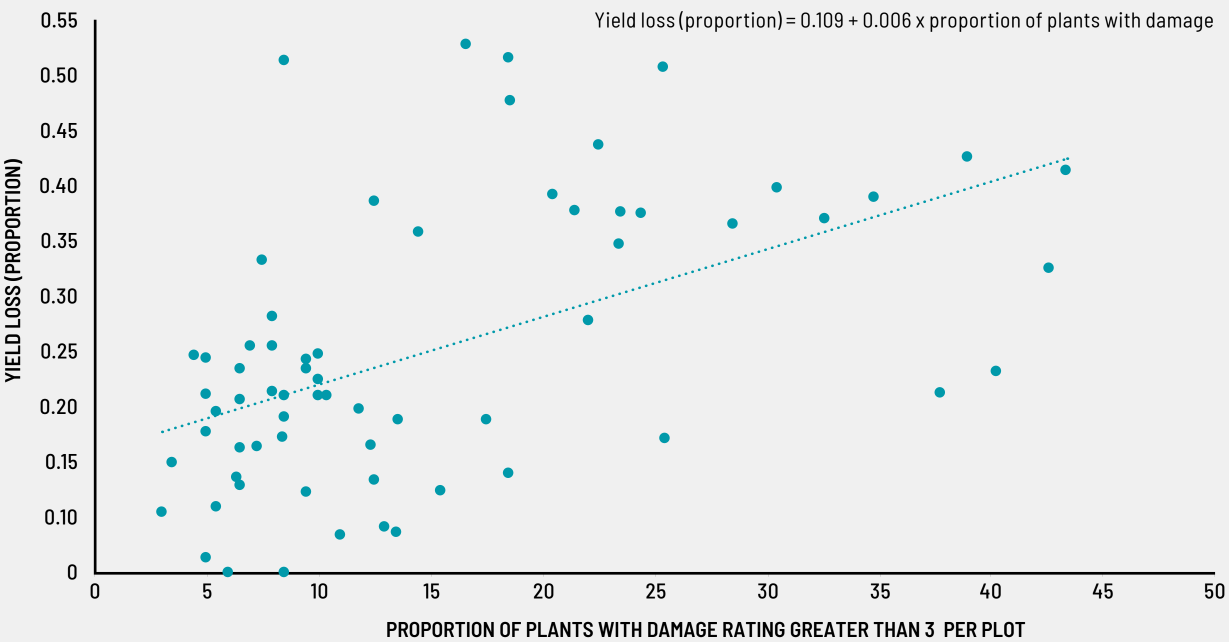
LINE OF BEST FIT WHEN TOTAL YIELD LOSS (PROPORTION) IS REGRESSED ON PLANT DAMAGE RATING



Source: Authors' own elaboration based on FAO data.

FIGURE 26

LINE OF BEST FIT FOR MAIZE WHEN YIELD LOSS (PROPORTION) IS REGRESSED FOR PLANTS WITH A DAMAGE RATING GREATER THAN THREE



Source: Authors' own elaboration based on FAO data.

2.3.2
NUTRIENT LOSSES IN THE FOOD SUPPLY DUE TO DISASTERS

Disasters and crises have well-known effects on food security, with critical implications for nutrition. They also impact nutrition through other pathways, specifically, the loss of food and the nutrients it contains, which could otherwise have contributed to healthy diets. Global losses in crops and livestock are converted to corresponding energy and nine micronutrient values lost for human consumption. Expressing losses as a percentage of requirements helps to gauge the extent to which food supply shortfalls resulting from disasters and crises may affect the ability to meet the population's nutritional needs.

It is important, in this connection, to emphasize that the focus here is on availability, and not on changes in consumption patterns due to disasters. Assessing lost consumption would require comprehensive and specific data that are currently limited. It is crucial to acknowledge that the availability of energy and nutrients in the food supply does not necessarily translate into an amount that individuals are taking in.

To provide a measure of the quantity of energy and nutrients lost, food composition data[74] were used to translate estimated losses in agricultural production into nutrient losses for nine vitamins and minerals (calcium, iron, zinc, vitamin A, thiamine, riboflavin, vitamin C, magnesium and phosphorus), as well as energy. Population estimates were then used to convert these values into the average amount of nutrients lost per person per day. These values are expressed as a percentage of adult requirements, using the daily estimated average requirement (EAR)[p] for each nutrient.[q,75,76,77,78]

p EAR is the amount needed to meet the requirement of 50 percent of healthy people (per day).

q Requirements are as follows – Calcium: men and women 800 mg; iron: men 6 mg, women 8.1 mg; zinc: men 9.4 mg, women 6.8 mg; magnesium: men 350 mg, women 265 mg; phosphorus: men and women 580 mg; vitamin A, retinol activity equivalents: men 625 mcg, women 500 mcg; thiamine: men 1.0 mg, women 0.9 mg; riboflavin: men 1.1 mg, women 0.9 mg; vitamin C: men 75 mg, women 60 mg).

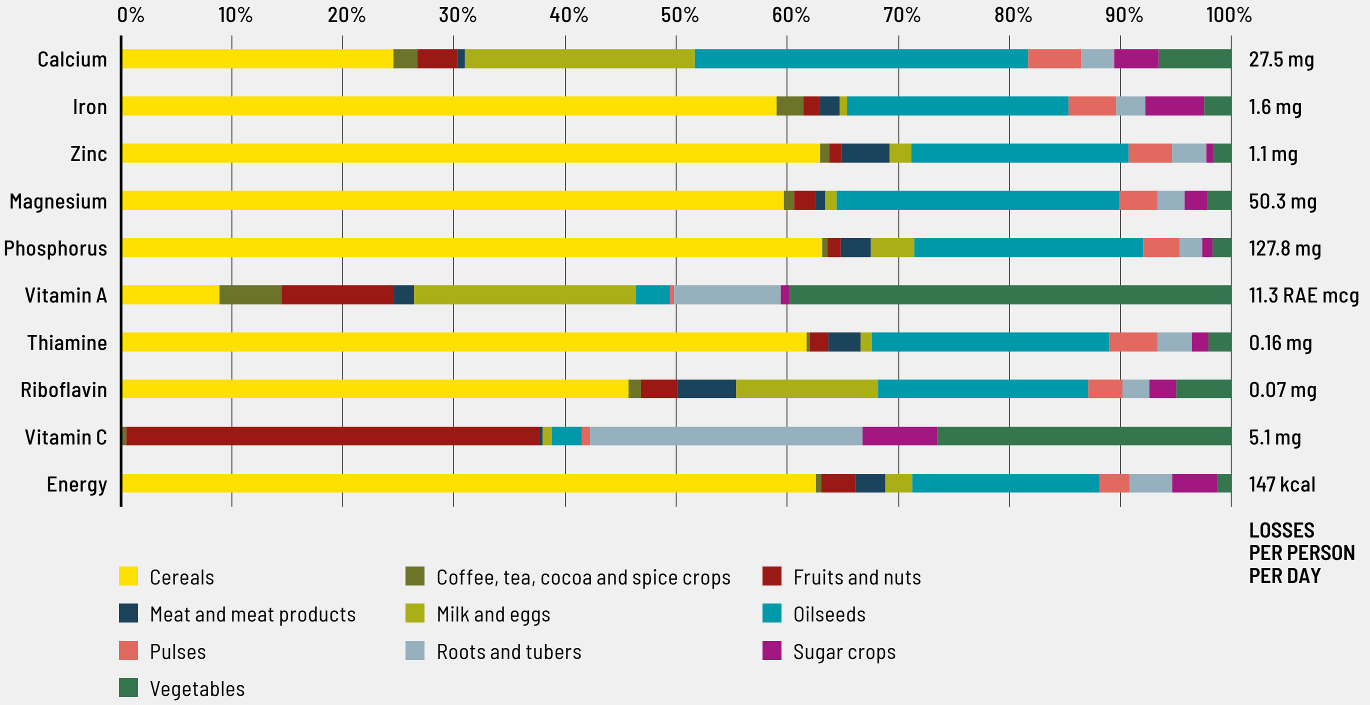
FIGURE 27 illustrates that on a global scale, estimated losses from disasters in the crops and livestock subsectors have averaged approximately 147 kcal per person per day over the past 31 years. This figure corresponds to about 6 to 7 percent of the average energy requirement for men and women, respectively (FIGURE 28). This reduced availability of energy corresponds to the requirements of approximately 455 million people (around 400 million men or 500 million women) each year over the last three decades.

Cereals contribute predominantly to the losses for energy and several nutrients (FIGURE 27), including iron, zinc, magnesium, phosphorus, thiamine and riboflavin. Cereal-based products are staple foods in many regions and serve as a significant source of these nutrients. Vegetables primarily contribute to the losses in vitamin A. This highlights the importance of vegetables as a source of this essential vitamin, which is crucial for vision, immune function and overall health. Fruits and nuts, along with roots and tubers, contribute mainly to the losses in vitamin C. These food groups are recognized for their richness in vitamin C, an antioxidant nutrient important for immune function and collagen synthesis. Milk and eggs contribute to losses in calcium, vitamin A and riboflavin. These food sources are known for their calcium content, which is vital for strong bones and teeth. Milk and eggs also provide vitamin A, crucial for vision and immune function, and riboflavin, which is important for energy production.

Compared to requirements, nutrient losses appear to be particularly prominent for iron, phosphorus, magnesium and thiamine (FIGURE 28). Percentage losses appear similar by gender for calcium, phosphorus and vitamin A, but display differently for the other nutrients. Given higher requirements, the potential nutrition impact would be more important for women for zinc, magnesium, thiamine, riboflavin, and vitamin C, with between 1 percent to 5 percent higher losses as a percentage of the EAR for these nutrients. Iron is the only nutrient for which potential loss could affect men more than women by a 7 percent difference. »

FIGURE 27

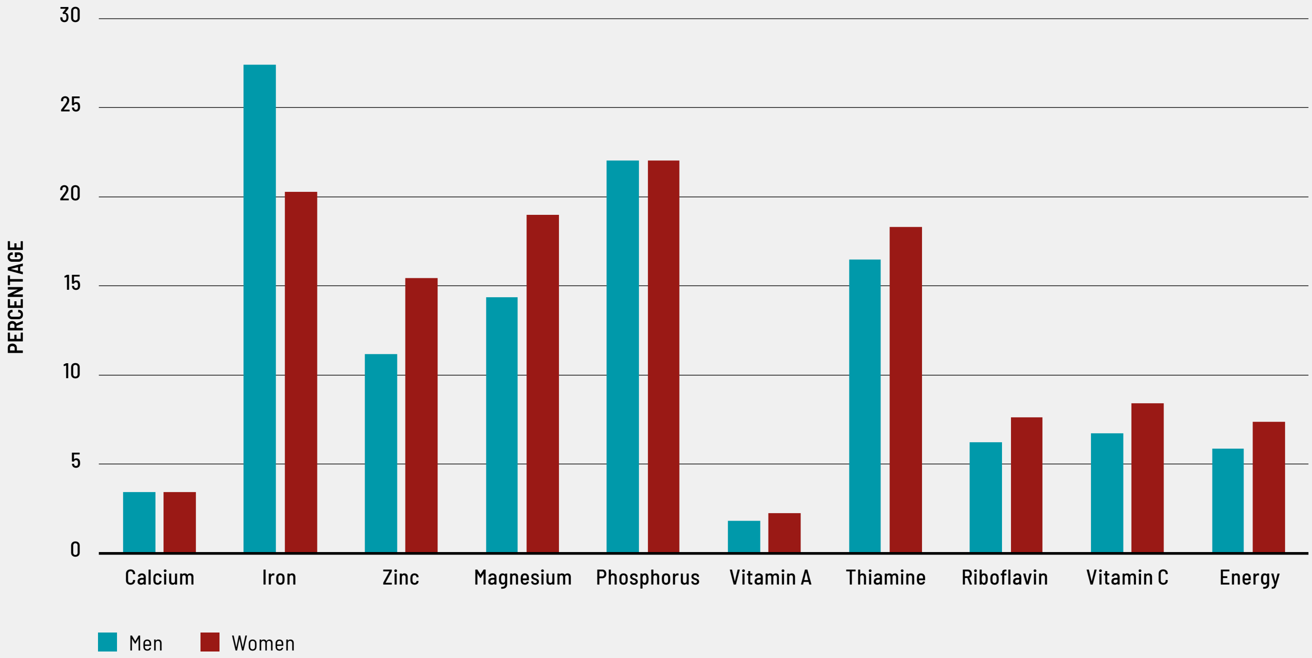
TOTAL ESTIMATED DAILY LOSSES OF ENERGY AND NUTRIENTS PER PERSON PER DAY BY FOOD (1991–2021)



Source: Authors' own elaboration based on FAO data.

FIGURE 28

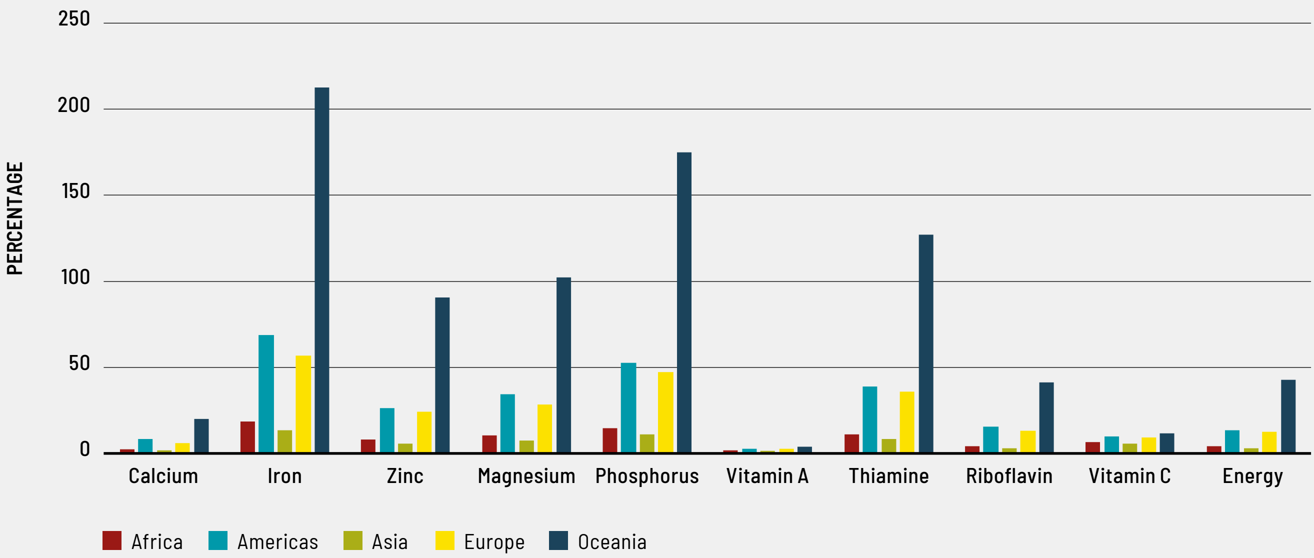
ESTIMATED DAILY LOSSES OF ENERGY AND NUTRIENTS AS A SHARE OF HUMAN REQUIREMENTS (1991–2021)



Source: Authors' own elaboration based on FAO data.

FIGURE 29

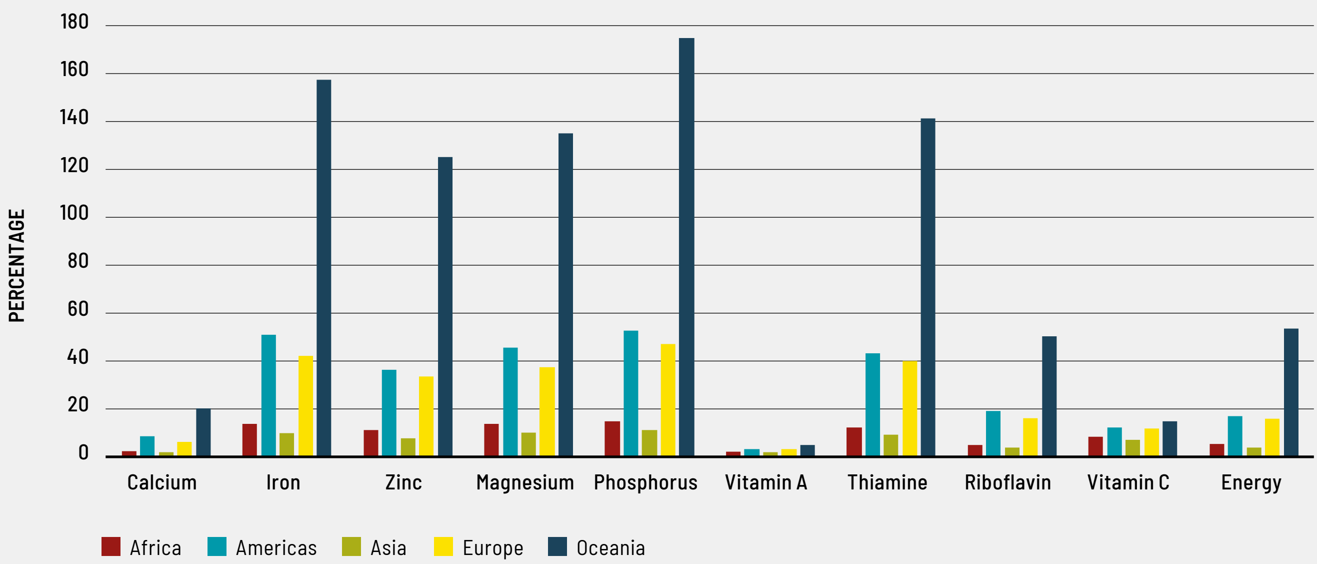
ESTIMATED DAILY LOSSES OF ENERGY AND NUTRIENTS AS A SHARE OF HUMAN REQUIREMENTS FOR MEN BY REGION (1991-2021)



Source: Authors' own elaboration based on FAO data.

FIGURE 30

ESTIMATED DAILY LOSSES OF ENERGY AND NUTRIENTS AS A SHARE OF HUMAN REQUIREMENTS FOR WOMEN BY REGION (1991-2021)



Source: Authors' own elaboration based on FAO data.

» At a regional level, the estimated nutritional losses linked to production lost due to disasters are around 31 percent in Asia and the Americas, 24 percent in Europe, 11 percent in Africa and 3 percent in Oceania. However, when looking at these losses with respect to the energy requirements of the population of the regions, these appear to be particularly prominent in Oceania with about 50 percent, followed by the Americas with about 15 percent and Europe at about 13 percent. In Africa and Asia, the share of lost availability of requirements due to disasters is much lower, with about 3.5 percent and 4.5 percent, respectively. It is worth noting that the estimated losses for Africa alone correspond to the daily energy requirements of more than 43.5 million men or 54.4 million women.

As seen in FIGURE 29 and FIGURE 30, the estimated daily losses as a percentage of the EAR are greatest in Oceania, with losses over 100 percent of EAR for both men and women for iron, magnesium, phosphorus, thiamine and, for women, zinc. This is a consequence of considering losses in the availability of nutrients rather than in actual intake. Even though nutrients lost in this region are lower than those presented by the other regions, the population in Oceania is small compared to that of other regions, and food exports are significant. This results in a high loss of nutrients per capita per day, which translates into a very high loss as a percentage of EAR. For iron, as an example, the estimated loss per capita per day in Oceania is 12.7 mg. The absolute losses might not seem very concerning; however, this translates into 212.5 percent of the share of EAR for men (EAR of 6 mg/day) and 157.4 percent for women (EAR of 8.1 mg/day).

Finally, the exclusion of fish and aquatic foods – due to the absence of systematic estimates of losses – may be particularly relevant when assessing the reduced availability, as these foods are important sources of specific nutrients. At the same time, these data, if available at a more granular level, allow for context when evaluating the availability in the food supply of specific countries.[r] ■

[r] More granular data, for instance, would make it possible to assess whether losing a given percent of the EAR of a nutrient is a minor loss if that nutrient is in abundant supply in that specific context, or to see if there could be a substantive public health issue if that nutrient is scarce in the local diet.

BOX 7

ESTIMATING NUTRIENT AVAILABILITY REDUCTIONS CAUSED BY DISASTERS

From the global disaster losses estimated in agricultural production over 1991–2021, nutritional losses are computed for calories and nine micronutrients, representing their reduced availability in the global food supply. Crop and livestock commodities lost due to disasters are matched to appropriate nutrient values in the global nutrient conversion table for calcium, iron, zinc, vitamin A, thiamine, riboflavin, vitamin C, magnesium and phosphorus, considering their edible coefficient. Total losses of nutrients from 1991 to 2021 are divided by the world population, and days in this period, to convert values into the average quantity of energy and nutrients lost per person per day due to disasters. The national population data used was retrieved from FAOSTAT. To express values as a percentage of human requirements for these nutrients, the daily per capita loss of each nutrient is divided by its estimated average EAR for adult men and women.

Source: Authors' own elaboration.

2.4 MEASURING IMPACTS IN FORESTRY AND FISHERIES AND AQUACULTURE

This section provides case studies for the forestry and fisheries and aquaculture subsectors, where limited data availability does not allow for the same type of systematic assessments of losses from extreme events as conducted for crops and livestock in **section 2.3.1.** The reasons for this data gap are a lack of baseline data, the complexity of the relationship between disasters and productivity in these two subsectors, which makes it complex to build a counterfactual scenario with no disasters. In the case of marine fisheries, it is also challenging to link national production areas to locations where disasters occur. Insights on the importance and relevance of losses from disasters in forestry and fisheries and aquaculture are therefore gathered from published literature and anecdotal evidence obtained from the analysis of specific cases.

The following subsection provides an overview of the two most significant hazards – wildfire and insect infestations – that are threatening the health and sustainability of forests around the world. It outlines the challenges of data collection in the subsector and offers a potential methodology for loss assessment. The last subsection looks at induced losses in the fisheries and aquaculture subsector, providing an overview of the specificities of the impact of disasters in that context.

2.4.1 FORESTRY: THE IMPACT OF WILDFIRES AND PEST INFESTATIONS ON FORESTS

Forests are extremely vulnerable to the impacts of disasters and climate change but also play a key role in risk reduction and mitigation. Halting deforestation and increasing forest cover are cost-effective solutions for mitigating climate change and cutting emissions by over five gigatonnes of CO_2 equivalent each year, which is about 11 percent of total annual emissions. Doing so also boosts biodiversity and provides ecosystem services, which enhance the adaptive capacity and resilience of people and ecosystems to extreme events.[5] At the same time, forests worldwide are threatened by many natural hazards, including wildfires, insect pests, diseases, droughts, storm damage, floods and landslides. The frequency and severity of disasters can result in forest degradation and loss, reducing their ability to store carbon, adapt to climate change and support vulnerable livelihoods.

Most hazards affecting the forestry sector are driven by meteorological factors (e.g. temperature and precipitation patterns), long-term climate variability and human influence (land-use change, land management practices and introduction of invasive species through international trade). Assessing and reducing forest risks are essential to helping countries meet their climate mitigation and adaptation goals, but the effective monitoring of forest degradation is still in the early stages. In the *Global Forest Resources Assessment 2020*, only 58 countries, representing 38 percent of the global forest area, reported monitoring the area of degraded forests.[79] Collecting data on forest impacts poses challenges due to inconsistent approaches to loss and damage assessments, insufficient application of methodologies, and a lack of comprehensive coverage of the full range of impacts. There is a clear need for better data and integrated risk management approaches.

The following sections elaborate on two of the most important hazards affecting the forest sector: wildfires and pest infestations. Fire is an essential component of many terrestrial ecosystems, and its impacts can be beneficial or adverse. Along with climate conditions, fire is a major driver of global vegetation patterns,[80,81] but it also poses a serious threat. Uncontrolled wildland fires (wildfires) have significant negative impacts, including CO_2 emissions, the loss of forest products and productivity, degradation of landscapes, the loss of human life, built assets, biodiversity, and habitats, and the disruption of livelihoods.[82] No vegetated region or country is spared this risk.[81] Reducing risk and managing the destructive effects of wildfires is an increasingly significant problem across the globe.

Trade, transport and human mobility have experienced exponential growth, and alongside them, non-native invasive species of insect pests, pathogens, vertebrates and plants have emerged as a growing threat to forests. Invasive species are now considered one of the most significant causes of biodiversity loss, especially in certain island countries.[83] Insect pests damage about 35 million ha of forests annually.[83] Invasive species, specifically insect pests and disease pathogens, affect tree growth and survival, reduce wood quality and impact other ecosystem services. Invasive plant species inflict harm upon forests by competing with native species and obstructing the regeneration of the latter. Endemic species, triggered by climate change or through ensuing weakened host plant defences, also contribute to increasing impacts. This alters the composition and structure of flora. Many countries are experiencing outbreaks of native pests like bark beetles due to the impacts of climate change and poor forest management practices.

Fire and forests

Driven by a rising population density in the wildland–urban interface, wildfires are increasingly damaging the environment, wildlife, human health and infrastructure.[84] Every year, about 340 million–370 million ha of the Earth's surface are burnt by wildfire.[85,86] Data show that nearly 391 million ha – including 25 million ha of forest land – were burnt in 2021 alone.[87] Actual burnt area is often underestimated due to technical limitations like sensor resolution (meaning small fires can go undetected), temporal coverage and clouds. Using Sentinel-2 data at a spatial resolution of 20 m, Chuvieco *et al.* calculated sub-Saharan Africa's burnt area to be 120 percent greater than that estimated by the moderate-resolution imaging spectroradiometer (MODIS) (500 m).[88] This means that fires not mapped by MODIS are not yet being accounted for in global burnt area analyses.

Changing demographics, climate and land use are causing wildfires to become more frequent and intense. They are also occurring in previously unaffected areas.[89] Relative to the levels in 2000, the global occurrence of extreme fire events is expected to increase by 14 percent in 2030, 30 percent in 2050 and 50 percent by 3000. Climate change and future fire meteorology will play the most significant role in enhancing wildfires, followed by land cover changes, lightning activity and land use.[90]

Caused primarily by greenhouse gas released from fossil fuel combustion, climate change has had a substantial impact on the fire environment.[91] Wildfires can accelerate the carbon cycle's positive feedback loop, making it more difficult to halt rising temperatures. Satellite observations of active fires indicate that wildfires in 2021 emitted 6 450 megatonnes of CO_2 globally, which was 148 percent more than total European Union fossil fuel emissions in 2020. According to recent IPCC findings, hotter, drier and windier weather is becoming more frequent in some regions and will continue to increase if countries do not meet and exceed their Paris Agreement commitments.[5] Many members of the international fire community recognize the growing problem of managing fire under increasingly difficult fire weather conditions and extended fire seasons influenced by climate change.[83]

FIGURE 31 shows burnt area, number of fires and CO_2 emissions for the period 2000–2021. There are no clear trends in the graphs, but it is notable that the Global Wildfire Information System (GWIS) dataset is based on the MODIS sensor (500 m resolution), and the analysis of global data does not reflect ground specificities. The charts demonstrate that fire data for Africa is significantly higher than that of other continents – approximately 70 percent of all global wildland fire occurred in sub-Saharan Africa, followed by 21 percent in Australia and South America.[85]

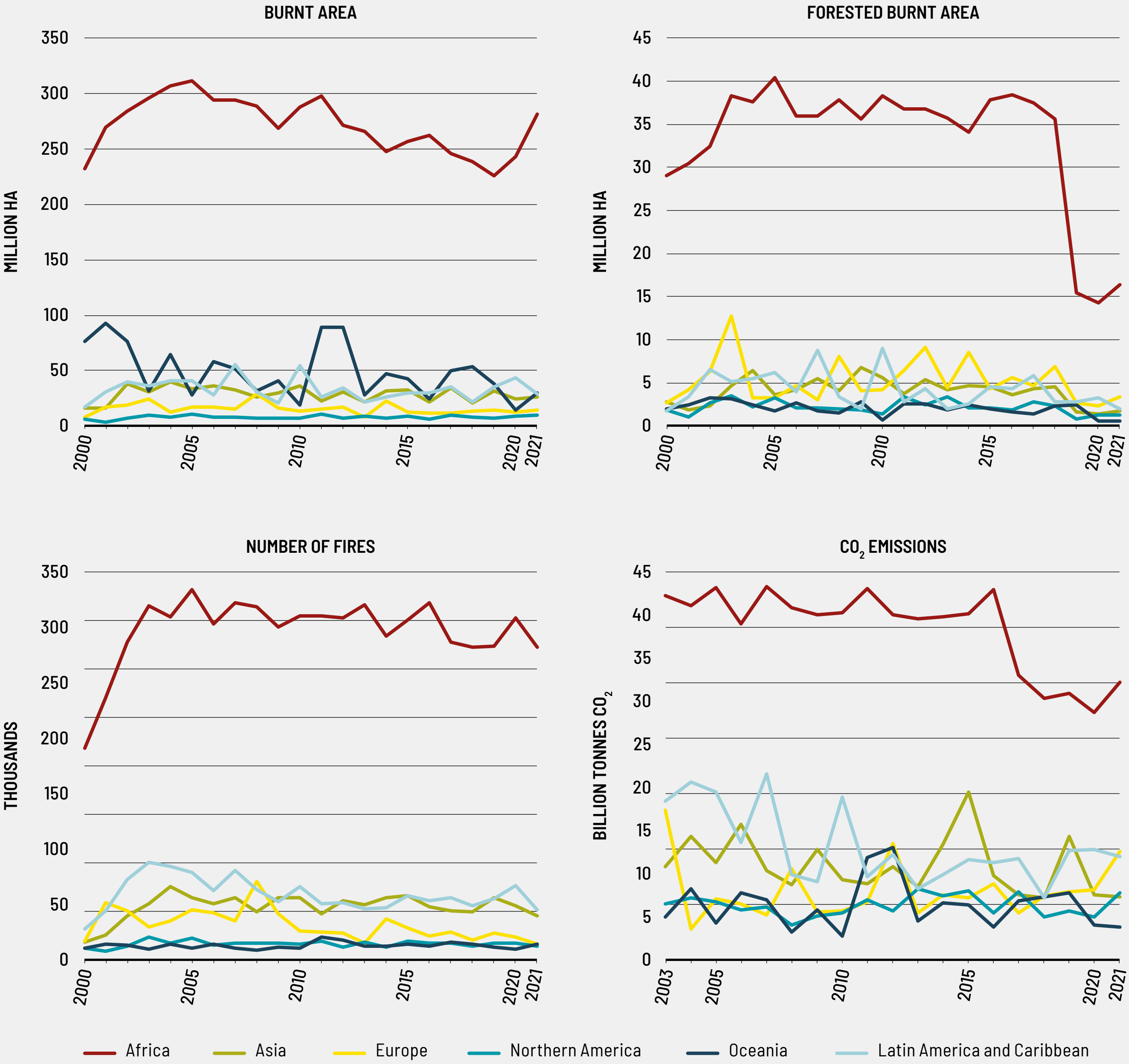
Earlier estimates of nationally reported annual forest burnt area (2002–2012) were approximately 67 million ha, which is equivalent to 1.7 percent of all forests worldwide.[86] However, the GWIS global fire dataset for 2002–2019[92] indicates an average of 176.9 million ha of burnt forest, which represents 3.6 percent of total global forest cover and 42.9 percent of global burnt area. According to Van Lierop *et al.*,[86] the global distribution of forest burnt area, and the percentage burnt of total forest land in that region, is:

- South America, 35 million ha (4 percent)
- Africa, 17 million ha (2.5 percent)
- Oceania, 7 million ha (4 percent)
- Northern and Central America, 5 million ha (0.7 percent)
- Europe and northern Asia, <5 million ha (0.3 percent)[86]

»

FIGURE 31

HISTORICAL DATA OF BURNT AREA, NUMBER OF FIRES AND CO_2 EMISSIONS FROM WILDFIRES (2000–2021)



Source: Global Wildland Fire Information System, https://gwis.jrc.ec.europa.eu/

» Nearly 58.6 percent of all fires in 2002–2019 (the latest available period of country level fire statistics) occurred in the 46 least developed countries, even though they accounted for just 14.2 percent of global vegetation cover, including cropland and natural vegetation. This suggests a connection between fire risk, lower income and resource management contexts. In 33 of the least developed countries, Africa appears to be the primary driver of this poverty–fire linkage, although Central and South American countries also suffer from it.

The 2002–2019 GWIS dataset shows 146 million ha of forest classified burnt land (including open and closed forests) in African least developed countries, which represents 82.6 percent of all forest fires globally. This could be an artefact of land cover classification (e.g. treed savanna is classified as open forest). However, it undoubtedly includes some forest cover burnt by fire that spreads from burning in grasslands/shrublands and croplands.

Wildfire-related damages and losses include negative ecological impacts (vegetation cover and biodiversity losses, soil losses, decreasing soil fertility) and socioeconomic harm (fatalities, livelihoods, agricultural, productivity, food security, human health, water security and infrastructure/assets).[93] Unfortunately, it is difficult to assess short- to long-term ecosystem responses to fire and measure ecological values. There is no consistent global database that reports socioeconomic fire impacts or even suppression costs, and many governments do not routinely assess and record this information or make it available.[94]

Tackling the underlying causes of fires using risk reduction actions can help avoid considerable losses. The purpose of integrated fire management (IFM) is to make landscapes and livelihoods resilient and sustainable. IFM does so by considering the ecological, socioeconomic and technical aspects of fire management. A focus on wildfire risk reduction is the right approach, but it must include using fire as a management tool. Some fires identified as extreme wildfire events in the United States of America were described in fire reports as the product of over-dense forests stemming from fire suppression policies in fire-adapted biomes.[94] The same happens in other countries. There is an opportunity to count on indigenous and traditional knowledge and experience in fire management to establish healthier fire regimes.

An IFM framework that assists in systematically assessing, planning and managing fires has evolved as part of FAO's Strategy on Forest Fire Management.[95] This framework focused on the five Rs: review and analysis, risk reduction, readiness, response and recovery. Applying the IFM approach and the five Rs and promoting dialogue through the experience, knowledge and good practices of researchers, practitioners, and indigenous and traditional communities can help decrease the vulnerability of people and landscapes.

Impact of forest invasive species and outbreaks of native pests

Forest damage by invasive species can be economically catastrophic, but there is a lack of information to quantify their global economic impact.[96] A major reason for this lack of data is the difficulty of establishing thresholds beyond which a tolerable presence of pests evolves into an infestation. Other factors include calculating the extent of forest damage and estimating the monetary value of lost tree and plant stocks.

Economic costs include timber losses, tree replacements, changes in ecosystem services, water retention, management costs, and climate and carbon loss mitigation. There are also socioeconomic consequences like public health outcomes, the loss of revenue by local communities that rely on productive forests, and the cultural and social significance of forests, which are difficult to quantify in economic terms. However, very little research has been done to quantify the implications of pests and diseases on forest ecosystem services and local communities. Current reporting of pest and disease damage is based on land area of damage, volume of tree mortality or economic impacts — there is no harmonized system for reporting impacts. For large outbreaks, it is relatively easy to assess damage based on land area for agents such as bark beetles. However, this method is not suitable for pests and pathogens that cause mortality in individual trees surrounded by non-hosts.

Overall, data on insect pest and disease outbreaks is limited, especially in developing countries. Additionally, available data focuses mainly on plantations and planted trees. Although forest declines and diebacks have been reported in many countries, there is a lack of accurate survey data. Australia, China, some Central American countries, New Zealand, the United States of America, and the United Kingdom of Great Britain and Northern Ireland have all reported losses by recent invasive species, native insect pests and pathogens.

The USDA Forest Service's annual report describes major forest insect pests and disease conditions in the United States of America. Tree mortality caused by forest insect pests and disease varies year to year, but over 11.8 million acres (4.8 million hectares) of mortality were reported in 2009.[97] By contrast, 5.9 million acres (2.4 million hectares) were affected by forest fires the same year. In 2018, more than 6 million acres (2.4 million hectares) of tree mortality was caused by insect pests and diseases in the United States of America, which was approximately 2.6 million acres (over 1 million hectares) less than that reported in 2017.

The United States of America estimates the annual economic damage arising from all invasive forest pests in the country to be USD 4.2 billion.[98] More recent studies for specific sets of species indicate even higher costs. In 2019, the United States of America estimated biomass loss associated with elevated mortality rates caused by the 15 most damaging non-native forest pests. The study found a combined tree mortality rate of 5.53 teragrams of carbon (TgC) per year.[99]

Elsewhere, Turner *et al.* concluded that the net value of economic impacts associated with a new forest pest in New Zealand was NZD 3.8 billion to NZD 20.3 billion when projected to 2070.[100] Damage by invasive species costs the United Kingdom of Great Britain and Northern Ireland's economy an estimated GBP 1.7 billion (more than USD 2.2 billion) per year.[101] In the Islamic Republic of Iran, the boxwood moth *Cydalima perdpectalis* and boxwood blight *Calonectria pseudonaviculata* affected about 80 000 ha of natural stands of box wood trees (*Buxus hyrcana*).[79] In Australia in 2015, the dieback of mangrove forests along the southern coast of the Gulf of Carpentaria included an area of 7 000 to 10 000 ha along a 700 km stretch of coastline. It is one of the largest mass-death events ever reported of mangrove ecosystems and is linked to climate anomalies.[102]

Other notable examples are the large outbreak of gum-leaf skeletonizer (*Uraba lugens*) that severely defoliated about 250 000 ha of jarrah (*E. marginata*) forest in western Australia during 2010–2011, although forests have since recovered.[103] In northeast Victoria, up to 3 000 ha of plantation have been treated for Dothistroma needle blight (caused by *Dothistroma septosporum*) each year since 2011. At the end of 2016, the cumulative total area of publicly owned native forests in western Australia affected by phytophthora dieback was 274 000 ha.[102] Sirex woodwasp in Australian softwood plantations is estimated to have cost around AUD 35 million in losses and control.[104] A similar sum was spent on the attempted eradication and containment of the European house borer since its detection in 2004.[105] In South Africa, 12 301 ha of planted trees are affected by pests and/or pathogens annually.

The southern pine beetle (SPB), *Dendroctonus frontalis*, is the most destructive native insect pest of pine forests in the south-eastern United States of America, Mexico and Central America.[109] SPB spread has remained low in the southern and north-eastern regions of the USA since 2002, when 5.26 million ha of pine forests were affected. In Mexico and Central America, the most recent SPB outbreak — with the possible involvement of the meso-American pine beetle — occurred in Honduras and accounted for some 500 000 ha of tree mortality in 2014/15.[110] An unprecedented outbreak of *Ips calligraphus* occurred in the Dominican Republic in 2019,[111] impacting over 8 000 ha of native and exotic pine forests.[112]

However, the bark beetle species causing the most pine forest losses in northern America has been the MPB since 2000. According to Canadian government records, an ongoing MPB outbreak that began in the early 1990s has affected over 18 million ha of pine forests in British Columbia. This had resulted in a loss of approximately 723 million m^3 (53 percent) of merchantable pine volume by 2012.[108] In 2010, surveys detected over 6.8 million acres with MPB mortality across the western states of the United States of America.[97]

Like all programmes, there are inevitable gaps and areas that require improvement. As mentioned above, one major gap is the lack of consistent data – not just on the losses caused by invasive and native species, but also on how countries are mitigating loss and damage. To better assess, prioritize and respond to the impacts that invasive and native species have on forests, harmonized information at the global, national and local levels must be collected through on-ground surveys, questionnaires, and technologies like satellite and remote imagery.

BOX 8

TWO PESTS AFFECTING FORESTS

Pine wood nematode

The pinewood nematode is considered one of the most devastating pine pests,[106] having caused severe damage to plantations in Portugal and native forests in China, Japan and the Republic of Korea. The Korea Forest Service reported the loss of 12 million pine trees to the pest over 1988–2022. The Forestry Agency of Japan reported an annual loss of about 0.3 million m^3 of pine trees due to pine wilt disease.[107]

Similarly, the eastern and southern areas of China have been hit the hardest by pinewood nematode disease. The economic losses of these regions accounted for 79.9 percent of total national economic losses (TABLE 2).

Bark beetles

Bark beetles are a natural component of forest regions around the world, but they can also be a major disturbance agent, especially in coniferous forests with low diversity of tree species, high density and environmental stresses. In Central and northern America and Europe, tree mortality caused by bark beetles was estimated in the millions of hectares in recent decades. In Belarus, bark beetles caused a loss of 36 million m^3 of pine wood from 2016–2021. In Canada, the forest area disturbed by the mountain pine beetle (*Dendoctronus ponderosae*) continued to decrease, from a high of almost 9 million ha in 2009 to only 357 000 ha in 2019.[108]

TABLE 2

PINEWOOD NEMATODE DISEASE IN CHINA

PROVINCE	ECONOMIC VALUE (RMB BILLION)	% OF TOTAL NATIONAL ECONOMIC LOSS
Zhejiang	2.14	26.8
Guangdong	1.81	22.7
Jiangsu	1.22	15.3

Source: Zhao, J., Huang, J., Yan, J. and Fang, G. 2020. Economic Loss of Pine Wood Nematode Disease in Mainland China from 1998 to 2017. *Forests*, 11(10): 1042. doi.org/10.3390/f11101042

Source: Authors' own elaboration.

Estimating loss and damage in forestry

Disasters affect forests in multifaceted ways and require the collection of a diverse range of data and indicators to assess loss and damage in all dimensions (TABLE 3). Direct impacts on productive assets – such as equipment – are the easiest to measure, as compared to estimating the effect on wood production, which requires differentiating maturity and values for the timber affected. In several country contexts, smallholder livelihoods can be affected by a loss of income from forest resources, both in terms of wood production and non-timber forest products like fuelwood, fruit, mushrooms, flowers and recreational activities.[117]

Secondary impacts on livelihoods require an assessment of records and data from household-level questionnaires. As highlighted previously, there is a lack of standardized methodologies for assessing disaster impacts on ecosystem services. Certain post disaster needs assessments have sought to address this gap by creating indicators and assigning monetary values to ecosystem losses.[118] The impacts of certain hazards, such as trade disruptions caused by pest infestations, are not limited to forestry but have a direct effect on forest-based revenues.

An important aspect of assessing timber losses after large-scale disasters in the forestry sector is that a significant portion of damaged timber can usually be salvaged. The number of trees destroyed after a disaster does not automatically result in a drop in timber production. Rather, an increase in timber sales is observed in the immediate aftermath of the event as more timber is put on the market than usual.

The delayed pattern of losses provides a challenge when conducting large-scale regression analysis on disaster and wood production over multiple countries and years. Actual timber production disaster losses might be observed over more extended periods after the salvaged wood has been

BOX 9

BARK BEETLE DAMAGE IN HONDURAS

The SPB killed trees in more than 580 000 ha in Honduras over the last 20 years during unprecedented outbreaks.[109] Honduras has a land area of about 11 million ha, of which 4.5 million ha (or 41 percent of the country) is forested. Around 60 percent of the forest area comprises *Pinus* species. Over 2 million ha were affected by SPB due to over-stocked stands, wildfires and a prolonged drought during 1962–1965. In 1964, the outbreak was estimated to be spreading at a rate of 150 000 ha per month.[113] This remains Honduras's most devastating SPB epidemic to date.

A notable SPB outbreak occurred in second-growth pine stands of *P. oocarpa* primarily in the country's Yoro region from 1982 to 1983,[114] where over 8 000 ha of young pine forests were attacked and killed. Honduras had developed an effective forest pest management programme for pine bark beetles since its 1982 outbreak. Losses during 1984–1998 were kept to a minimum through early detection and the prompt application of control measures, particularly cut-and-leave.[115]

However, another SPB outbreak occurred during 1998–2003 and killed an estimated 45 885 ha of pine forests.[116] Just 17 percent (403 000 m^3) of the 2.4 million m^3 of dead timber resulting from the outbreak were salvaged. Another severe SPB outbreak developed in 2014, where delayed control action eventually affected 500 000 ha of *P. oocarpa* forests[110] before declining in 2017. Outbreaks of native bark beetles in northern and Central America and introduced bark beetles in the Caribbean can be expected to occur periodically, particularly in older, unmanaged pine forests and plantations.

Source: Authors' own elaboration.

sold and wood production does not return to normal. Estimating this long-term effect on forest productivity would require production analysis based on supply and demand characterizations that are context-specific. This approach is not globally feasible, which is why most of the currently available assessments of disaster impacts in forestry focus on specific disasters for which precise data collection was carried out post-event, relying on the availability of localized data (TABLE 3).

FAO has been promoting a specific methodology for data collection and for calculating losses and damages to improve and standardize the estimation of forestry losses from disasters. It offers an assessment of forest resources that differentiates between the value of mature merchantable timber stands (stumpage) and timber stands that have not yet reached their rotation ages at the time of damage.

The market value of the unit stumpage is used for calculating the loss in merchantable timber stands, while four valuation techniques can be employed to estimate the value of pre-merchantable timbers lost, which are comparable sale, replacement cost, internal rate of return and income approaches. Income generated by non-timber forest products is the third aspect of forest resources.

TABLE 3
DIMENSIONS OF DISASTER IMPACTS IN FORESTRY

IMPACT CATEGORY	DAMAGED/LOST	DATA AND INDICATORS
Direct impacts	Wood production	• Value of all mature timber or standing timber affected or damaged • Present value of all timber stands that have not reached their specified rotation ages when the damage occurred • Present value of timber salvaged and marketed after the fires
	Productive assets	• Inventory of assets damaged (fences, equipment) • Present value of assets damaged
	Livelihoods	• Destroyed housing, damaged roads and other infrastructure • Relevant historical records kept by the forest owner/manager on non-timber forest products such as fuelwood, fruit, mushroom, flowers and recreational activities[117]
	Forest ecosystems and biodiversity	• Area of the ecosystem impacted • Valuation of the ecosystem asset destroyed • Period of time for the ecosystem to recover • Identification and valuation of ecosystem services losses for the period • Reconstruction needs for the effective recovery of environmental assets (management and control of pests, clearing debris, ecological surveys, etc.)
Indirect impacts	Human health (wildfire)	• Premature deaths caused by smoke inhalation
	Disruptions to social processes and functioning (wildfire)	• Disruptions to road and air traffic • Closure of businesses during and immediately after the fire • Long-term reduction of tourism, aesthetic value of the landscape or home values
	Trade loss of export markets and import restrictions (pest infestation)	• Trade restrictions put in place

Source: Authors' own elaboration.

This includes all activities related to tourism, hunting or other forest products. Based on the annual income generated in this category, a loss estimate is computed by evaluating the proportion of damaged forest area and the rotation age of the timber stands. Given that a portion of forest resources can be salvaged after a disaster, this estimated value is deducted from the income loss estimated.

2.4.2 FISHERIES AND AQUACULTURE: DIVERSE RISKS AND DISASTER IMPACTS

The sustainability of fisheries and aquaculture around the world is being threatened by the increasing frequency and intensity of disasters. Fisheries and aquaculture are of great importance in providing food security, nutrition and livelihoods for some of the most vulnerable and disadvantaged communities worldwide. As of 2020, 58.5 million people worldwide were engaged in capture fisheries (38 million people) and aquaculture (20.5 million people).[119] Of that global total, 84 percent are in Asia, and 21 percent are women.[119] The livelihoods of about 600 million people, including subsistence and secondary sector workers and their dependents, rely at least partially on fisheries and aquaculture, which forms approximately 7.5 percent of the global population.

Wild capture and aquaculture fisheries are vulnerable to multiple sudden and slow-onset disasters, including storms, tsunamis, floods, droughts, heatwaves, ocean warming, acidification, deoxygenation, disruption to precipitation and freshwater availability, and salt intrusion in coastal areas.[120] A key ecosystem risk driver for capture fisheries is the increasing intensity and frequency of marine heatwaves, which threaten marine biodiversity and ecosystems, make extreme weather more likely, and also negatively impact fisheries and aquaculture. In aquaculture, short-term impacts can include losses of production and infrastructure, increased risks of diseases, parasites and harmful algal blooms. Long-term impacts can include reduced availability of wild seed as well as reduced precipitation leading to increasing competition for freshwater. There are also increased risks for animal health, for example the changing occurrence and virulence of pathogens or the susceptibility of the organisms being cultured to pathogens and infections.

Extreme events and climate change directly affect the distribution, abundance and health of wild fish, and the viability of aquaculture processes and stocks. They compound other pressures arising from human activities such as overfishing, further affecting the environmental and economic sustainability of fisheries. In addition to natural hazards, technological disasters (e.g. chemical and oil spills), conflict and complex emergencies also affect the viability of fisheries and fishing communities. Fisheries are also exposed to a diverse range of direct and indirect disaster impacts, including displacement and migration of human populations, impacts on coastal communities and infrastructure due to rising sea levels, and changes in the frequency, distribution or intensity of tropical storms.

All these emergencies pose serious challenges to fish production, and lead to disruptions in value chains that adversely affect the well-being and livelihoods of people. The fisheries sector is greatly affected by increases in the price of inputs such as fuel, rising food costs, shifting populations and trade restrictions such as those that occurred during the COVID-19 pandemic. Located at the interface between land and water, disasters affecting fisheries can develop in isolation, in triggered consecutiveness (e.g. a tsunami following the volcanic eruption in Tonga in 2021) or in simultaneous combination, and often have mutually amplifying effects.

Fishing communities, ports, harbours, market infrastructure and aquaculture installations are commonly located at the seashore, as well as along rivers and lakes, which are areas vulnerable to various hydrological and meteorological threats. Climate change, variability and extreme weather events are compounding threats to the sustainability of capture fisheries and aquaculture development in marine and freshwater environments.

At the same time, the rapid restoration of capture fisheries activities after a disaster can provide nutritious food and employment and can fast track a community's return to normal economic activity. Fishing vessels are often used after a disaster to trade foods, materials and transport people supporting food security and livelihoods. In the event of conflicts and complex emergencies, when the movement of internally displaced people (IDP) and refugees intensifies, fisheries can play an important role in providing food security and livelihoods for them as well as the local population.

The adaptation of fisheries to the impacts of extreme events and climate change is hampered by a lack of targeted vulnerability assessments and uncertainty in the impacts on commercial fisheries, especially for countries located in tropical areas. Climate change is anticipated to have a profound impact on critical food production sectors, with the tropics projected to experience losses, particularly in the context of fisheries. For example, by 2100, fishable biomass in the ocean could drop by up to 40 percent in some tropical areas. Simulations suggest that climate change has already reduced stocks in just under half of the marine regions studied. The effects of 1.8 °C warming would see fish stocks unable to rebuild themselves, and paired with overfishing beyond sustainable levels, the result is estimated to be a decrease of global stocks of over 35 percent.

The following section discusses impacts of disasters in the fisheries and aquaculture sector and showcases various national case studies of disaster impacts on the fisheries and aquaculture sector.

Droughts, floods and harmful algal blooms (HABs) in South Africa

The fisheries and aquaculture sector in South Africa faces considerable impacts from climate change and associated disaster events, which affect the livelihoods of numerous people, especially those who are vulnerable to food insecurity and live in poverty or are dependent on this sector for their livelihoods.[121,122]

HABs occur when algae – simple photosynthetic organisms that live in the sea and freshwater – grow out of control and produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds. There are many kinds of HABs globally, caused by a variety of algal groups with different toxins. Anoxic coastal waters in South Africa are associated with the development of red tides or HABs and pose a serious threat to the fisheries and aquaculture sector. HABs are associated with a group of phytoplankton known as dinoflagellates accumulating and decaying. The resulting decay causes hypoxic conditions that can result in the mortality of marine species.[123] On the west coast of South Africa, red tides are routine in nature, while on the east coast of the country they are less predictable.[124]

In March 2021, South Africa's west coast experienced a 500 tonne "walk out" of west coast rock lobster.[125] Walkouts are a recurring event, characterized by lobsters moving out of the ocean due to hypoxic conditions resulting from local red tides, and dying on the beach.[126] While a lobster walk out in 1997 was estimated at 2 000 tonnes,[127] the 2021 event should still be considered highly impactful considering the stock status of the species (estimated at 1.9 percent of pristine levels).[128] This event was of particular concern given that local small-scale fishers identified most of the lobster that died to be small in size. In addition to the red tide-induced lobster walkout, several fish species were found beached and in shallow waters outside of their typical habitat. Also, most lobster fishers, traditional line fishers and commercial line fishers were unable to access their nearshore fishing grounds. While some fishers managed to collect lobsters that had walked out, enabling them to meet their total allowable catch quota, many others were unable to do so by the end of the season due to the loss of fishing days caused by the red tide. The red tide, therefore, resulted in a loss of income for many households, and this event could be considered economically devastating for small-scale fishers.

Data on the impact of typhoons in the Philippines

Since 1990, the Philippines has been affected by 565 disaster events that have caused an estimated USD 23 billion in damage. Approximately 85 percent of the sources of the country's production have been reported to be susceptible to disasters, and 50 percent of its territory is economically at risk. Coastal communities, especially small-scale enterprising poor people, such as fishers and shellfish gatherers, have been found to be most vulnerable to coastal flooding, coastal erosion and saltwater intrusion.

Even though the Bureau of Fisheries and Aquatic Resources (BFAR) collects specific information on the impacts of disasters in the fisheries sector, the significance of the fisheries and aquaculture sector to the national economy and as an essential source of livelihood for numerous people is not adequately reflected in government allocations, especially when compared to other agriculture subsectors. For example, for four regions impacted by Typhoon Odette (December 2021), the fisheries and aquaculture sector was allocated one-quarter of the sum directed towards the relief for rice farmers of one region only. For this reason, BFAR is frequently required to bridge the financial relief gap left for the fisheries and aquaculture sector.

In addition, the available data does not appear to be sufficiently reflected in needs assessment reports. In the needs assessment reports of the three larger typhoons that hit the Philippines in the last five years, namely Typhoon Kammuri (Tisoy), 2019,[129] Typhoon Goni, 2020,[130] Typhoon Rai (Odette), 2021,[131] the necessity to better highlight the impacts on the fishing and aquaculture communities is well reflected, including the sector-specific needs and priorities. While the assessments provide estimates for crop damages and losses, none or very few figures are reported for the fisheries and aquaculture sector. Some information on fisheries is presented for Typhoon Rai (Odette), which may indicate a push to better highlight impacts on this sector. Fish cages accounted for 63 percent of damages in aquaculture, whereas in capture fishing, fishing boats suffered the most significant part of the damage (FIGURE 32). For fisheries, 2 126 fishers were affected by the loss of their produce of USD 3.5 million from seaweeds, milkfish, tilapia and shrimp production (cages and ponds) in the three regions. For fisheries and aquaculture, fishers were unable to continue fishing after the typhoon as they lost their equipment and gear.[132] FAO observed even more significant damages to the fisheries and aquaculture sector, with losses amounting to PHP 3.97 billion (USD 79.4 million).[131]

Volcano eruption in Tonga

The Hunga Tonga–Hunga Ha'apai (HT–HH) undersea volcano in Tonga erupted on 15 January 2022 in a blast that was felt across the world. The eruption resulted in two events: the fallout of the volcanic ash cloud and a tsunami, both of which had potential impacts on fisheries production and livelihoods.

The initial disaster assessment report produced in February 2022 by the Ministry of Fisheries in Tonga focused on damage to fisheries assets covering small-scale tuna and snapper vessels, and their engines and gear. The total estimated damage to the fisheries and aquaculture subsector was USD 4.6 million. Since the report only examined damage, a second assessment was conducted as a collaboration between the Ministry of Fisheries and FAO to further examine incurred loss, reductions in economic flows and recovery requirements.

When including losses in economic flows, the HT–HH eruption and associated tsunami in January 2022 caused an estimated USD 7.3 million loss in the fisheries and aquaculture sector in Tonga (TABLE 4). Ash fall impacts were not considered in this assessment, as physical impacts from the fallout of the ash cloud were estimated as relatively minor.

The fishery sector made up 2.1 percent of Tonga's GDP in 2020–2021.[133] With a total GDP of USD 488.83 million in 2020 according to World Bank data,[134] this presents a value of about USD 10.3 million. The estimated USD 7.3 million incurred in loss and damage in the fisheries and aquaculture sector represents roughly 71 percent of the fishery sector value in GDP, indicating how significant this disaster was for the sector.

The category most impacted by this event is the artisanal/small scale fisheries, with estimated damages and losses of

USD 3.5 million accounting for 48 percent of the total estimated. According to the 2015 agriculture census,[135] only 15 percent of all households surveyed are involved in fishing activities. Out of those, 54 percent are engaged in subsistence fishing for consumption, about 42 percent in semi-subsistence (mainly for consumption and some for sale), and only 4 percent in commercial fishing. These are households indicating fishing as a main income or livelihood source. The fact that their loss is the highest despite representing a small

TABLE 4

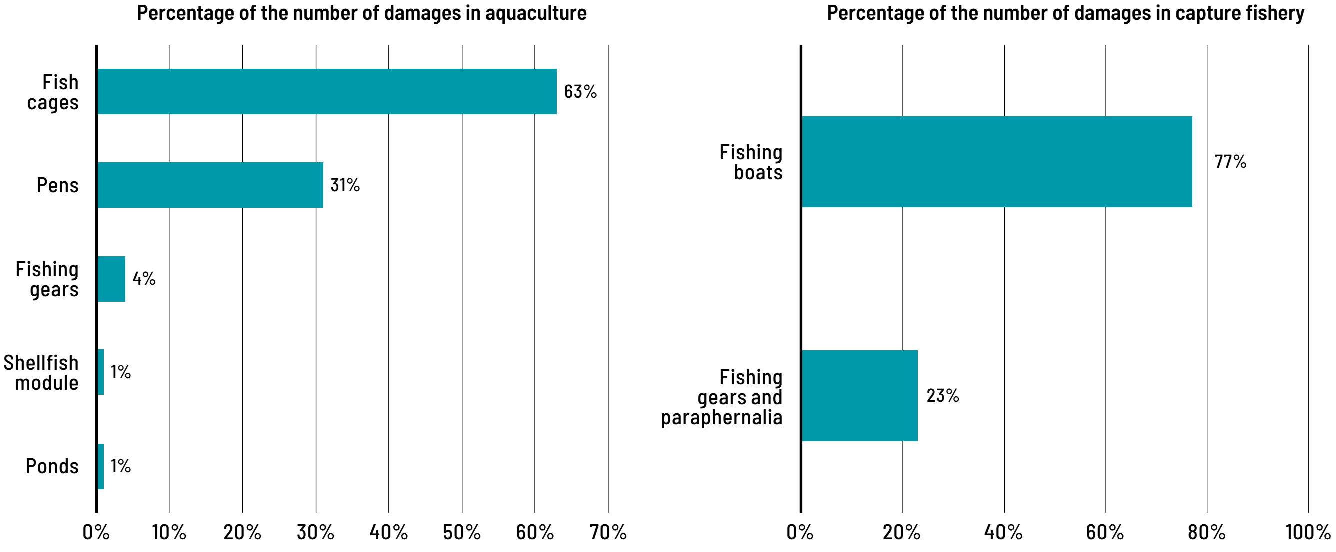
LOSS AND DAMAGE IN FISHERY AND AQUACULTURE CAUSED BY THE HUNGA TONGA–HUNGA HA'APAI ERUPTION AND TSUNAMI

CATEGORY	DAMAGE IN USD	LOSS IN USD	RECOVERY COST IN USD	ESTIMATED TOTAL IN USD
Artisanal/small scale fisheries	3 445 006	29 998	53 190	3 534 202
Commercial domestic fishing	254 859	1 425 076	-	1 680 379
Tuna foreign catch	-	560 790	-	560 790
Aquaculture/mariculture	185 985	918 665	234 872	1 339 847
Infrastructure/facilities	231 496	-	-	231 900
GRAND TOTAL	4 124 528	2 934 529	288 062	7 347 118

Source: Authors' own elaboration of FAO data.

FIGURE 32

DAMAGE AND LOSS IN FISHERIES AND AQUACULTURE CAUSED BY TYPHOON RAI



Source: FAO. 2022. *Philippines: Damages and needs assessment of families affected by Super Typhoon Rai ("Odette") in selected provinces of Region VIII and Region XIII*. FAO. doi.org/10.4060/cc0207en share of Tonga's households suggests they were strongly affected. Moreover, from a food security point of view, fish and seafood make up 10 percent, 11 percent and 13 percent of overall food expenditure in 'Eua, Tongatapu and Ha'apai divisions, respectively, according to the Household Income and Expenditure survey 2015/16.[136] About 10 percent of the total fish and seafood expenditure is covered by subsistence, i.e. households fishing activities. Overall, the access to and consumption of fish and seafood are critically important to household food security and nutrition for most households in Tonga.

The aquaculture and mariculture sector present an overall estimate of USD 1.3 million worth of losses, about 18.2 percent of the overall sector total. Within these sectors, economic losses dominated the overall estimates due to the loss of harvestable stock. The highest economic losses were experienced within commercial domestic fishing. Fortunately, very little damage occurred to brood stock since Tonga follows a catch-and-release approach for brood input and assets. However, there is no available information on impacts on the marine environment where brood stock are captured for spawning at the aquaculture farms. Apart from ornamental tropical aquarium fish production, all losses were experienced in pilot farms and projects. The large economic loss for sea cucumber was due to the loss of an estimated 6 000 mature and ready to harvest sandfish that were affected by the tsunami. ■

KENYA
View of a dry corn field in Kolewa, where a gender-transformative approach developed by FAO and its partners is implemented to achieve equality and empowerment for women in commercial agriculture.
©FAO/Patrick Meinhardt

PART 3

DISASTER RISK DRIVERS AND CASCADING IMPACTS

KEY MESSAGES

➔ Understanding systemic drivers of disaster risk – such as climate change, pandemics, epidemics and armed conflicts – and their cascading impacts on agricultural production, value chains and food security is key to building resilient agrifood systems.

➔ Attribution science can be used to demonstrate the degree to which climate change is increasing the occurrence of yield anomalies, and consequently is reducing agricultural production. Although the analysis contains high levels of uncertainty, estimates of loss and damage for four country-crop pairs – soy in Argentina, wheat in Kazakhstan and Morocco and maize in South Africa – show mostly negative impacts on yield that range from 2 to 10 percent.

➔ Pandemics such as the COVID-19 related emergency can have a significant effect on agriculture. Data from food-insecure countries shows that the COVID-19 pandemic created considerable problems for farmer access to input and output markets, such as constraints to access mechanized equipment, a shortage of labour, and in some cases, reductions in areas planted by up to 50 percent.

➔ The 2019–2020 spread of African swine fever had wide-ranging negative impacts at the global level, causing substantial socioeconomic losses. In 2020, pork production in China decreased by 26 percent in comparison to 2017 levels, and knock-on effects on production and prices were recorded in other countries such as the United States of America, Brazil, Mexico, Canada and the Philippines.

➔ Armed conflicts have a significant impact on agriculture and food security, as demonstrated by recent assessments in Somalia, the Syrian Arab Republic and Ukraine. Although the Post-Disaster Needs Assessment in Conflict Situations provides guidance on estimating losses and damages, this framework should be further developed to provide better information to foster risk reduction during armed conflicts, and, PDNAs in conflict situations carried out more systematically.

In today's interconnected world, overlaying and compounding risks lead to both indirect and direct impacts on agriculture. Risk is omnipresent and is growing at a rate that is outstripping our efforts to reduce it. The interconnectedness of global systems, including food systems, means they are more vulnerable in an increasingly uncertain and changing risk landscape. Global risks like climate change, environmental degradation and biodiversity loss are existential in nature, and contribute to increasing disaster risk. Beyond the direct impact of disasters, indirect, cascading impacts are also significant, even at the global level. This section discusses the systemic nature of risk from the perspective of the agriculture sector.

Addressing risk requires not only an assessment of the direct impacts of disasters, but also an understanding of how the impact of disasters cascade within and across sectors and over geographic areas, the way in which elements of affected systems interact with each other during a hazard event and the systemic factors driving risks. This depends on the context in which the risk manifests, including the adverse or positive outcomes of policies and actions. The future cost of damage and loss will continue to escalate unless vulnerability and exposure to hazards, along with other concurrent crises, are systematically addressed.

This part of the report builds on the analysis presented in **Part 2** by advancing an understanding of the drivers and the increasing exposure to systemic risk in agriculture. It does so through a series of case studies selected based on four criteria: i) scale of impacts; ii) data availability; iii) recent occurrence; and iv) evidence of implications on a scale from the origin of the hazard to global. The study cases that are presented reflect the main underlying risk drivers, which are climate change, pandemics and epidemics, and conflicts. The limited availability of case studies and data sets restricts the amount of evidence that can be drawn upon, and although disasters and crises affect vulnerable populations such as women, older persons, persons with disabilities, migrants, or Indigenous Peoples, it was not possible at this stage to unpack these subdimensions in detail within the following case studies.

The first section of **Part 3** focuses on climate change as a risk driver in agriculture. An impact modelling approach is deployed based on attribution science to disentangle the effect that climate change has on agricultural yields and increased disaster risk. If climate change impacts further increase, some extreme events are likely to become more frequent, with a higher likelihood of unprecedented intensities, durations or spatial extent. The analysis in this section is limited in geographic and product scope, but the modelling approach demonstrates a method that can potentially be expanded and scaled up. Advancing the understanding of how disaster-affected yields were influenced by climate change in the past is important to enhance the understanding of this driver in the evolving risk landscape.

In the following section, the discussion moves to the impacts of biological hazards – pandemic and epidemic – which also cause substantial damage and loss in agriculture and the agrifood systems. The COVID-19 emergency is analysed as an example of a pandemic, while the African swine fever (ASF) outbreak is presented as a case of an epidemic. The cascading global impacts of these disasters caused by biological hazards and their interplay with underlying risk drivers are analysed. Information on armed conflicts in the Syrian Arab Republic, Somalia and Ukraine complements this section as a key example of this type of hazard and its impact.

These case studies contribute to an understanding of risk and of the cascading nature of systemic risks. Climate change is driving a rise in the frequency and intensity of natural hazards. Starting off as a public health disaster, the COVID-19 pandemic amplified existing risks and vulnerabilities and aggravated losses in agriculture by restricting access to resources and services. ASF is a clear example of how transboundary animal diseases (TADs) that are non-transmissible to humans have wide-ranging systemic impacts, including when occurring simultaneously with other disasters such as the COVID-19 pandemic. In conflict situations, the combination of armed conflict, multiple hazards, climate change and the depletion of natural resources is amplifying disaster risk. Armed conflict can exacerbate a country's underlying exposure and vulnerability and diminish coping capacity for hazards of all kinds.

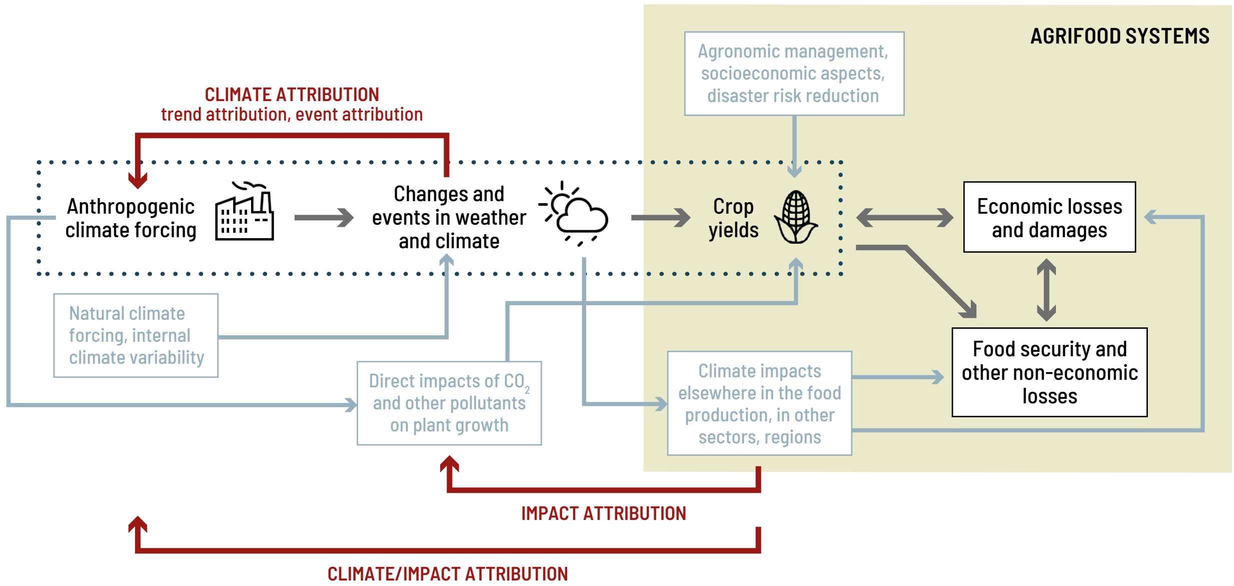
Together, these three sections provide evidence on the systemic nature of risk, and the increasing vulnerability and exposure to disasters that agriculture is currently facing in several countries. Lessons learned and recommendations stemming from these studies demonstrate that policies, plans, programmes and investments should be reoriented further towards enhancing resilience. ■

3.1. LINKING CLIMATE CHANGE TO AGRICULTURAL PRODUCTION LOSS

Climate change is contributing to a rise in hazard incidence, leading to increased vulnerability and exposure and diminishing the coping capacity of individuals and systems.[5] The consequences are manifested not only in the loss of crops and agricultural production, but also in the devastation of agricultural livelihoods with cascading negative chain reactions with long-lasting effects at the domestic, community, national, regional and even international levels.

Agriculture is particularly exposed and vulnerable to a multitude of changes and events in the climate system, impacting agricultural production, food security and agricultural livelihoods (FIGURE 33). When occurring simultaneously with other disasters and

FIGURE 33
CLIMATE IMPACTS ON AGRIFOOD SYSTEMS AND RELEVANT ATTRIBUTION CONCEPTS



Sources: Authors' own elaboration based on extending concepts from O'Neill, B., van Aalst, M., Zaiton Ibrahim, Z., Berrang Ford, L., Bhadwal, S., Buhaug, H., Diaz, D. *et al.* 2022. Key Risks Across Sectors and Regions. In: Climate Change 2022: *Impacts, Adaptation and Vulnerability*. Cambridge, UK, Cambridge University Press and the wider literature.

crises, such as biological hazards and conflict (explored later in **Part 3**), climate change risks will become increasingly complex and more difficult to manage. Climate and weather-related hazards are already affecting food security, particularly in low-latitude regions, and the likelihood of abrupt and irreversible changes and their impacts is estimated with a high level of probability to increase with higher global warming levels. According to the IPCC report, cereal prices will increase by 1–29 percent in 2050 due to climate change, and an additional 1–183 million people will be at risk of hunger.[137] Enhancing the understanding of how climate change is driving disaster risk in food systems is essential for understanding how food systems will be impacted, and should influence the design of the policies, programmes, and financing mechanisms necessary to strengthen the resilience of agriculture and agrifood systems.

The analysis method outlined in this chapter concentrates on agricultural crops. It isolates the climate change contribution and models the impacts while considering the interactions of multiple climate hazards.

3.1.1 ATTRIBUTION OF THE IMPACTS OF CLIMATE CHANGE ON AGRICULTURE

Attribution science[s] offers an entry point for estimating the effect of climate change on crop yields and the degree to which agricultural production is being influenced by extreme and slow-onset events exacerbated by climate change. Attribution science is defined as evaluating and communicating linkages associated with climate change,[43,138] such as between greenhouse gas emissions over climate and extreme weather events and impacts in

s "Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assessment of confidence." See, IPCC. 2021. Annex VII: Glossary. In: Matthews, J.B.R., V. Möller, R. van Diemen, J.S. Fuglestvedt, V. Masson-Delmotte, C. Méndez, S. Semenov, A. Reisinger, eds. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou, eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 2215–2256. www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_AnnexVII.pdf

BOX 10

METHODOLOGY TO ATTRIBUTE YIELD CHANGE TO CLIMATE CHANGE

The aim of this analysis is to evaluate how climate change affects yield levels in different contexts. The results of this study are based on comparing observed yield records with estimated counterfactual and factual crop yield distributions for soy yields in Argentina, wheat yields in Kazakhstan and Morocco, and maize yields in South Africa (see **Technical annex 3** for a more detailed description of the methods and data used).

Factual yields are the yields simulated for climate as it has actually been evolving, while counterfactual yields are those simulated for climate as it might have been without greenhouse gas increases and other anthropogenic climate forcing factors. For that purpose, a statistical, multivariate crop yield model based on the observed crop yield data in the full length of their available record[140] and observationally derived climate data (20CRv3-W5E5) is built.

The statistical yield model is then applied to a set of factual and counterfactual climate data, taken from the Detection and Attribution Model Intercomparison Project (DAMIP)[141] component of the Coupled Model Intercomparison Project Phase 6 (CMIP6). A set of historical simulations includes historical changes of both anthropogenic (greenhouse gases, ozone, aerosols, land use, etc.) and natural (solar irradiance, volcanic aerosol) climate forcing factors. Using the variable selection and model parameters from the observationally derived statistical model gives the distributions of factual and counterfactual yields, from which the likelihoods of yield levels associated with a specific extreme event are derived.

Source: Authors' own elaboration.

human and natural systems. Synthesizing such linkages builds up a general picture of the effect of climate change to date on certain types of hazards in given regions, with hazard- and region-dependent uncertainty.[139]

To demonstrate the effectiveness of this approach, the methodology was applied to estimate crop loss and damage in four countries: soy in Argentina, wheat in in Kazakhstan and Morocco, and maize in South Africa – representing the most important crops for each country in terms of economy and food security. TABLE 5 summarizes the attributed influence of climate change – integrating slow-onset changes as well as different types of extreme weather and climate events – on yield anomalies. The "historical attribution" result states the influence that climate change since pre-industrial times is estimated to have had on yields overall in the period of 2000–2019. This is negative for three out of the four countries. The magnitude of the influence is demonstrated by giving a best estimate for the climate change impact on the mean yield. The "event attribution" result states complementarily how more or less likely the yield levels recorded in a specific year of interest have become because of climate change. For this, a year in the recent past is chosen with particularly low yields, for which substantial socioeconomic impacts are documented. An important caveat concerning the results is that there is a significant degree of uncertainty involved in the estimation of such attributions, and although no uncertainty quantification was attempted for this assessment, all results should be treated as approximations.

Results of the attribution analysis

In Argentina, the model shows that observed variations in high and low temperatures, rainfall intensity and drought explain the higher share of the recorded soy yield variations in the highest-producing provinces of Argentina. The model indicates that climate change to date has been statistically significantly beneficial to soybean yields in Argentina (FIGURE 34). Results suggest that climate change increased average yields during the period of 2000–2019 by less than 0.1 t/ha, amounting to about 3 percent of the average observed yield during that period. Low yield levels recorded in 2018 specifically make for an interesting case study due to the lasting impact they had as a reference point for bad years, with the Rosario Grains Exchange speaking in 2022 of "the ghost of the 2018 production disaster."[2,142] Results also indicate that yield anomalies in Argentina that are as low or lower than those in 2018 may have become about half as likely due to climate change, subject to uncertainty. Note, however, that the yield model only captures some of the recorded yield anomaly.

In Kazakhstan, results show that a substantial share of recorded wheat yield variations in the highest-producing oblast can be explained by variations in growing degree days, temperature variability, cold, precipitation variability and drought. The yield model is less robust than is the case with the other case studies. Still, the modelling indicates that climate change to date has been statistically significantly detrimental to wheat yields in this part of Kazakhstan (FIGURE 34). It suggests that climate change decreased average yields during the period of 2000–2019 by about 0.1 t/ha, which is more than 10 percent of the average observed yield during that period. Low yield levels recorded in 2010 specifically make for an interesting case study because that year showed a record low of below 8 million tonnes of wheat production in northern Kazakhstan.[143] The model results also indicate that yield anomalies in this region of Kazakhstan as low or lower than those found for 2010 may have become about 2.5 times more likely due to climate change to date, subject to uncertainty.

The model shows that a large share of the recorded wheat yield variability in the highest-producing regions of Morocco can be explained by variations in temperature variability, high temperatures, drought and high precipitation. The modelling indicates that climate change to date has been statistically significantly detrimental to wheat yields in Morocco (FIGURE 34). It suggests that climate change decreased average yields during the period of 2000–2019 by less than 0.1 t/ha and amounted to about 2 percent of the average observed yield during that period. Low yield levels recorded in 2019 specifically make for an interesting case study because they prompted a response from Morocco's central bank[144] and were followed by even lower yields in 2020,[145] multiplying the impacts. The modelling indicates that yield anomalies in Morocco as low or lower than those derived for 2019 may have become slightly more likely due to climate change, subject to uncertainty.

For South Africa, the model shows that a large share of the recorded maize yield variations in the highest-producing provinces can be explained by variations in growing degree days, temperature variability, cold, drought and high precipitation. Climate change to date has been statistically significantly detrimental to maize yields in South Africa (FIGURE 34). It suggests that climate change decreased average yields during the period of 2000–2019 by more than »

TABLE 5

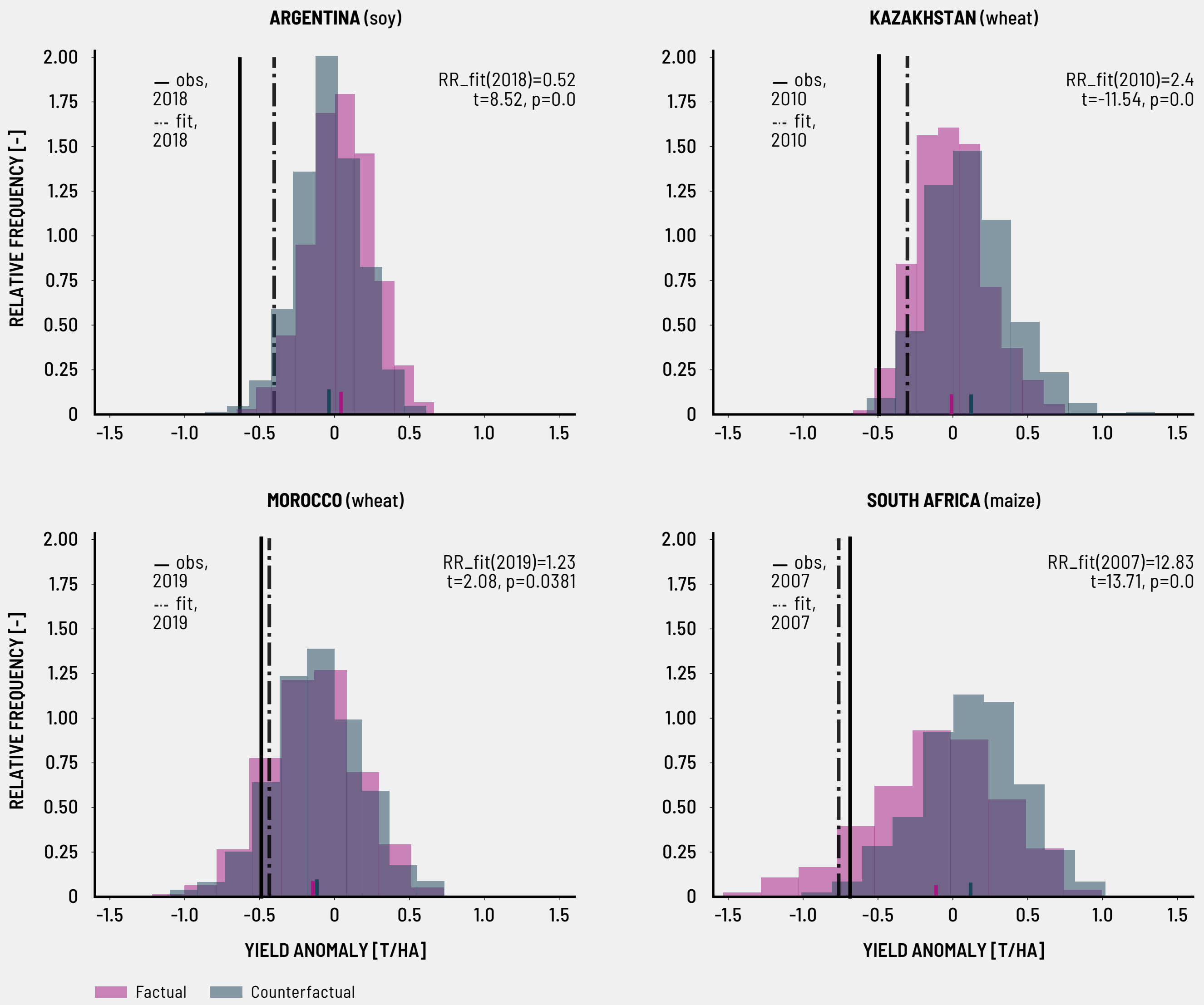
OVERVIEW OF ATTRIBUTION RESULTS

COUNTRY	CROP	HISTORICAL ATTRIBUTION **Influence of human-induced climate change, including slow-onset events and extreme events, on overall crop production in the last two decades.**	EVENT ATTRIBUTION **Influence of human-induced climate change on the likelihood of yield levels associated with a specific extreme event observed in the recent past.**
ARGENTINA	SOYBEAN	Historically, climate change is estimated to have been beneficial to yields in Argentina. With climate change, simulated average yields are less than 0.1 t/ha higher with climate change for 2000–2019 when observed yields averaged about 2.7 t/ha. Annual soy production during 2000–2019 may on average have **increased by about 3 percent** due to climate change.	With climate change, yield anomalies in Argentina as low or lower than those derived for 2018 are estimated to be approximately half as likely in 2000–2019 due to climate change.
KAZAKHSTAN	WHEAT	Historically, climate change is estimated to have been detrimental to yields. With climate change, simulated average yields are about 0.1 t/ha lower for 2000–2019 when observed yields averaged about 1.0 t/ha. Annual wheat production during 2000–2019 may on average have **decreased by more than 10 percent** due to climate change.	With climate change, yield anomalies in northern Kazakhstan as low or lower than those derived for 2010 are estimated to be approximately 2.5 times more likely in 2000–2019 due to climate change.
MOROCCO	WHEAT	Historically, climate change is estimated to have been detrimental to yields. With climate change, simulated average yields are less than 0.1 t/ha lower for 2000–2019 when observed yields averaged about 1.6 t/ha. Annual wheat production during 2000–2019 may on average have **decreased by about 2 percent** due to climate change.	With climate change, yield anomalies in Morocco as low or lower than those derived for 2019 are estimated to be slightly more likely in 2000–2019 due to climate change.
SOUTH AFRICA	MAIZE	Historically, climate change is estimated to have been detrimental to yields. With climate change, simulated average yields are more than 0.2 t/ha lower for 2000–2019 when observed yields averaged about 4.0 t/ha. Annual maize production during 2000–2019 may on average have **decreased by more than 5 percent** due to climate change.	With climate change, yield anomalies in South Africa as low or lower than those derived for 2007 are estimated to be more than approximately ten times more likely in 2000–2019 due to climate change.

Source: Authors' own elaboration.
Note: The results are subject to uncertainty that is not quantified.

FIGURE 34

ESTIMATED INFLUENCE OF CLIMATE CHANGE ON CROP YIELDS TO DATE: FOUR CASE STUDIES



Notes: Red = factual yield distribution for 2000–2019 based on the statistical yield model run applied to 50 factual historical climate simulations from the MIROC6 climate model from CMIP6-DAMIP. Blue = counterfactual yield distribution based on corresponding counterfactual climate simulations in which greenhouse gases and other anthropogenic forcing factors are set to their pre-industrial value. The factual and counterfactual distributions are statistically significantly different in each case as indicated by the t-test results stated. Solid black line = yield anomaly observed in a year of specific interest as indicated in the text in the plot. Dashed black line = yield anomaly predicted by the statistical model based on observationally derived climate data for the same year of specific interest. The RR fit value stated indicates how the predicted value for that specific year is estimated to have changed due to climate change.
Source: Authors' own elaboration showing analysis results based on crop yield data from FAOSTAT. 2023. Argentina, Morocco, South Africa. In: *FAO*. Rome. [Cited June 2023]. https://www.fao.org/faostat/en/#data/QCL and Bureau of National Statistics Kazakhstan. 2022. *Statistics of agriculture, forestry, hunting and fisheries.*; climate reanalysis data from Frieler, K., Volkholz, J., Lange, S., Schewe, J., Mengel, M., del Rocío Rivas López, M., Otto, C. *et al.* 2023. Scenario set-up and forcing data for impact model evaluation and impact attribution within the third round of the Inter-Sectoral Model Intercomparison Project (ISIMIP3a). Preprint. In: *EGUsphere*. [Cited July 2023]. doi:10.5194/egusphere-2023-281; Lange, S., Mengel, M., Triu, S. and Büchner, M. 2022. ISIMIP3a atmospheric climate input data (v1.0). In: *ISIMIP*. [Cited July 2023]. doi:10.48364/ISIMIP.982724 and references therein; output data from the MIROC6 climate model from Tatebe, H., Ogura, T., Nitta, T., Komuro, Y., Ogochi, K., Takemura, T., Sudo, K. *et al.* 2019. Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6. *Geoscientific Model Development*, 12(7): 2727–2765. doi.org/10.5194/gmd-12-2727-2019 that are part of CMIP6/DAMIP (Eyring, V., Bony, S., Meehl, G.A., Senior, C.A., Stevens, B., Stouffer, R.J. and Taylor, K.E. 2016. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development*, 9(5): 1937–1958. doi.org/10.5194/gmd-9-1937-2016; Gillett, N.P., Shiogama, H., Funke, B., Hegerl, G., Knutti, R., Matthes, K., Santer, B.D. *et al.* 2016. The Detection and Attribution Model Intercomparison Project (DAMIP v1.0) contribution to CMIP6. *Geoscientific Model Development*, 9, 3685–3697. doi:10.5194/gmd-9-3685-2016); bias-correction code from Lange S. 2019. Trend-preserving bias adjustment and statistical downscaling with ISIMIP3BASD (v1.0). *Geoscientific. Model Development*, 12, 3055–3070. doi:10.5194/gmd-12-3055-2019 developed for ISIMIP3, and methods adapted and combined from the climate attribution and impact modelling literature.

» 0.2 t/ha, amounting to more than 5 percent of the average observed yield during that period, and that the negative impact of climate change was even stronger in the lowest-yielding years. Low yield levels recorded in 2007 specifically make for an interesting case study because of the food insecurity that ensued. Together with similar maize yield anomalies in neighbouring Lesotho, which is subject to largely the same weather and climate, the low yields in South Africa in this year have been implicated in food shortages in Lesotho.[146,5] The modelling indicates that maize yield anomalies in South Africa, as low or lower than those derived for 2007, have become about ten times more likely due to climate change to date, subject to uncertainty.

The results show negative impacts of climate change in three out of the four cases analysed, with a range of yield losses explained by anthropogenic climate change depending on crop type and country of up to 10 percent, subject to yet unquantified uncertainty. Going forward, it will be important to further evaluate how much climate change contributes to aspects of the agrifood system's other yields. The nutrient content of crops is also thought to be impacted by climate change,[5,147] as well as other parts of the crop value chain (food processing, aggregation, transport, distribution), the demand side, and other agricultural sectors such as animal and livestock health and productivity, or fisheries yields and aquaculture.[5]

To summarize, results suggest that climate change may be already exacerbating agricultural losses. The results also highlight the importance of investing in measures to reduce losses and damages. If the methodology presented here is applied to future climate projections, as opposed to the counterfactual past, and complemented with a quantification of economic losses and consideration of non-economic losses, such evidence may inform comprehensive climate and disaster risk management and contribute to the loss and damage negotiations, including aspects of the agriculture sectors under the United Nations Framework Convention on Climate Change (UNFCCC) framework.

The results suggest that climate change may be already exacerbating agricultural losses, and they highlight the importance of investing in mitigation, adaptation and disaster risk reduction among other measures to avert, minimize, and address losses and damages. ■

3.2 PANDEMIC AND EPIDEMIC: COVID-19 AND AFRICAN SWINE FEVER

This subsection presents and analyses the impacts on agriculture and food security of two recent biological disasters, the COVID-19 pandemic and ASF. These disasters did not only have wide ranging impacts on human and animal health, but also had cascading impacts on agrifood systems and exacerbated disaster risk in society at large. This section provides an overview of impacts on agriculture and agricultural producers in 19 countries[t] classified as being in a food crisis,[u] and then zooms in on a cross-country analysis of 11 food-insecure countries to provide insights on how restrictions imposed to stop the spread of the pandemic affected the already precarious situation of agricultural production and food security in those countries. Referring to and building on available literature on the impacts of the pandemic on the agriculture sector, the findings in this section are generated from DIEM monitoring surveys carried out between 2020 and 2022 in over 44 000 farming households in 19 countries.[v] Results

t The countries selected for inclusion in the study are priority countries in the Global Humanitarian Response Plan for COVID-19 (OCHA, 2020) or the Global Report on Food Crises (WFP, 2020, 2021). These countries are: Afghanistan, the Central African Republic, Chad, Colombia, Haiti, Iraq, Lebanon, Liberia, Libya, Mali, Mozambique, Myanmar, the Niger, Pakistan, the Philippines, Sierra Leone, Somalia, Togo and Zimbabwe.

u These countries are: Afghanistan, the Central African Republic, Colombia, the Democratic Republic of the Congo, Liberia, Mali, the Niger, Sierra Leone, Somalia, Yemen and Zimbabwe.

v The countries selected for inclusion in the study are priority countries in the *Global Humanitarian Response Plan for COVID-19* (OCHA, 2020) or the *Global Report on Food Crises* (WFP, 2020, 2021). While past studies were limited in temporal frame and scope, this analysis of cross-country surveys repeated over three years demonstrates the lagged effects of restriction policies on agricultural production.

offer insights and recommendations on how policymakers and practitioners can incorporate lessons learned into future multihazard DRR and response plans, strategies and disaster risk financing arrangements.

The evidence of severe implications of transboundary animal diseases on economies and food security is presented within the section on the ASF epidemic. A viral disease of domestic and wild pigs, ASF has been framed as one of the most serious animal health threats ever. The 2019–2020 spread of ASF had wide-ranging negative impacts at the global scale, causing substantial socioeconomic losses across the pig value chain, threatening production, food security, livelihoods and impacting global markets. Although not transmissible to humans, ASF poses significant threats to food security and sustainable development. This section also offers solutions and ways forward to address and manage TADs through risk-informed preventative and anticipatory approaches – including adopting One Health approaches at the global, regional, national and local levels.

3.2.1 EFFECT OF COVID-19 RESTRICTIONS ON CROP PRODUCTION

It is estimated that between 691 and 783 million people in the world faced hunger in 2022. This is 122 million more people than in 2019, before the global COVID-19 pandemic.[148] Populations in food crisis countries were severely affected by restrictions enforced in 2020, affecting household incomes across economic sectors. Even though the COVID-19 pandemic was primarily a health crisis, it had cascading impacts on livelihoods, agrifood systems, inputs, services and production.

Despite exemptions for the agricultural sector on the restrictions imposed in many countries, initial assessments from DIEM surveys show that pandemic-related measures negatively affected farmers' livelihoods. The pandemic disrupted food systems through labour shortages, impeding seasonal labour movements, particularly for labour-intensive production systems. Disruptions in transport and logistics services for agricultural products also pushed down farm-gate prices just as retail prices were driven up, affecting farmers' incomes as the cost of living increased.

The DIEM survey reports highlighted that the immediate impact of the COVID-19 pandemic on agriculture had negatively affected farmers' livelihoods despite restriction exemptions for the agriculture sector. In Bangladesh, the price of rice and food increased by more than 35 percent, while farm-gate prices dropped due to transportation and market access restrictions, particularly for short shelf-life products.[149] In the Niger, households reported exceptional difficulties in marketing their products due to increased transportation costs, low farm-gate selling prices for farmers, and low demand from traders who were unable to travel to the farms.[150] Similar trends were observed in India.[151]

A cross-country analysis conducted by FAO on the agriculture sector in 11 food-insecure countries[w] found that the COVID-19 pandemic had caused a shock to food security and livelihoods comparable to that of conflicts or natural hazard-induced disasters.[152] Building on data collected between June and November 2020, the study showed how within the agriculture sector, restrictions affected subsectors differently. Impact pathways largely depended upon the frequency with which households needed to secure production inputs, supply chain constraints and the ability to store or keep the agricultural product when facing delays accessing markets.

Livestock and cash crop producers were among the most severely affected, reporting difficulties in accessing inputs, selling their products, accessing pastures (due to movement restrictions) and accessing international markets. Coping mechanisms, including delaying sales or proceeding to distress sales if feeding herds became too costly, helped these producers avoid total losses. For petty traders and producers of fish and vegetables, the inability to access markets caused a complete loss of rapidly perishable goods and caused an immediate income shock. Other DIEM monitoring survey reports found bottlenecks

w Afghanistan, the Central African Republic, Colombia, the Democratic Republic of the Congo, Liberia, Mali, the Niger, Sierra Leone, Somalia, Yemen and Zimbabwe.

to access inputs in almost every country surveyed.[153,154,155,156,157,158,159,160,161,162,163]

Additional assessments of the COVID-19 pandemic lockdowns in various countries confirmed a contraction in agricultural input supply and labour shortages as well as reduced delivery of veterinary services.[164] The overwhelming majority of smallholder farmers surveyed in 2021 in South Africa could not purchase seeds and seedlings, and over 75 percent faced constraints in accessing mechanized equipment for the 2020/21 crop cycle.[165] Farmers in Bangladesh, India and Pakistan were affected by a shortage of labour and of intermediate inputs including fertilizer, pesticides, seeds, livestock feed and even power supply, particularly for the *kharif* season.[166] In Bangladesh, over 90 percent of farmers had difficulties sourcing agricultural inputs, manpower and machinery for rice planting, harvesting and threshing and over 60 percent faced difficulties in commercializing their produce, leading to food price increases.[167] In India, over 50 percent of farmers reported the disruption of supplies for one agricultural input, over one-third reported higher fertilizer prices, and farmers who faced lower farm-gate prices and higher production costs faced difficulties in repaying debts, exacerbating supply chain tensions and eroding coping capacity.[151]

As restrictions were loosened, the spike in food prices across countries decreased and prices stabilized[168,169] but did not return to pre-pandemic levels, and income shocks caused by reduced farm-gate prices or production losses affected food security by reducing farmers' purchasing power. The COVID-19 pandemic had lingering effects on the agriculture sector, causing supply chain crises that continued to push prices upwards despite the global economic recovery in 2021.

Although transportation disruptions within countries were normalized at the end of lockdowns, international movement restrictions affected the highly concentrated fertilizer trade. This pushed the price of agricultural inputs upwards, leading the Organisation for Economic Co-operation and Development (OECD) to warn that it "could weigh on yields and crop production in 2020 and 2021, particularly in developing countries."[170] Successive waves of COVID-19 subvariant epidemics also prompted additional restrictions in countries, particularly in regions where access to vaccines remained limited. As shown in FIGURE 35, difficulties in accessing transportation were high in 2020 and peaked in 2021, and then generally decreased in 2022. Conversely, access to inputs increased sharply in 2021 and 2022 in many regions.

In 2022, long after COVID-19 restrictions had been lifted, farmers across many countries continued to report challenges in gaining access to chemical inputs and seeds. In Myanmar, difficulties led to a reduction in area planted and a decrease in production.[158] Reduced access to fertilizer was the primary explanation for the reduction of the area of wheat planted in Pakistan.[171] In the Near East, difficulties in accessing inputs were compounded by devaluation of the national currencies in Lebanon and Iraq.[172,173]

COVID-19 and area planted

The results of the regressions show that planted areas were more likely to be reduced for cereal and vegetable crops than for fruit or cash crops, where the latter are produced for their commercial value rather than for use by the grower. The models considered the impact of rainfall anomaly, gender of household head and conflict. As expected, the models found that these factors contributed to a reduction in the area planted.

The results show that when COVID-19 restrictions were implemented during the main planting season, there was an unambiguous reduction in the area planted. The log-odds coefficient for restrictions on people gathering is -0.157, with a 95 percent confidence interval,[x] which translates into an average predicted probability of farmers reporting less or much less area planted that increases from around 22 percent, without gathering restrictions to roughly 50 percent, if the gathering restrictions were very stringent (when groups of ten or fewer people were banned). The negative impact of gathering restrictions extended to the

x The confidence interval for all the log-odds ratio coefficients cited in this chapter is 95 percent.

growing period when the crop cultivated was rice, which must be transplanted after the first planting period.

When controlling for the closure of business in addition to stay-at-home orders, holding gathering restrictions constant, the chances of reducing the area planted increase from a probability of about one-third without stay-home restrictions to 50 percent when staying home was a requirement, with a log-odds coefficient of -0.127, and the closure of businesses more than doubled the chances of reducing the area planted – from 29 percent to 64 percent – when holding the level of other restrictions constant, as it deprived farmers of access to inputs and equipment or animals for land preparation.

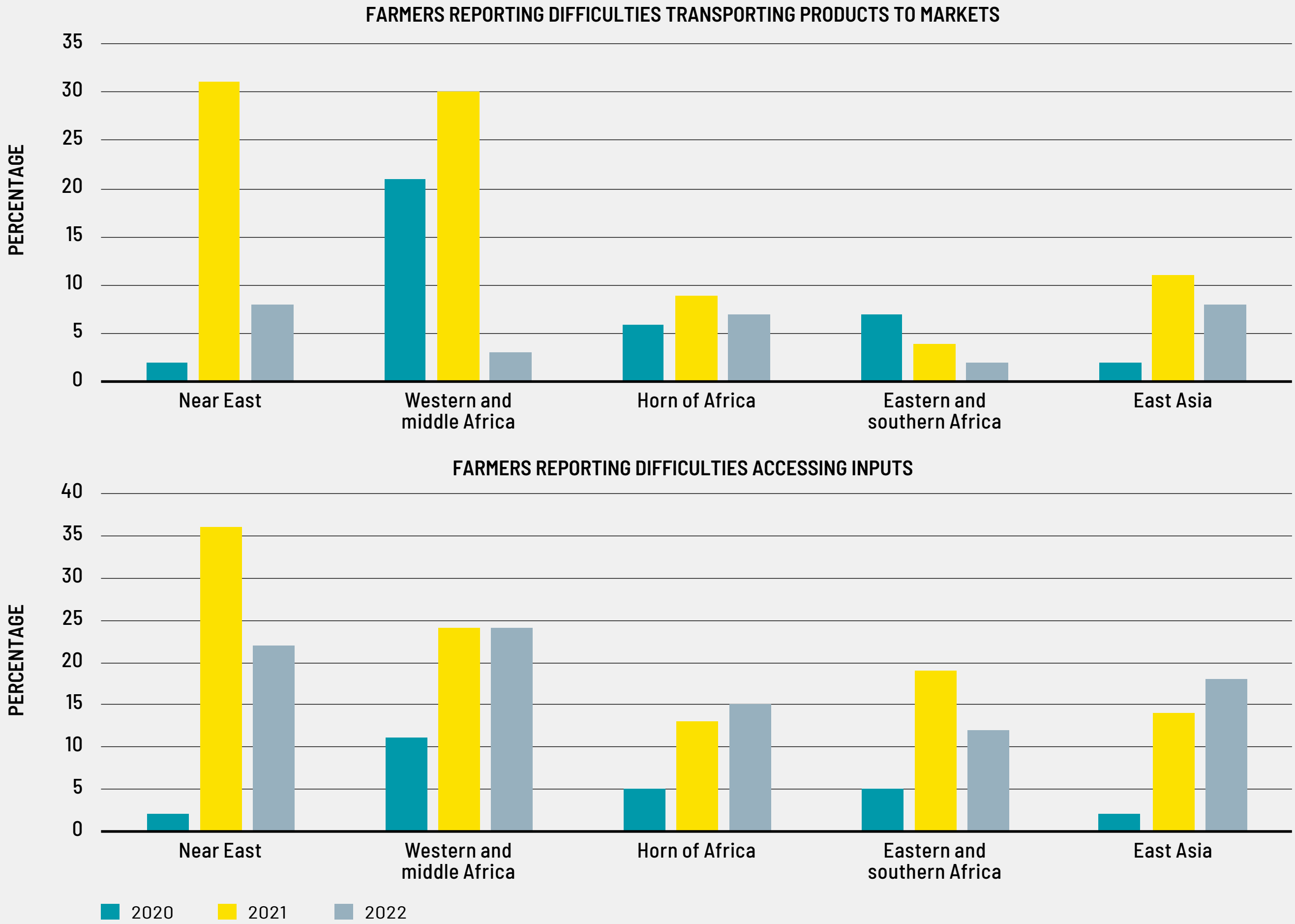
COVID-19 and perceived harvest change

Consistent with the results of the analysis of changes in planted area, producers of fruit and cash crops were comparatively less affected than those of staples (cereals and pulses). Much of the negative changes in harvest are explained by changes in the area planted, with an average predicted probability for farmers affected by workplace closure during the time of planting of reporting a reduction in harvest reaching 97 percent (against 40 percent without business closure restrictions).

During the harvest period, lockdowns were found to be associated with odds of reporting positive harvest changes of only 73 percent of those who were not under restrictions. In other

FIGURE 35

PERCENTAGE OF FARMERS REPORTING DIFFICULTIES TRANSPORTING PRODUCTS AND ACCESSING INPUTS



Source: Meta-analysis of Data in Emergencies (DIEM) Monitoring data (FAO, September 2022). FAO. 2022. Data in Emergencies (DIEM) – Monitoring: Monitoring of shocks and agricultural livelihoods in priority countries. In: *FAO*. Rome. [Cited July 2023]. https://data-in-emergencies.fao.org/pages/monitoring words, while holding other factors constant, the average predicted probability of reporting negative harvest changes was 55 percent when farmers were not subjected to lockdown during the harvest period, and it was as high as 75 percent if they were under lockdown restrictions during that critical time.

Likewise, gathering restrictions are associated with odds of only 56 percent reporting an increase in harvest compared to places that were not under these restrictions at harvest. Holding other factors constant, this implies that restrictions on gatherings during the harvest period nearly doubled the likelihood of reporting negative harvest changes, with a probability of 77 percent. Workplace closure during harvest is also associated with a 64 percent lower chance of reporting positive harvest changes, thus increasing the probabilities for farmers to report a reduction in their harvest from roughly half to 84 percent while holding other factors constant.

COVID-19 restrictions and access to inputs

Finally, the analysis shows the associations between COVID-19 restrictions and the likelihood of farmers reporting difficulty in accessing agricultural inputs. Those who were most likely to be affected by difficulties in accessing agricultural inputs were cereals and pulses producers, while fruit and cash-crop producers were significantly less likely to report such difficulties, particularly cash-crop producers.

The results show that restricting internal movements during the growing period significantly increased the likelihood of reporting such difficulties, likely because the growing period is a time when smallholder farmers in developing countries also earn income from secondary sources, which were more affected by COVID-19 restrictions.

Controlling for the price of rice shows how access to inputs for smallholder farmers – who account for most of the respondents – is conditional upon access to food markets. This is a critical reminder that COVID-19 restrictions affected access to inputs not only through supply shocks, but also through their immediate negative impact on income sources by impeding access to food and labour markets for farmers.[y,174]

Stay-at-home requirements as well as international trade restrictions during the planting season were the restrictions that most heavily affected access to inputs in this subset

y See the results from household surveys in 11 countries with high pre-existing levels of food insecurity in FAO. 2021. *Agricultural Livelihoods and Food Security in the Context of COVID-19, Cross-country monitoring report*. Rome. https://www.fao.org/3/cb4747en/cb4747en.pdf

BOX 11

METHODOLOGY TO ESTIMATE THE IMPACT OF THE COVID-19 PANDEMIC ON AGRICULTURE USING THE DATA IN EMERGENCIES (DIEM) INFORMATION SYSTEM

Using data from DIEM surveys and DIEM survey reports across 11 food-insecure countries, the pandemic impact channels on agriculture production are characterized. Agricultural production was affected by reduced input access or labour shortages. Disruptions in transport and logistics for agricultural products led to a decrease in farm-gate prices. Meanwhile, retail prices increased, affecting farmers' incomes as the cost of living rose.

Ordinal logistic regressions are employed to assess the correlation between COVID-19-related restrictions and changes in planted area, perceived harvest changes, and access to inputs. Distinct impacts are evaluated for producers of cereals, vegetables, fruits and cash crops. The models considered the impact of rainfall anomaly, gender of household head, and conflict. The effects of COVID-19 restrictions are estimated depending on their time of implementation (planting period, growing period, harvest) and their types (closure of business, stay-home orders, internal movement restrictions and gathering restrictions).

Source: Authors' own elaboration.

of countries, increasing the odds of reporting difficulty in finding inputs by 33 percent and 53 percent, respectively. Internal movement restrictions during the planting period also reduced the likelihood of farmers complaining about access to inputs, something that can easily be explained by the reduction in planting areas associated with this restriction.

Farmers particularly needed access to inputs such as seeds during the planting season, when restrictions were most harmful, and the lack of such inputs has the most damaging effect on agricultural production. Many individual survey reports support this conclusion. In Sierra Leone, for example, it was reported that seeds, particularly vegetable seeds, were difficult to supply due to COVID-19 restrictions. In Somalia, in 2021, farmers who reduced the area they planted largely explained such reductions as the result of the inability to control pest diseases, difficulties accessing seeds and generally higher input prices.[175] The inability to import spare parts for essential machinery for land preparation was also reported to reduce access to essential machinery, causing reductions in planted areas.

During the planting period, in order of magnitude, the closure of businesses, stay at home orders, gathering restrictions and internal movement restrictions were the most damaging to agriculture. During the harvest period, labour availability, gathering bans and workplace closure impeded agricultural production, including by stopping workers from reaching fields where extra labour was needed.

The above factors were associated with a reduction of area planted and lower agricultural production. This is particularly concerning in low- and lower-middle-income countries, where a vast proportion of the population relies on subsistence agriculture, and in countries where food security can easily be threatened by fluctuations in agricultural production.

The results presented above should be considered in conjunction with the findings of other cross-country assessments on the impact of the COVID-19 pandemic on the agricultural sector. While more research is necessary to assess the lasting impact on the health of food security shocks versus illness and death caused by COVID-19, maintaining operations is critical for agricultural production and food security.

3.2.2 EPIDEMIC: AFRICAN SWINE FEVER AS AN EXAMPLE OF TRANSBOUNDARY ANIMAL DISEASES

Transboundary animal diseases such as ASF can have catastrophic impacts on sustainable development, affecting the livelihoods and food security of the people involved in the livestock value chain and impacting global markets. Although historically endemic to eastern Africa,[176] ASF was reported across Africa, the Americas, Asia, Europe and Oceania between January 2020 and March 2022. It affected over 1 million domestic pigs, caused the loss of 1.8 million animals as a result of deaths of affected animals as well as animals culled and disposed of as a control measure.[177]

ASF is one of the most complex viral diseases affecting both domestic and wild pigs. Considered one of the most serious global animal health threats in history, ASF has a case fatality rate close to 100 percent and there is no effective and safe commercial vaccine or treatment available at present.[178] Transmission can occur through direct contact with an infected pig, ingestion of pork (pig meat) or other contaminated pork products, fomites, vehicles, shoes, and through competent vectors, for instance arthropod vectors such as soft ticks of the genus *Ornithodoros*.[179] The main pathways for ASF spread are the movement of pigs due to trade, sale of infected meat, spread via fomites such as farm or veterinary tools and free-range pig raising.

Human-mediated transmission of ASF is the prevailing driver of global spread, with long distance jumps followed by endemic persistence and spread to neighbouring areas and countries. Since January 2020, ASF has been reported in 35 countries across five continents.[z] The global consequences of the spread of ASF have been most evident since its spread into Asia, due to China's pig meat market being the largest in the world. Accounting for approximately 45 percent of global production and consumption, the

z Africa, the Americas, Asia, Europe and Oceania.

introduction of ASF into China led to supply shocks that affected global pig markets.[180] Between 2018 and 2019, the outbreak of ASF in China caused more than 1.2 million pigs to be culled.[181]

Production and market impacts of African swine fever in China and globally

Between the first ASF outbreak in China on 3 August 2018, and 1 July 2022, a total of 218 outbreaks have been reported to the World Animal Health Information System of the World Organization of Animal Health (WOAH). Culling has been demonstrated to diminish the peak value and cumulative number of ASF cases by 99 percent, and combined with improvements in the detection rate of infectious pigs and biosecurity spread, it is an effective measure against ASF in China.[182] However, the culling of 1.2 million pigs as of 2019 has led to heavy economic losses.[181]

While the national average price of live pigs did not change substantially in 2018 (RMB 12.2 per kg as of 1 August 2018 compared to RMB 13.1 per kg as of 28 December 2018), the interprovincial pig spread[aa] rose from RMB 2.01 per kg to RMB 8.1 per kg during the same period.[ab]

By the end of 2019, it became evident that the national demand for pork could not be met, as indicated by the average pig and pork prices, which skyrocketed to 161 and 141 percent higher than pre-ASF levels, respectively. The impacts of both ASF and the COVID-19 pandemic compounded, and pork production in China in 2020 decreased by 25.8 percent compared to 2017.[183]

In terms of volume, pork production in China experienced a 22 percent contraction when comparing 2017 to 2019.[184] However, over the same period, the breeding sow population contracted by 35 percent. The liquidation of the breeding herd as a precautionary measure against ASF temporarily increased the domestic pork supply by approximately 25 percent.

While the Government of China tried to stabilize pork prices by releasing pork reserves to the market, the gap covered by the reserves was not enough to have a substantial impact on prices. For example, the pork reserves released by the government in 2019 and 2020 represented just 0.4 percent and 1.8 percent of the domestic pork production, respectively.

China tried to partially cover the gap by importing pork, which increased from 1 501 000 tonnes to 5 281 000 tonnes. Pork imports to China went from 20 percent of the global pork trade in 2017 to 45 percent in 2020. Relative to domestic pork production, imports went from 2.8 percent in 2017 to 14.5 percent in 2020, partly due to the contraction in domestic production described above. The increase in imports had global implications and pork prices on the international market increased drastically. This opened new opportunities for exporting countries but affected importing countries, which had to compete with China for pork procurement.

As proven in Asia, ASF can quickly spread in highly interconnected regions due to the constant movement of people and goods. Since the detection of ASF in Haiti and the Dominican Republic, collaborative efforts to respond to ASF are ongoing in the Americas.[185] A recent risk assessment by FAO found that if the disease spreads throughout the Americas, more than 48 million pigs could be lost, leading to USD 7.8 billion in direct losses, including impacts on mortality rate, pork production, trade and market prices, and jobs.[186] These losses would mainly occur in the four countries with large pig industries, namely the United States of America, Brazil, Mexico and Canada. In 2019, these four producers exported pork to over 100 countries, accounting for 27 percent of the global pork exports.[187]

aa The interprovincial pig price spread is measured as the price of live pigs in the province with the highest price minus the same price in the province with the lowest price. All provinces were included, except for Qinghai due to data limitations.

ab ASF's impact was assessed through literature reviews and by calculating direct losses and costs of response using the FAO OutCosT tool. OutCosT was piloted to determine retrospectively the cost of ASF outbreaks in Viet Nam's Lao Cai province (2020) and in the Philippines (2019), including production losses due to the disease, impacts on trade, as well as control and eradication costs, including treatment, surveillance and awareness activities. Generating cost estimates per farm and per pig affected can predict the impact of the disease if it spreads.

Beyond direct costs, ASF can have a dramatic impact on food security in countries where pork represents an important source of protein. In the Americas, this is the case for Belize, Cuba, Ecuador, Haiti and Paraguay, which are more food-insecure than the regional average. In Haiti, Jean-Pierre, Hagerman and Rich reported that ASF-induced high prices lead to increased consumer expenditure losses by up to 200 percent over the outbreak period.[188] Depending on the epidemic's magnitude, it can also lead to an increase in the price of other animal proteins as consumer demand for substitutes rises. This was observed in 2019 in China, where chicken and beef prices increased more than 20 percent (year-over-year), leading to additional challenges for food security and nutrition. The impact of the introduction of ASF in the Americas has been extensively analysed and discussed in FAO's risk assessment.[186]

The estimate generated with OutCosT for the cost of ASF outbreaks in Viet Nam's Lao Cai province in 2020 is USD 826 911, which represents USD 234 per pig lost. For the same province, the number of pigs lost in 2019 was ten times higher than 2020. Using the findings from OutCosT in 2020, it can be estimated that the cost of the ASF outbreaks in the same province in 2019 was USD 8.6 million.[ac] The difference between the 2019 and 2020 cost reflects the rapid spread of ASF in its initial stages and the effectiveness of later control measures.

In the Philippines, ten provinces were affected by ASF in 2019, but by the end of 2020 it had affected 32 provinces. The cost per pig lost due to ASF in 2019 was USD 281,[189] which can be used to assess the cost of ASF outbreaks in 2020, namely using the most likely proportion of the reduction in the number of pigs slaughtered (approach A) and using the higher bound of the proportion of the reduction in the number of pigs slaughtered (approach B). Details are as follow:

a. Calculating the number of pigs lost due to ASF as the most likely proportion of the reduction in the number of pigs slaughtered (38 percent),[ad] using 2019 as a reference year. Using this method, the number of pigs lost was 689 000.[ae]
b. The higher bound of the proportion of the reduction in the number of pigs slaughtered can be estimated using the contraction in the volume of pigs slaughtered between 2019 and 2020, which is 1.8 million heads. However, this contraction could be influenced by factors other than ASF that we cannot measure.[af]

Using these estimates, the approximate cost of the ASF outbreaks in 2020 in the Philippines was between USD 194 million and USD 507 million, 3.3 to 8.7 times higher than the cost in 2019. The high cost is unsurprising considering the large geographical spread in 2020. In Viet Nam and the Philippines the estimated losses were mainly due to domestic pigs and to national costs versus in Germany where the outbreak was in wild boars and due to the loss in the export market.

Tools like OutCosT can support countries in assessing outbreak costs under different disease spread scenarios and guide decision-making, including resource allocation for controlling the disease and preventing further spread. While the results can be easily extrapolated, it is important to calibrate the tool properly, so the results are consistent with local market conditions and policies in place.

Estimation of indirect losses

Assessing the indirect impact of ASF requires approaches such as value chain analysis because disruptions in a specific node of the value chain (in this case, the production node) have upstream and downstream spillover effects. There is some evidence of substantial implications of ASF for feed suppliers, despite the partial offset associated with shifting to other livestock species.[190] Downstream spillovers are more evident due to the less efficient use of productive assets that diminishes the availability of

ac In extrapolating, we are assuming that the control policies are practically the same in both periods, the period used to calibrate the tool and the period used to generate the cost estimates.

ad 208 594 pigs lost due to African swine fever / 545 729 pigs slaughtered lost = 38%.

ae 38% x 1 804 246 pigs slaughtered lost = 689 637 pigs lost due to African swine fever estimated for 2020.

af Such as the effect related to the COVID-19 pandemic.

production resources and inputs for downstream actors of the value chain. In Viet Nam, less than 35 percent of the job losses associated with ASF occurred in the pig sector, while the rest are distributed among other related sectors such as wholesale and retail sale, feed and veterinary services.[191]

In highly intensive systems, indirect costs of notifiable animal disease outbreaks such as ASF often significantly exceed the direct costs but remain poorly characterized due to their complexity. In a recent modelling effort, Savioli *et al.*[192] reported that the most important measures for controlling ASF in the event of an incursion in Switzerland were related to transport and slaughter logistics, consumer demand, and the prevention of contact between wild boar and domestic pigs. The greatest costs associated with contact prevention were due to assumed partial or total depopulation of fattening pig farms to reduce herd size and therefore comply with the simulated control regulations. ■

3.3 THE IMPACT OF ARMED CONFLICT ON AGRICULTURE

Active armed conflicts[ag] are at their highest level since the Second World War. Since 2015, each year has seen over 50 armed conflicts,[ah] with 54 occurring in 2019 and 56 occurring in 2020.[193] The inclusion of armed conflicts as a societal hazard within the ISC-UNDRR Hazard list represents a response to calls for stronger coherence across disaster risk reduction, climate change and humanitarian agendas.[194] While the risk of armed conflict is outside the scope of the Sendai Framework for Disaster Risk Reduction 2015–2030, the interplay between conflict and disaster risk is an area that requires further examination, including as it relates to damage and loss. These compound conflict-disaster risk crises are an example of what is increasingly referred to as polycrises.[195] All other things being equal, the impact of these crises can be far greater that a single hazard event, becoming amplified with cascading impacts on agriculture and the sectors upon which it depends.[196]

The 2023 Midterm Review of the Sendai Framework for Disaster Risk Reduction 2015–2030 demonstrated that Member States "frequently position considerations of conflict, violence and instability as indistinguishable from other types of risk as they consider how to achieve resilience, both as catalysts of vulnerability and as hazards in themselves,"[197] and reported "improvements in the comprehensive understanding of the systemic nature of risk in protracted crises"[198] towards the implementation of Priority 1 of the framework.

The number of national, regional, and sectoral disaster risk reduction strategies and plans[ai] that factor in societal hazards is increasing. For example, the Central African Republic's draft National Strategy explicitly discussed armed conflict, and Iraq's National DRR Strategy describes addressing risks of toxic and non-toxic remnants of war in addition to those of floods and droughts. Afghanistan's National Strategy on Disaster Risk Reduction identified conflict as undermining coping mechanisms and driving degraded public service delivery and infrastructure. In Mozambique, the National Policy and Strategy for Internal Displacement Management addresses Sendai Framework Target B and covers displacement resulting from climate-related hazards and conflict, and crucially focuses on resilience building, finding durable solutions and risk prevention.[199]

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ag It is important to qualify the word "conflict". FAO uses the following definition of conflict, recognizing that it does not necessarily need to be armed or violent (for example in FAO. 2022. *Operationalizing pathways to sustaining peace in the context of Agenda 2030 – A how-to guide*. Rome. Available at https://doi.org/10.4060/cc1021en: "An inevitable aspect of human interaction, conflict is present when two or more individuals or groups pursue mutually incompatible goals. Conflicts can be waged violently, as in a war, or non-violently, as in an election or an adversarial legal process. When channelled constructively into processes of resolution, conflict can be beneficial.") From Snodderly (Ed.) (2018). *Glossary of Terms for Conflict Management and Peacebuilding*. Second edition. United States Institute of Peace. Washington D.C. Available at https://www.usip.org/publications/usip-peace-terms-glossary

ah https://www.prio.org/news/2736

ai The implementation of Sendai Framework Target E. Note that not all strategies use "armed conflict" and refer solely to "conflict". The original language used in a strategy is also used here.

Research on the relationship between armed conflict and disasters can be categorized broadly into two areas: the impact of armed conflict on disaster risk, and the influence of disasters on armed conflict dynamics. For the former, research suggests new disaster risks can emerge through compounding and diverse pathways that are not linear or consistent, influencing exposure, vulnerability and coping capacity. In this regard, fighting can increase the vulnerability of a society to disasters as infrastructure is destroyed, poverty increases and long-term investments in disaster risk reduction are no longer considered important or cannot be funded. Unsustainable agricultural practices that lead to increased disaster risk may be driven by disruption and/or loss of livelihoods due to armed conflict. Conversely, there is evidence that conflict can increase local coping capacity.[200] For example, a recent study of Rohingya refugees looked at how coping strategies were developed and adopted, both at the individual and collective levels, in the Kutupalong Rohingya camp in Bangladesh.[201] Given that armed conflicts also limit access to land, cause population movements, and disrupt access to health care and social protection systems, we need to be cognizant of armed conflicts' wider damage and loss implications.

Some analysts[202] argue that in the aftermath of a disaster, ceasefires and negotiations in civil armed conflicts become more likely, suggesting the potential for at least a temporary de-escalation effect of disasters. This effect could arise due to heightened local and national solidarity in response to a disaster, the desire of armed actors to project a positive image, or the disruption of armed groups' functioning, including limitations on their mobility. This has been posited to be the case when the Government of Indonesia and armed independence groups in Aceh signed a comprehensive and ongoing peace agreement just a few months after the 2004 tsunami.[203]

Yet disasters can also lead to or extend the duration of ongoing conflict, including when they drive resource scarcity.[204] For example, the 2004 tsunami also had an impact on Sri Lanka. However, in that case, the armed conflict intensified, possibly due to the increased inflow of aid. In general, a 2019 review of the climate-conflict literature[205] concluded that while climate variability, hazards and trends do have an impact on armed conflict within countries, this link is relatively minor compared to other influential conflict drivers.

Highlighting the importance of contextual and local-level differences on how disasters can influence conflict dynamics, a comprehensive study by von Uexkull *et al.*[206] looking at Africa and Asia found that in very poor countries local drought increased the likelihood of sustained violence for agriculturally-dependent groups as well as politically-excluded ones. There have also been case studies that indicate that the 2010 Pakistan floods allowed Islamist groups to recruit more easily due to their rapid humanitarian response and perceived lack of support from the government, and thus enhance their ability to escalate the armed conflict,[207] though this is contested by others.

A recent qualitative comparative analysis of 36 cases of major disasters[aj] finds that they have an impact on armed conflict dynamics in 50 percent of all cases, evenly split between escalation and de-escalation. The degree of vulnerability to disasters and a strong disaster impact on at least one armed conflict party are the two critical contextual factors. Tobias notes that "Armed conflicts escalate either when the rebel group gains power vis-à-vis the government during the disaster or when the rebel group intensifies its activities in reaction to the grievances of the disaster-affected population, while a strong government fights back. Disasters facilitate armed conflict de-escalation by weakening at least one conflict party while the other is unable to capitalize on this weakness."[208]

The broader geopolitical context influences the operation of food systems, as this often affects how armed conflict is shaped at the local level, as well as through more macrolevel impacts on trade flows because of the interconnectivity of global trade, and how this may be manipulated for political reasons. Food systems that are

aj Evidence drawn from 21 countries: Afghanistan, Algeria, Bangladesh, Burundi, Colombia, Egypt, India, Indonesia, Iran, Myanmar, Nepal, Pakistan, Peru, the Philippines, the Russian Federation, Somalia, Sri Lanka, Tajikistan, Thailand, Türkiye and Uganda.

repeatedly put under stress by conflict tend to move from predictability to instability and volatility. Food supply chains may function during long-term, protracted conflicts, such as in Yemen, where food importers on all sides have adopted dynamic operational methods in a complex and politicized environment. However, this kind of functionality comes at a cost. For instance, food prices in Yemen doubled between 2015 and 2019, and have continued to rise since.[209]

Research findings are mixed, both in terms of how armed conflict can influence the risk of disasters and how disasters can affect the dynamics of armed conflict. On the latter, it seems that the dynamics of armed conflict can be influenced under specific conditions and can manifest either positively or negatively.

Measuring damage and loss in armed conflict contexts

Assessments of the impact of armed conflicts on agriculture include calculations of damage and destruction of equipment and infrastructure, and loss of productive assets such as livestock. However, other impacts on agriculture have longer-term consequences, including forced displacement and the availability of agricultural labour. Tools and guidance have been developed for adapting PDNAs to complex operating environments, including where armed conflict manifests. As part of a joint initiative, the European Union, World Bank and the United Nations, led by UNDP, have developed a guide to conduct PDNAs in conflict situations that outlines how to perform a conflict-sensitive PDNA in response to growing awareness of the link between conflict and disasters. The guide provides information on how to ensure that post-disaster activities and response operations do not exacerbate conflict dynamics.[210] Whilst this guidance document does not cover a detailed study of the linkages between conflicts and disasters, it highlights how thinking about this is evolving and maturing.

In fact, an overall conceptual and analytical framework for framing and analysing all relevant interactions is not available yet. Beyond the elements laid out in *Guidance for PDNA in Conflict Situations*,[211] much remains to be considered. It is recommended that such a framework be developed as one of the next steps in improving thinking around post-disaster assessment as well as disaster risk reduction in armed conflict settings. Access to conduct on-the-ground damage and loss assessments is becoming increasingly challenging. Advances in the field of remote sensing such as frequency of image acquisition, a massive increase in availability of high-resolution imagery and major advances in speed of processing and interpretation can assist in quantifying agricultural sector damage and loss in armed conflict situations. Techniques are available to understand not just impacts on access to land and land use types, but also crop types and accurate livestock estimates.

Increased investment in addressing underlying disaster risks is essential to build resilience and should be integrated into both humanitarian and development interventions. Preparedness for response and to build back better must consider the various hazards a locality faces, including layered or compounding hazards such as armed conflict and natural hazards that can have a higher aggregate impact than separately occurring hazards.[212]

Somalia: Drought impacts exacerbated by chronic armed conflict, displacement and insecurity

Recurrent drought, food insecurity and subsequent famine risk have become a devastating and increasingly unsustainable cycle in Somalia in recent decades. Since the beginning of the civil war in 1991, these issues have become even more devastating than before. Between the 2011 famine and the huge 2016–2017 drought, it was estimated that approximately USD 4.5 billion was spent on emergency responses to save lives.[ak] The confluence of factors contributing to repeated emergencies in Somalia – including multilayered conflict, poverty and displacement – creates an exceedingly complex situation when it comes to calculating damage and loss. In 2017, a multisectoral damage and loss assessment was conducted under the overall coordination of UNDP, the World Bank, the European Union and the Government of Somalia. The Somalia Drought Impact and Needs Assessment (DINA) provided an assessment of drought damage and loss impacts and an estimation of recovery and resilience needs. It was intended to provide

ak Somalia Drought Impact and Needs Assessment (2017).

essential information for the government to fulfil its obligation to lead the recovery from drought. The DINA was also designed to provide recommendations on what would be required to move Somalia beyond perpetual emergency response, into recovery and eventually towards resilient development.

The overall results of the DINA were that damage and loss in the agricultural sector (rainfed and irrigated crops, livestock and fisheries) amounted to a combined total of just under USD 2 billion. As in other drought contexts, the largest impact was on agricultural losses (USD 1.5 billion), which represented 68 percent of total losses across all sectors. An interesting consideration here is the extent to which these agricultural damage and loss figures were affected by the protracted instability within the country. This was never quantified in the DINA; however, it was noted that the security situation had been a prominent factor in contributing to the degradation of rangelands, massive deforestation and degradation of agricultural infrastructure, particularly irrigation systems, and hence the overall figures for damage and loss in the sector.

The Syrian Arab Republic: The impact of widespread and rapid increases in instability and conflict

Before the start of the crisis in 2011, the Syrian Arab Republic was the only country in the region that was self-sufficient in food production, especially in staple agricultural crops such as wheat and barley. It had turned into a regional exporter before a major drought in 2008–2009 forced the country to import large quantities of wheat for the first time in many years. In the years before 2011, the Syrian Arab Republic had witnessed higher yields due to improvements in land and crop management practices that helped it capture major markets in neighbouring countries and the Gulf. In addition, the country had huge strategic wheat reserves that were a cornerstone of the Baath Party's food security policy to create self-sufficiency.

Rather quickly after the initial uprisings in 2011, the country was plunged into a complex set of conflicts. Five years into the crisis, FAO conducted a comprehensive damage and loss assessment to understand the impacts of five years of armed conflict on the agricultural sector. The Syrian Arab Republic Damage, Loss and Needs Assessment (DLNA) was conducted during 2016–2017, in an attempt to quantify the impact as well as look at the livelihood effects and the priorities for recovery.

The results of the assessment indicated that during the first five years of the crisis, total damage in the agricultural sector amounted to USD 16 billion. This was the equivalent to one-third of the Syrian Arab Republic's GDP in 2016. As in Somalia, the largest dollar impact was in terms of losses (USD 9.21 billion), although in this case the level of damages was USD 6.83 billion (or 75 percent of the value of losses) as opposed to 33 percent in the case of the Somalia case study. This was because agricultural assets and infrastructure suffered extensive damage and destruction as a direct consequence of armed conflict. In this case, the impact of conflict on agriculture was very direct, whereas in the case of Somalia it was indirect.

Ukraine: Localized and global impacts of armed conflict on agriculture

The Ukraine case study illustrates the magnitude of the impact of armed conflict on agricultural production and food security within the country, and its global ramifications. Ukraine is one of the world's top agricultural food producers and exporters and plays a critical role in supplying oilseeds and grains to the global market. However, the war in Ukraine has significantly affected production. Agriculture was a key driver of Ukraine's economy before the war, contributing 10 percent to the country's GDP, providing employment for 14 percent of the labour force and generating 24 percent of the total exports in the country.[213,214,215]

The impact of the armed conflict presented below is the result of assessments conducted between September and October 2022 in 22 oblasts,[216] showing the damage and loss of the war as experienced by rural households, livestock keepers, and fishers and aquaculture producers to be nearly USD 2.3 billion. On average, 25 percent of the rural population stopped or reduced agricultural production, although along the contact line more than 38 percent of respondents reported stopping agricultural production. Factors limiting or stopping agricultural production included damage to productive equipment and infrastructure (reported by 5 percent of household surveyed), an increase in domestic production costs by an average of 25 percent, limited access to financial services necessary to obtain inputs, and contamination of land by mines and unexploded ordinances.[al] One in six (15.7 percent) of crop storage facilities were also impacted by the armed conflict since it started in February 2022.[217] The figures below break down the damage and losses within the crop and livestock subsectors. The overall effects on the fisheries and aquaculture sector in Ukraine for the first eight months of the war in 2022 accounted for damage of USD 4.97 million, and losses (changes in financial flows) of USD 16.6 million, which is 63 percent of the total annual output of the Ukrainian aquaculture sector (USD 34 million).

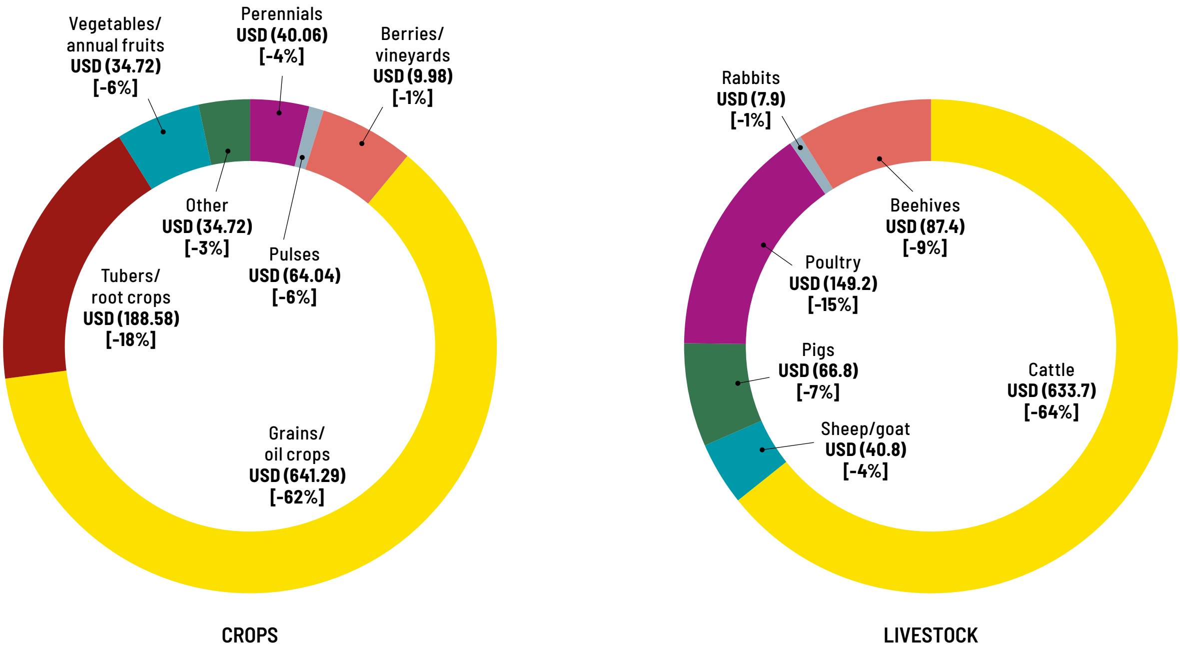
As this analysis is limited to the first eight months of the war in Ukraine, it does not account for damage resulting from the collapse of the Kakhovka Dam. The Kakhovka Reservoir and wider Dnipro River system are the primary agricultural water resource for the area. At the time of writing, the post disaster needs assessment was still underway. These damage and loss figures are likely to increase significantly depending on the evolution of the armed conflict and the level of support for recovery that the agriculture sector and related subsectors will receive in response to the war.

Ukraine is prone to a variety of hazards which can impact the agricultural sector, including natural hazards such as floods, droughts, landslides and storms, as well as technological and biological hazards. Should one occur simultaneously with the armed conflict it could send further shocks throughout global agriculture, compounding the systemic disaster risk. The environmental impacts of the war itself are also leading to significant disaster risks in the long-term, including through damage to chemical industrial sites, which can create both immediate and longer-term ecological hazards.[218] To increase the resilience of Ukraine's agricultural sector, recovery efforts must be risk-informed, and building back better may have additional costs beyond those captured within the PDNA. ■

al The Government of Ukraine estimated that around 62 000 square miles (160 579 km²) of national territory may be contaminated with landmines and unexploded munitions, including 10 percent of the country's farmland.

FIGURE 36

DAMAGE AND LOSS IN CROPS AND LIVESTOCK SUBSECTORS IN UKRAINE (USD MILLION AND PERCENTAGE)



Source: National Household (HH) assessment conducted by FAO in 22 oblasts (except for the occupied oblasts of Lugansk and Kherson) in September 2022. Data available at https://data-in-emergencies.fao.org/apps/c5e28e7c958b4748bb806e1fe28ccf7b/explor

KENYA
Swarm of desert locusts in Isiolo County illustrate the gravity of the situation in East Africa. FAO is combatting this unprecedented threat by scaling up its emergency response.
©FAO/Sven Torfinn

PART 4

DISASTER RISK REDUCTION SOLUTIONS IN AGRICULTURE

KEY MESSAGES

➔ Urgent action is required to foster the adoption of available innovations in disaster risk reduction, promoting the generation of more scalable risk management solutions, and enhancing early warning that leads to anticipatory action. Multihazard DRR approaches need to be mainstreamed into policy and decision making, with a view towards prioritizing disaster risk reduction across sectors and geographical scales.

➔ Technical interventions and farm-level good practices can proactively prevent and reduce risk in agriculture, thus building resilience. They are shown to perform on average 2.2 times better than previously used practices.

➔ The knowledge base for technical solutions that address risk in agriculture and protect livelihoods is limited. Efforts to expand and improve the base of knowledge on the returns of investment for resilience are needed for risk-informed policy and action.

➔ Anticipatory actions, especially when used in conjunction with early warning systems to mitigate the impact of disasters, show mostly favourable BCRs, up to 7.1 in a pool of countries across Asia, Africa and Latin America.

➔ A combined preventative control and anticipatory action approach has shown demonstrable benefits in the case of the desert locust 2020–2021 outbreak in the Horn of Africa. In this case, investment has averted losses of 4.5 million tonnes of crops and 900 million litres of milk, securing food for nearly 42 million people in the aftermath of this outbreak.

While disasters may not be a daily occurrence, preventing hazards from triggering them must become one if we are to achieve the goals of the 2030 Agenda for Sustainable Development, the Paris Agreement and the Sendai Framework. As outlined in the Sendai Framework for Disaster Risk Reduction 2015–2030, this can be done through the following actions : i) generating better and actionable risk information and analysis to inform decision making and actions; ii) strengthening disaster and climate risk governance; iii) increasing investments in risk reduction for resilience; and iv) enhancing preparedness and anticipatory action capacities.

The conceptual framework reported in FIGURE 2 of the **Introduction** indicates how **Part 4** of the report complements the previous three. While the discussion in **Parts 2** and **3** conveyed the available evidence on the impact of disasters on agriculture, the discussion here focuses on the viability of investments in enhanced disaster risk reduction in agriculture; and in anticipatory action to increase the resilience of livelihoods to disasters. The actions to reduce the potential impacts of disasters and underlying risks are thus analysed in terms of their potential to reduce such impact – as a benefit – vis-à-vis the cost of their implementation.

This part of the report offers several examples of analysis of the benefits associated with disaster risk reduction good practices and anticipatory action, that can serve as blueprints for the comparative assessment of different scalable investments in each context. These examples can be used as a reference to undertake similar and possibly more specific assessments in support of risk-informed decision making.

As seen in **Parts 2** and **3**, to date, there is a lack of systematic and comprehensive information on the impact of disasters, as well as standardized approaches to the definition and estimation of implementation costs of disaster risk reduction good practices and anticipatory actions. As such, the analysis of the benefits associated with disaster risk reduction good practices and anticipatory action is performed in the absence of systematic data and homogeneous information. The impact of an intervention depends crucially upon the economic, social and natural environment in which it needs to take place, along with the institutional and policy frameworks, which are context-dependent. For this reason, creating global assessments or large-scale solutions remains a challenge, as risk-reducing and mitigating investments will always require context-specific analyses and assessments.

The first section of **Part 4** focuses on proactive disaster risk reduction measures that can be implemented in agriculture. The quantifications that are presented indicate the extent of the benefits that can be derived from investments in risk-informed agricultural practices when hazards strike. As discussed in the section, risk-informed agriculture interventions bear broad and mutually reinforcing socioeconomic and environmental co-benefits. The approach adopted in this section is cost–benefit analysis, which is used to demonstrate the potential of disaster risk-informed agricultural good practices vis-à-vis previously used practices.

The second section of **Part 4** demonstrates the benefits that can be derived from anticipatory action that are implemented when a shock or stressor is forecast, and before it materializes. Anticipatory action contributes to enhancing the resilience of vulnerable communities, hence protecting livelihoods while reducing the need for more costly ex-post recovery. In this way, anticipatory action complements and protects the gains achieved through risk-informed practices – such as those highlighted in **section 4.2** – protecting food security and nutrition, and easing pressure on strained humanitarian resources.[219] The analysis framework, also in this case, is the benefit–cost ratio of taking action.

The third section of **Part 4** presents one more case of risk-informed action, combined with preventative control and anticipatory action. The specific case analysed is that of the desert locust outbreak, which was implemented during the upsurge in the greater Horn of Africa during 2020–2021. The approach employed in the analysis is again a cost–benefit one, which highlights the averted losses from a combined surveillance and anticipatory action.

The approach of comparing benefits and costs is implemented in this context by highlighting and considering its main assumptions. This is the case of discount rates and the time frame in which the assessments are cast. To properly inform policy decisions, cost–benefit assessments require evidence of the sensitivity of the results to such parameters.

The discussion in this part of the report is also supplemented by several insights and suggestions on how the adoption of disaster risk reduction good practices can be promoted at the farm level through extension, and how disaster risk reduction measures and anticipatory action can be institutionalized and scaled up in policymaking.

4.1 BENEFITS FROM FARM-LEVEL DISASTER RISK GOOD REDUCTION PRACTICES

Farmers, particularly smallholders farming under rain-fed conditions, are the most vulnerable stakeholders in the agrifood systems and thus tend to bear the brunt of disaster impacts. Farmers, policy makers, and development and humanitarian actors can pursue multiple pathways to reduce the vulnerability of smallholders. Among those are farm-level DRR good practices and technologies. These technical solutions are scalable and tested under both hazard and non-hazard scenarios, and thus proven to help avoid or reduce agricultural production losses caused by natural or biological hazards.

Several studies provide evidence of the benefits of preventative action in the agriculture sector, which avoids losses caused by disasters.[220,221,222] Some of those highlight benefit–cost ratios of DRR good practices in agriculture, focusing mostly on the crops and livestock subsectors such as improved crop varieties (drought/saline/flood tolerant), crop diversification, conservation agriculture, adjusting cropping calendars and fodder conservation, improved animal shelter, vaccination and preventive disease control measures, and, in a more limited number, on forestry and fisheries.[223,224,225] While the specific findings differ, due to assumptions of the cost–benefit calculation and set ups, some similartities across studies were observed.

First, when farm-level DRR good practices are combined, benefit–cost ratios are higher than when the same practices are implemented in isolation. This means that good practices tend to mutually reinforce each other, and that potential benefits from the simultaneous implementation of multiple practices are higher than those of single practices. Second, grey infrastructure-related interventions in agriculture have lower ratios compared to nature-based solutions, such as improved crop varieties and people centred approaches. This is largely the consequence of the lower input costs of these actions compared to those of infrastructure.

Further evidence is available from a set of multiyear trials on farm-level DRR good practices that were undertaken by FAO during the 2016–2021 period on a total of 1 112 farms in ten countries.[am] The study analysed locally collected field-level data on farm-level disaster and climate risk reduction practices and technologies. The aim was to measure and quantify the avoided damage and losses resulting from the implementation of these practices and technologies at individual

am FAO. 2019. *Disaster risk reduction at farm level: Multiple benefits, no regrets*. Rome. www.fao.org/3/ca4429en/CA4429EN.pdf. This study reports evidence on the Plurinational State of Bolivia, Cambodia, Colombia, Guyana, Haiti, Jamaica, the Lao People's Democratic Republic, Pakistan, the Philippines and Uganda.

farms and through broader scaling up. Tested under both hazard and non-hazard scenarios, these good practices were proven to reduce disaster risk and should be integrated in both development and longer-term humanitarian action, such as in rehabilitation and recovery periods towards building back better.

In Uganda, to reduce the impact of increasing dry spells, the cultivation of high-yield and drought-tolerant banana varieties was combined with soil and water conservation practices such as mulching, trenches and the use of organic compost. These practices were implemented in the cattle corridor districts. Bananas are becoming a major cash crop in the country, with an estimated 24 percent of agricultural households cultivating it. The crop grows best under conditions in which relative humidity is greater than 60 percent and with an average annual rainfall of 1 500 mm to 2 500 mm. However, there has been an increase in the frequency and intensity of dry spells as well as delays in the rainy seasons due to climate change. This is affecting the livelihoods of smallholder farmers who primarily cultivate this crop and own less than 0.5 ha of land.[226,227]

The study showed that in farms affected by dry spells, the good practice package brought cumulative net benefits per acre (about .4 ha) over 11 years about ten times higher than those of the existing local practices. The benefit–cost ratio of good practices was 2.15, as compared to 1.16 for the existing local practices (FIGURE 37). The low-cost, high-returns feature of this good practice package makes it highly suitable for this agroecological zone of Uganda.

Given the high returns of the good practice package[an] compared to the previously used banana cultivation practices, its low costs and high replicability, a simulation scaling up analysis was undertaken. This showed that the difference in average annual net benefits is overwhelming: the benefits of the good practice would be between 95 percent and 695 percent higher as compared to the previously applied practice, depending on the hazard frequency »

an Although it was not possible to isolate the effects of each element of each intervention in the DRR good practice on banana yields and returns, the synergies among the various interventions likely played a central role in enhancing the resilience of banana farming systems to rainfall deficits and dry spells.

BOX 12

METHODOLOGY FOR COST-BENEFIT ANALYSIS (CBA) OF FARM-LEVEL DRR GOOD PRACTICES

This methodology is developed to provide an effective means for conducting robust assessments of the costs and benefits of agriculture-specific DRR interventions at the farm level, with a particular focus on the needs and challenges specific to smallholder producers.

This study calculates the benefit-cost ratio ex-post, with data being collected over several seasons and the benefit-cost ratio (BCR) is computed for an 11-year appraisal period. Therefore, observed data are utilized to project costs and benefits over the appraisal period, as opposed to assumed inputs used in ex-ante assessments. This increases the validity of the findings. The 11-year appraisal period allows an understanding of whether longer term benefits compensate for the capital investment made at the beginning of the intervention. A relatively short period of time was chosen to reduce uncertainty associated with longer term analyses, because no major capital outlays were involved in the farm-level good practices analysed by the study.

To provide a useful counterfactual, a distinction is made between hazard and non-hazard conditions, as well as between intervention and non-intervention cases within each hazard- and non-hazard scenario. In addition, this study combines quantitative assessments with qualitative interviews and scaling up simulations to assess costs and benefits of farm-level DRR good practices from a variety of angles. This contributes to provide a holistic analysis of applied good practices, generating important evidence for wider uptake by farmers, policy formulation and further guidance for DRR practices (ibid).

For further details, please refer to **Technical annex 4**.

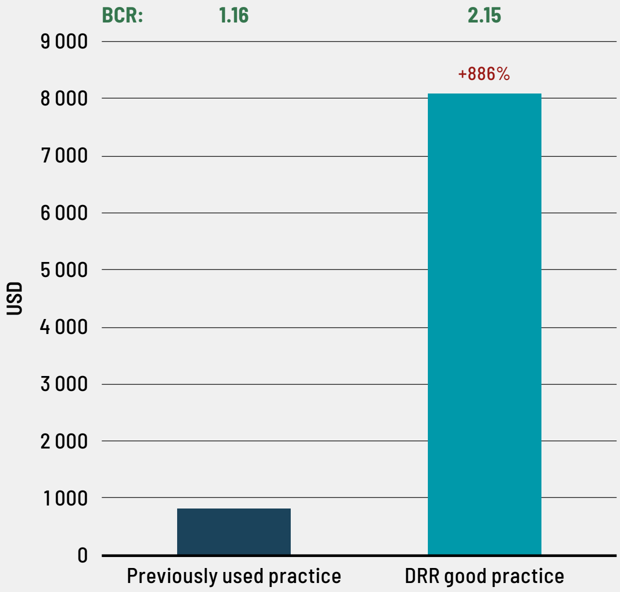


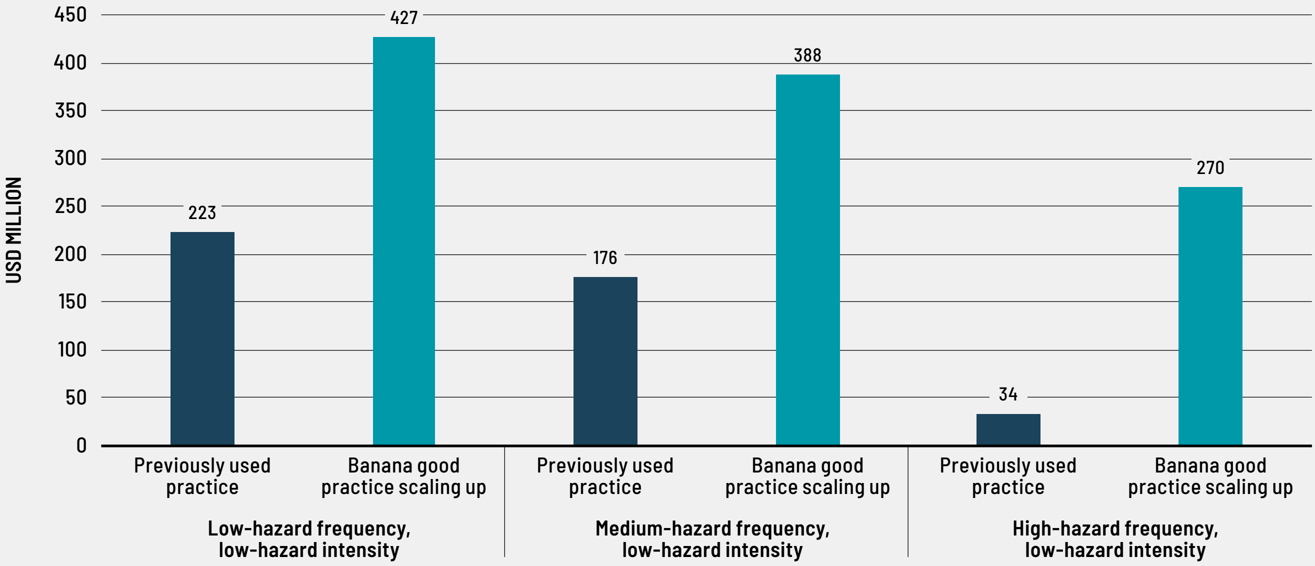
FIGURE 37

CUMULATIVE NET PRESENT VALUE PER ACRE OVER 11 YEARS OF BANANA CULTIVATION WITH MULCHING, CONTOUR TRENCHES, ORGANIC COMPOSTING AND IMPROVED VARIETIES IN UGANDA

Note: An acre is equivalent to roughly 0.4 hectares.
Source: FAO. 2019. *Disaster risk reduction at farm level: Multiple benefits, no regrets*. Rome. www.fao.org/3/ca4429en/CA4429EN.pdf

FIGURE 38

SIMULATION RESULTS – AVERAGE ANNUAL NET PRESENT VALUES FROM BANANA PRODUCTION UNDER DIFFERENT HAZARD FREQUENCY SCENARIOS: DISASTER RISK REDUCTION GOOD PRACTICE SCALING UP SCENARIO VERSUS PREVIOUS PRACTICE SCENARIO, CENTRAL REGION, UGANDA



Notes: Appraisal period: 11 years; discount rate: 10 percent; sensitivity analysis uses 15 percent and 5 percent discount rate.
Source: FAO. 2019. *Disaster risk reduction at farm level: Multiple benefits, no regrets*. Rome. www.fao.org/3/ca4429en/CA4429EN.pdf

» scenario. It is estimated that on average, losses that were avoided and added benefits of between USD 212 million and USD 236 million could annually be obtained by banana farmers in the central region through systematic scaling up (including farmer-to-farmer and vertical government scaling up) under the low, medium and high scenarios respectively (FIGURE 38).

The low cost, high return aspect of this good practice package suggests that farmer-to-farmer replication would be a viable scaling up option. Eighty-five percent of farmers interviewed indicated that applying the good practices resulted in higher banana yields, and around 70 percent of farmers found that their income increased. On a 1 to 5 scale, farmers assigned a 4.4 score to the performance of this good practices in the face of dry spells. Most farmers said that they would replicate the good practices in the coming season since it resulted in higher yields and had a positive impact on income and food security. At the same time, most farmers recommended conducting additional training on banana plantation management as a crucial support element.

In the highlands of the Plurinational State of Bolivia, to reduce mortality of the llama camelids from frost, snow, heavy rains and hailstorms, good practices were experimented, entailing the building of semi-roofed livestock shelters (*corralónes*) and the deployment of veterinary pharmacies. These combined practices were prioritized based on agroecological suitability due to the location and context specificities, and because farmers were willing to replicate them.

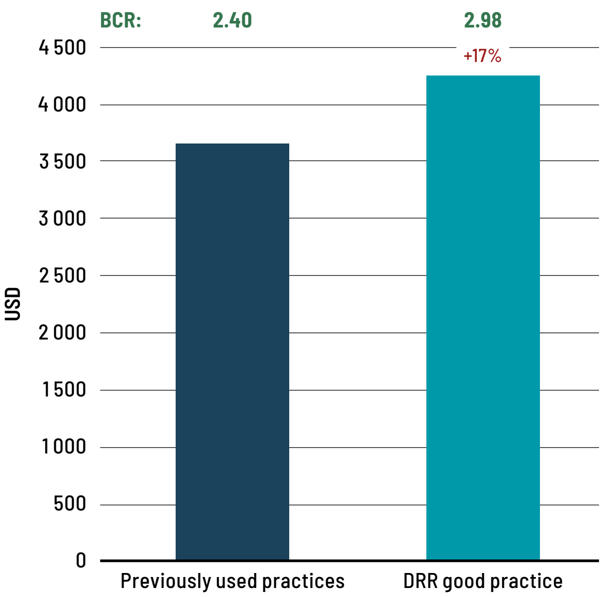
The benefit–cost ratio of these practices resulted in 17 percent higher cumulative net benefits than that of the previous local practices over 11 years (FIGURE 39). The analysis also showed that if the good practices were systematically scaled up, camelid mortality could become 12 times lower than under the previous practices. They would result in less camelid deaths and at the same time avoid related damage and losses due to intense and prolonged extreme weather.[228]

In Pakistan, DRR practices were tested on wheat, cotton, rice, sugar cane, and vegetable and oilseed crops, including okra and sunflower during the two main cropping seasons, namely the dry (*kharif*) season and the wet (*rabi*) season in districts of the Punjab and Sindh provinces, which are highly vulnerable to climate change and among the most vulnerable districts within the Indus Basin. Cost–benefit analyses were conducted over six seasons, where seven types of farm-level DRR good practices[ao] were tested both under hazard[ap] and non-hazard conditions. Practices that performed best under both hazard and non-hazard conditions included vegetable cultivation with multicropping,

ao 1) Rice cultivation with line sowing and alternative wet and dry method; 2) wheat cultivation with farmyard manure and compost; 3) vegetable cultivation with ridge sowing, farmyard manure, multicropping and integrated pest management; 4) wheat cultivation with levelling and integrated pest management; 5) cotton cultivation with laser levelling, ridge sowing, integrated pest management and compost application; 6) wheat cultivation with zero-till (drill) sowing and integrated pest management; and 7) cotton cultivation with ridge sowing and integrated pest management.

ap These include heavy rainfall, drought, high temperature, pests and weed infestations.

FIGURE 39
CUMULATIVE NET BENEFITS AND BENEFIT COST RATIO OF DISASTER RISK REDUCTION GOOD PRACTICES FOR LLAMA CAMELIDS IN THE PLURINATIONAL STATE OF BOLIVIA



Notes: Appraisal period: 11 years; discount rate: 10 percent; sensitivity analysis uses 15 percent and 5 percent discount rate.
Source: FAO. 2019. *Disaster risk reduction at farm level: Multiple benefits, no regrets*. Rome. www.fao.org/3/ca4429en/CA4429EN.pdf

ridge sowing, farmyard manure and integrated pest management.

Results indicate that every USD 1 invested in this good practice package will generate USD 8.18 and USD 6.78 in benefits under non-hazard and hazard conditions, respectively. Other practices that showed a higher benefit–cost ratio included the good practices of cotton cultivation with laser levelling, ridge sowing, integrated pest management, and compost application and wheat cultivation with levelling and integrated pest management. In this case, every USD 1 invested in cotton and wheat cultivation practices will generate USD 4.69 and USD 3.89 for cotton and USD 3.22 and USD 2.67 for wheat under non-hazard and hazard conditions, respectively.

The net present values of the tested good practices showed positive results with increases ranging from 3 percent to 99 percent. Rice cultivation and the alternate wet and dry method in Pakistan showed the highest increase in net present value under both non-hazard (86 percent) and hazard (85 percent) conditions, followed by wheat cultivation with levelling and integrated pest management with 54 percent and 53 percent, under both non-hazard and hazard conditions, respectively. These positive results provide insight into the scale of absolute benefits that farmers can achieve when investing in these tested good practices. For instance, the alternate wet and dry method requires less water, resulting in water savings as well as other benefits, such as lower methane emissions and higher soil fertility.

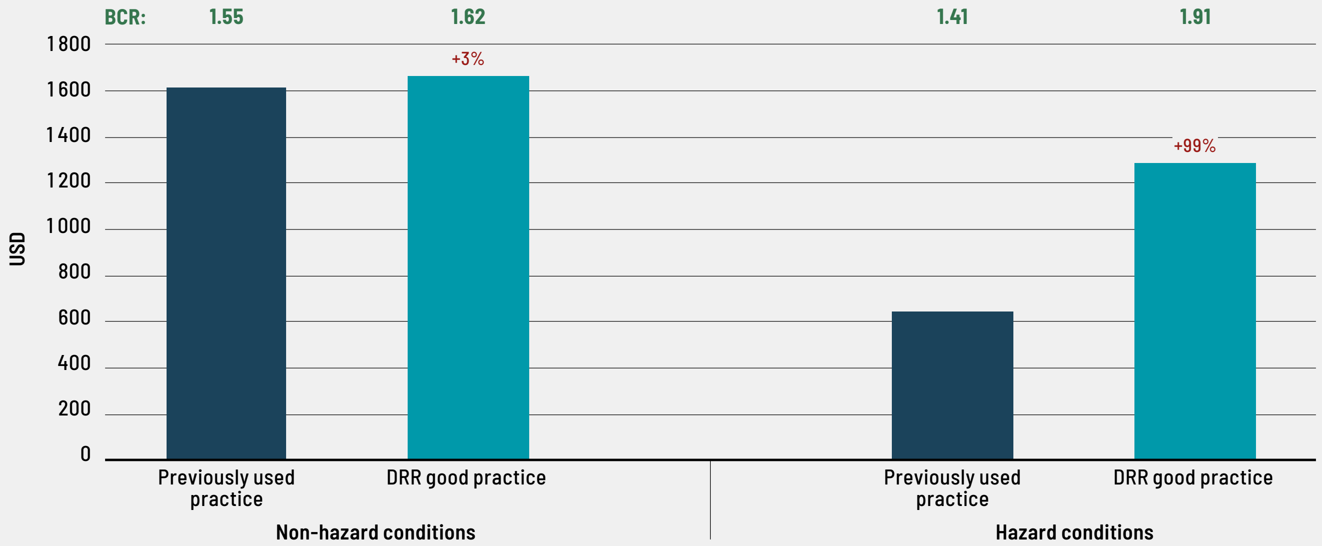
Moreover, the results from implementing the ridge sowing practice for cotton with integrated pest management showed that the highest increase of 99 percent in the net present value for the DRR good practices was observed as compared to the previously used practices under hazard conditions, in contrast to a net present value increase of 3 percent under non-hazard conditions (FIGURE 40). High temperatures were experienced during the hottest month of June in Pakistan when the cotton was at its flowering stage, which can lead to severe flower shedding, stunted plant growth, reduced number of cotton balls and weight, resulting in significant yield losses. The farmers interviewed after the good practices were tested also indicated that using yellow card double-sided insect traps helped protect from pests at a minimum cost. In addition to increasing production and income, this good practice also reduced the labour and time required for crop irrigation, resulting in cost savings due to increased efficiency and water conservation.

In terms of farmers' feedback and potential uptake, three good practices that obtained a 5 out of 5 score, included rice cultivation using the alternate wet and dry method, wheat cultivation with levelling and integrated pest management, and vegetable cultivation with ridge sowing, farmyard manure, multicropping and integrated pest management. Farmers indicated that these good practices produced higher benefits, such as higher production and more income while using less labour, they grew better and more diverse foods, increased resistance to climate constraints such as dry spells/drought, heavy rainfall and floods, and were better able to control pests by using integrated pest management techniques. They also shared their willingness to replicate these good practices in the future.

In the Philippines, green super rice (GSR) cultivation in the Bicol region was tested over three successive seasons (the 2015 dry and wet seasons, and the 2016 dry season). Results showed clear economic benefits, along with an increased agricultural productivity when adopting the multistress tolerant crop variety compared to the local varieties under both hazard and non-hazard conditions. The benefit–cost ratio of adopting GSR varieties was higher than that of cultivating local varieties in both the wet and dry seasons. FIGURE 41 demonstrates the high profitability of adopting GSR during non-hazard conditions in the wet season. GSR-adopting farms saw nearly a 60 percent increase in net benefits compared to farms that did not adopt it. The benefit–cost ratio for cultivating GSR was 6.1, while it was 4.6 for local rice varieties. The adaptive rice line also had a remarkably higher benefit–cost ratio of 3.5 compared to 2.8 for local rice varieties in hazard conditions in the dry season, when GSR-adopting farms had over 50 percent higher net benefits compared to other farms.[228] »

FIGURE 40

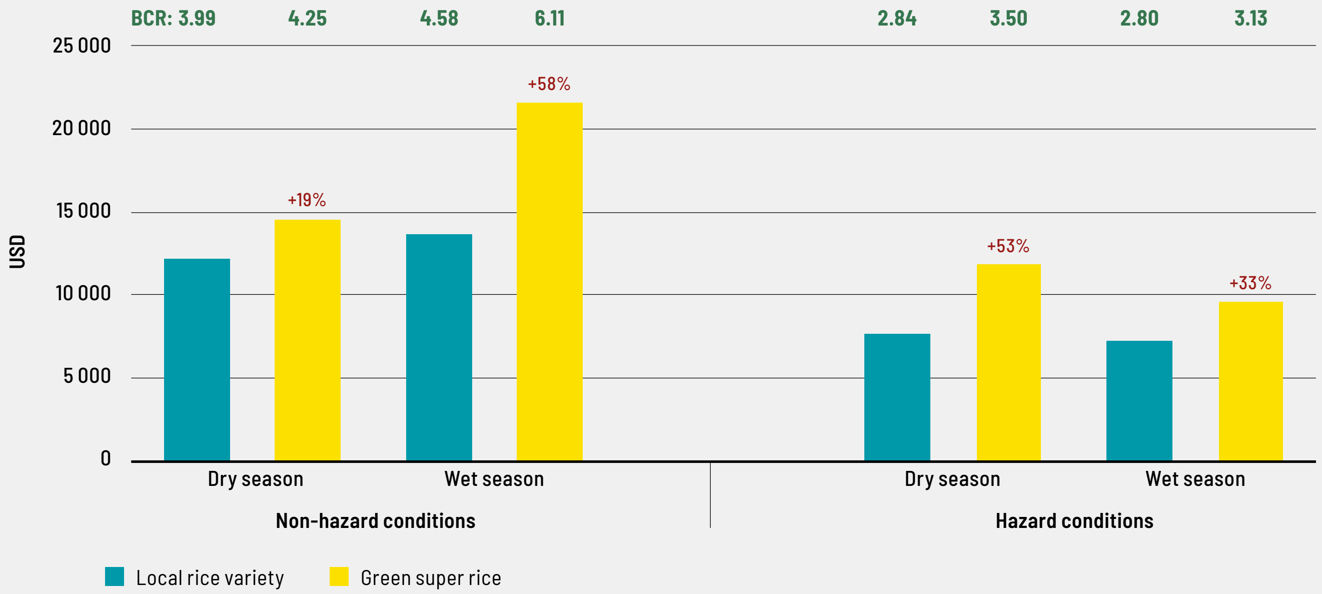
BENEFIT–COST RATIOS AND NET PRESENT VALUES OF THE DISASTER RISK REDUCTION GOOD PRACTICE OF RIDGE SOWING OF COTTON COMBINED WITH INTEGRATED PEST MANAGEMENT IN THE MUZAFFARGARH DISTRICT OF PAKISTAN DURING *KHARIF* IN 2021



Notes: Appraisal period: 11 years; Discount rate: 10 percent; Sensitivity analysis uses 15 percent and 5 percent discount rate.
Source: Authors' own elaboration based on FAO data.

FIGURE 41

BENEFIT–COST RATIOS AND NET PRESENT VALUES OF THE GREEN SUPER RICE AND LOCAL RICE VARIETY UNDER NON-HAZARD AND HAZARD CONDITIONS IN THE BICOL REGION OF THE PHILIPPINES



Notes: Appraisal period: 11 years; Discount rate: 10 percent; Sensitivity analysis uses 15 percent and 5 percent discount rate.
Source: Authors' own elaboration based on FAO data.

» A simulation scaling up analysis was conducted, given the high return of cumulative net benefits. It showed that scaling up GSR cultivation in the Bicol region would bring an increase in annual average net benefits in both the dry and wet season compared to continuing with the status quo. By adopting GSR, the annual average net benefits gained from rice production in the Bicol region, in a scenario where there is a high frequency of hazards, would be up to 71 percent higher during the dry season and 42 percent higher during the wet season (FIGURE 42).

Compared to the usual crops, GSR lines perform remarkably better in hazard conditions and would prevent a sizeable share of losses when dry spells affect farms. If scaled up, the potential losses that could be avoided in the Bicol region would be between USD 33 million and USD 129 million per year.

Following a suggestion for a vertical scaling up of GSR cultivation in the region, the Government of the Philippines has integrated the promotion of this type of cultivation in targeted areas of the country as part of its flagship rice programme. It is important to note that a key enabling factor of the transition to the vertical or government-led scaling up of this good practice was the extensive state presence in the Bicol region offering agricultural services.

Overall, the analysis of the 1 112 farms shows that on average, farm-level DRR good practices make good economic sense and are proven effective in providing added benefits even in the absence of hazards. These practices perform on average 2.2 times better than the usual practices under hazard conditions (low intensity, high frequency hazards). Not only do almost all good practices show positive net present values, but they also exhibit large net present value percentage increases versus previously used practices in most cases. In monetary terms (USD), the benefit–cost ratio was 3.6 under hazard conditions and increased to 4.3 under non-hazard conditions (FIGURE 41).

To realize the full potential of risk reduction measures such as those analysed here, they must be broadly scaled up and replicated. As a result, addressing challenges and barriers encountered by farmers in adopting these measures requires supportive policies.

In this vein, it must also be made clear that good practices and technologies can only be scaled up if they constitute viable business opportunities for farmers, and particularly for smallholders and the most vulnerable communities engaged in agriculture. Often these farmers are forced to operate in challenging conditions, with no markets and limited availability of key inputs in production. Innovations and good practices must demonstrate economic and social viability to ensure sustainable scalability beyond specific incentives or projects.

For the scaling up of disaster risk reduction measures, involved government institutions must be informed and be prepared to buy-in the associated social, economic, and environmental benefits, including so that they can be sustained beyond donor support. Training and awareness-raising exercises can be useful tools to discuss and demonstrate the viability of the proposed measures in specific contexts. Extension support packages for farmers can be useful vehicles to roll out disaster risk reduction practices and technologies.

FIGURE 42

DIFFERENCE IN RETURNS FROM RICE PRODUCTION, GSR SCALING UP VERSUS PREVIOUS PRACTICE SCENARIO

	LOW-HAZARD FREQUENCY	MEDIUM-HAZARD FREQUENCY	HIGH-HAZARD FREQUENCY
Dry season	+ 25.1%	+26.7%	+71.2%
Rainy season	+ 29.5%	+28.6%	+41.6%

Source: FAO. 2019. *Disaster risk reduction at farm level: Multiple benefits, no regrets*. Rome. www.fao.org/3/ca4429en/CA4429EN.pdf

The integration of DRR measures and social protection programmes can also offer important opportunities. Social protection can support comprehensive, inclusive and cost-effective disaster risk management practices by:
(i) channelling support either in anticipation of or in response to a shock or disaster;
(ii) enabling post-disaster rehabilitation and reconstruction, for instance through public work programmes; and (iii) supporting the government disaster management preparedness efforts, especially in ensuring that systems are prepared and ready to act in case of shocks.

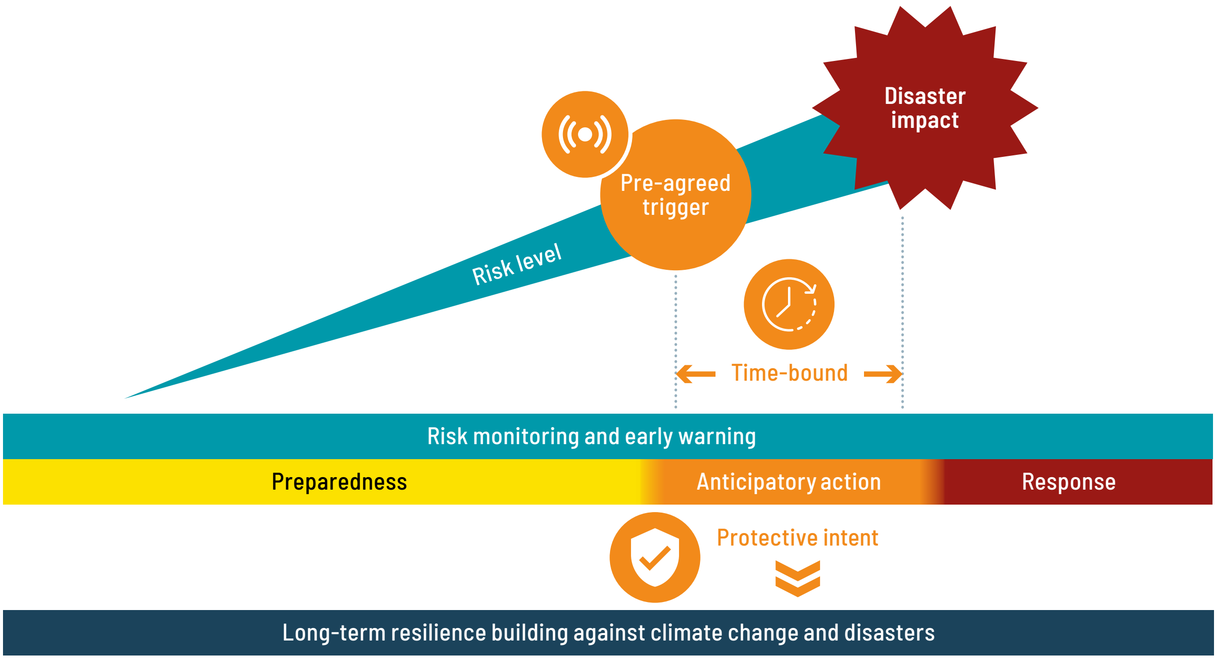
In Ethiopia, for instance, social protection programmes include a public work scheme component that works to reduce the vulnerability and exposure of participants, communities and local livelihoods by addressing environmental degradation among other things. This integration could be modelled in other contexts.

More broadly, it is important for DRR practices to be developed and mainstreamed within the policy and institutional environment. Understanding the political economy underpinning the functioning of DRR and climate change adaptation through governance analysis, including support to their integration when relevant – with a view to reducing agricultural production loss attributed to disasters and climate change – can reveal opportunities for integrated action where bottlenecks are present.

4.2 RETURN ON INVESTMENT OF ANTICIPATORY ACTION INTERVENTIONS

Anticipatory action is defined as acting ahead of predicted hazards to prevent or reduce acute humanitarian impacts before they fully unfold. The window of opportunity for anticipatory action is between an early warning trigger (the point in time when forecasts show that a hazard is likely to occur in the future) and the actual impact of the hazard is felt on lives and in livelihoods. A trigger system is developed and dedicated

FIGURE 43
KEY CHARACTERISTICS OF ANTICIPATORY ACTION



Source: ASEAN (Association of Southeast Asian Nations). 2022. *ASEAN Framework on Anticipatory action in Disaster Management*. Jakarta, ASEAN Secretariat. https://asean.org/book/asean-framework-on-anticipatory-action-in-disaster-management-2/

funds are pre-allocated to be quickly released when pre-agreed thresholds are reached. The trigger system is developed based on relevant forecasts (for instance, rainfall, temperature, soil moisture, vegetation condition, and others in the case of climate-related hazards), along with seasonal observations and vulnerability information.

Anticipatory action is a proven cost-effective measure for mitigating the impact of disasters with significant resilience dividends. By delivering support before a crisis has occurred, efficient and timely anticipatory action can curb food insecurity, reduce humanitarian needs and ease pressure on strained humanitarian resources. Triggered by context-specific early warning systems, anticipatory actions are short-term interventions that aim at protecting development gains from the immediate impact of forecast shocks.[229]

Supporting agricultural livelihoods ahead of shocks is a direct investment in the food security of farmers, pastoralists, fishers and by extension the resilience of the agricultural sector. It has been demonstrated that when hazards strike, anticipatory action interventions help communities to maintain dietary diversity and high-calorie intake, and to avoid resorting to negative coping mechanisms. The ripple effects of anticipatory action can also allow households to build and diversify economic opportunities and financial capacity.

This section provides concrete quantification of avoided damage and losses and added benefits through anticipatory action interventions. Since 2016 and in coordination with governments and partners, FAO has implemented more than 50 anticipatory action interventions within a range of contexts across various regions including Latin America and the Caribbean, Africa, the Near East and Asia. These interventions were aimed at anticipating and mitigating the impact of forecast drought, cold wave (known as *dzud*), the COVID-19 pandemic, plant pests and animal disease, among other hazards and shocks. Results presented in this section correspond to ten such interventions.

One measure used of the direct economic benefits of anticipatory action is the return on investment. The main output of the return on investment is the BCR, which provides a summary of the value for money spent for acting before the occurrence of a forecast hazard to prevent or mitigate its impact on the livelihoods of affected communities. For the ten interventions analysed, data was collected through structured interviews with beneficiary and control households. The counterfactuals between the two samples are used to form the basis of outcomes from anticipatory action interventions that then follow calculations of added benefits and avoided losses from the intervention.

Results of the BCR for anticipatory action for the ten interventions analysed have been mostly positive, up to 7.1 as shown in TABLE 6. In the cases of Ethiopia and Mongolia, where the BCR is highest, investing USD 1 in anticipatory action led to over USD 7 in avoided losses and added benefits for beneficiaries. A range of benefits were calculated, including those related to livestock health and mortality, crop production, as well as animal products such as dairy production. While the BCRs provide an understanding of the cost effectiveness of anticipatory action interventions, it is important to unpack the impacts of these benefits on households.

TABLE 6

BENEFIT–COST RATIOS FOR FAO'S ANTICIPATORY ACTION INTERVENTIONS

COUNTRY	BCR
Afghanistan	1.42
Bangladesh	0.83
Colombia	2.6
Kenya	3.5
Ethiopia	7.0
Madagascar	2.5
Mongolia	7.1
Philippines	4.4
Sudan	6.7
Viet Nam	0.46[39]

Source: Authors' calculations.

The BCRs in Bangladesh and Viet Nam were considerably lower than other anticipatory action activations. These were the only FAO impact analyses focusing on anticipatory action for rapid-onset hazards, which normally cause immediate impacts that are more difficult to prevent compared to slow-onset hazards. The differences in BCRs stem from higher operational costs associated with distributing goods to hard-to-reach communities in remote areas within a short period of time, or the types of calculated benefits. For example, the distribution of waterproof drums ahead of rapid onset hazards potentially delivers years of future benefits that are not included in the calculation. Hence, differences in the return on investment should not be viewed as being the result of stronger or weaker preparedness.

Anticipatory actions to protect livestock ahead of forecast hazards have proven particularly effective in reducing animal mortality, maintaining animal body condition and productivity, as well as the reproductive capacity of herds. In the case of Colombia, Kenya, Mongolia and Sudan, feed distribution and animal health campaigns before a drought or cold wave had major effects on livestock health and productivity, with cascading positive effects on nutrition.

In Mongolia, early distribution of feed ahead of the winter *dzud* led to avoided losses reducing animal mortality by the equivalent value of four cattle per household; and at the same time increasing milk production, which is key for children's nutrition.[230] In Colombia, the quantitative value of reduced animal mortality was equivalent to the value of 11 sheep or goats per household.[231]

Acting ahead of drought in Sudan had a significant effect on reducing livestock mortality rates, which for goats was reduced by 11 percent.[232] In Kenya, anticipatory actions focused on protecting the livestock assets of semi-nomadic pastoralist communities delivered major benefits for animal health as well as milk production. Cows produced almost one additional litre of milk per day, 80 percent of which was used for household consumption, mainly for children under 5 years of age.[233] In Afghanistan, feed distributions and animal health campaigns ahead of *La Niña*-induced drought in 2021 improved animal health, as well as increasing milk production. The percentage of livestock with deteriorated body condition was lower for cows, sheep and goats as well as reducing newborn mortality rates. Milk production also increased by almost 10 litres of cow milk and 3.3 litres of sheep milk per household. Improved animal health, reported by several beneficiaries, allowed them to sell their livestock at higher prices.

Positive results were also recorded for anticipatory action interventions centred on crops. Depending on the context, these may include stress-tolerant seeds, early harvesting, plant protection from hazard-induced pests and diseases, short-cycle crop seeds, and small irrigation equipment, among other interventions.

Historically *El Niño* has had devastating effects on agricultural production in the Philippines. For example, during the 2015/16 *El Niño*, Filipino farmers lost 1.5 million tons of crops and more than 400 000 people needed assistance. Learning from this lesson, anticipatory actions were triggered in 2019 ahead of *El Niño*-induced drought in Mindanao. As a result, families saw fewer crops fail and were able to cultivate larger plots of land and grow a wider variety of vegetables.[aq] Farmers were able to maintain an acceptable diet, were also able to sell vegetables in the local markets to support themselves through the drought and were less likely to revert to negative coping strategies.

In Colombia, acting ahead of the drought allowed beneficiaries to expand cultivation and increase agricultural yields. Actions included establishing community fields for rapid crop production, distributing seeds and tools, providing support for animal health and rehabilitating the water infrastructure. Without these anticipatory actions, food insecurity and economic hardships would likely have increased as migration from the neighbouring Bolivarian Republic of Venezuela continued placing further pressures on households and increased resource scarcity.[231]

aq Poultry, seed, drum and equipment distributions, cash for work activities, rehabilitation of small-scale irrigation systems, training on productive vegetable techniques as well as the development of women-led cooperative of farmers.

Acting ahead of drought in Madagascar, anticipatory actions such as the distribution of vegetable seeds and micro-irrigation equipment were implemented. The interventions had significant effects on increasing vegetable production as well as decreasing crop loss. Production was up to six times higher for some vegetables.[234]

Additional benefits of anticipatory action interventions included some households avoiding vicious debt cycles. In the Philippines, for instance, the distribution of drought-tolerant seeds prevented beneficiaries from buying seeds on credit with high interest rates of up to 15 percent. Savings generated from seeds helped farmers keep their children in school and avoid potential negative consequences.

Positive impacts of anticipatory action are also reported in terms of enhanced food security across a wide range of projects and geographies. They help families and communities to maintain dietary diversity and high-caloric intake when hazards strike and to avoid negative coping mechanisms like skipping meals. While positive results have been recorded, they are not uniform across interventions.

In Madagascar, support to vegetable production through anticipatory action helped boost local food production and protected farmers from droughts.[234] About 16 percent of beneficiaries reported poor food consumption, compared to over 40 percent of households that did not receive support from the anticipatory action intervention.[234] In Bangladesh, 10 percent more beneficiaries of anticipatory action ahead of floods recorded acceptable food consumption than did control groups, but no major difference was recorded in adopting negative coping strategies.

In Afghanistan, anticipatory action interventions undertaken in 2021 included cash, livestock and agricultural support, and training. Beneficiary families displayed significant increases in their food consumption: families with acceptable levels of food consumption increased from a baseline of 6 percent to over 50 percent following the intervention.

Similar findings were reported in Sudan in 2017–2018 after a drought, as a consequence of an anticipatory action intervention.[235] Feed distributions and animal health campaigns had a major effect on household milk production. On average, each household consumed an additional 0.8 litres of milk per day, which represents an additional 528 kcal per day. Just half a litre a day gives a five-year-old child 25 percent of the calories and 65 percent of the protein they need for healthy growth and development. Overall, beneficiary households were 12 percent less likely to have reduced meal size or number of meals per day. Similarly, in Mongolia, milk cows owned by beneficiaries produced six times more milk per day than non-beneficiaries during the *dzud*.[230]

In Viet Nam, waterproof drums were distributed ahead of Typhoon Noru in September 2022. These were used to save valuable goods for the household. Specifically, 57 percent of beneficiaries noted that waterproof drums were used to save food items with an average market value of about USD 9 per household.

EFFECTS ON RESILIENCE

While quantitative measurements of resilience are limited for anticipatory action interventions, qualitative evidence points to increased levels of household resilience following anticipatory action interventions. Refraining from distress sales of animals due to lack of feed or economic instability, not having to take out loans, holding onto seeds for future harvests and boosting income that can be used to purchase assets or increase productivity are some examples of how anticipatory action helps increase resilience.

In the Philippines, anticipatory action interventions ahead of the drought in 2019 helped families to avoid selling off valuable assets or keeping children home from school.[ar] In the 2016–2017 drought in the Horn of Africa, beneficiaries of anticipatory action interventions spent extra funds – including from increased milk production – on education, healthcare, and food and animal feed, and some households reported that they were able to save part of their earnings.

ar Women farmers' cooperatives received a mix of ducks and goats, training was held and a cash for work programme focused on cleaning local water canals that had fallen into disrepair.

Anticipatory action interventions can also reduce existing risk, protecting livelihoods well past the effects of the initial hazard. For example, waterproof drums distributed ahead of floods in Bangladesh or ahead of typhoons in Viet Nam, can be used for more than ten years, including during future flooding. In Colombia, beneficiaries noted how drip irrigation systems and techniques allow them to produce multiple harvests per year, greatly expanding their level of food production.

Training given during anticipatory action interventions offered an opportunity to raise awareness and build skills for disaster risk reduction. In Colombia, water management training delivered as part of anticipatory action, helped to build community-level adaptive capacity to droughts. More research is needed to assess how communities have developed and utilized new skills and assets.

Ideally, revisiting areas that have received anticipatory action interventions in the future to assess how communities have developed and used their new skills and assets would provide further insight into how these programmes may have benefitted community resilience. This should be a focus for future learning and analysis to further understand the long-lasting effects of anticipatory action implementation.

TOWARDS THE INSTITUTIONALIZATION OF AN ANTICIPATORY ACTION SYSTEM

Effective early warning systems can lead to timely interventions, and further incorporating anticipatory action within disaster risk reduction policies, plans and financial frameworks, as well as within humanitarian and development frameworks, will allow countries to strengthen resilience and reduce disaster risks.[236,237] Integrating anticipatory action interventions into legislation for disaster risk management and across sectors is another step to bolster institutional capacity.

Adding evidence of the benefits of anticipatory action programming, such as the cost effectiveness of anticipatory action, and the loss that can be avoided if the intervention is implemented on the ground in a timely manner may also be key in increasing government buy-in, and also show how these benefits can have long-term impacts on individuals and communities. It is important that international organizations and key stakeholders work with governments to build these internal institutions and policies to provide a platform for greater institutionalization of anticipatory action to be run and led by local bodies.

The effectiveness of anticipatory action means that this approach should be scaled up, especially as the frequency and intensity of hazards increases due to climate change.[238] To date, anticipatory action has been implemented predominantly for natural hazards.[239,240] However, acute food insecurity is often the result of compounding shocks such as conflicts, economic shocks, natural hazards and food chain crises, among others. Anticipatory action provides excellent scope to proactively manage residual risks, and in some cases reduce existing risk.

To sustainably expand the scale and scope of the anticipatory approach to crises, anticipatory action cannot be solely conceived as a proactive response measure pertaining to humanitarian actors. Instead, it is an opportunity to enhance coordination with other actors across humanitarian, development, peace, climate, and related programmes and financing frameworks.[241] A layered financing approach combining different instruments under the same objectives represents an unprecedented opportunity to protect large numbers of vulnerable people against shocks. Partnerships with the private sector could have the potential to boost capacities for timely and effective action ahead of shocks.[242]

A particularly promising area of development in the anticipatory action space, with notable potential to bridge the humanitarian and development divide, is the growing interest in linkages between social protection, particularly adaptive or shock-responsive social protection systems, and anticipatory action approaches. Large scale examples from Kenya, Somalia, Ethiopia and recently Malawi are contributing to a growing evidence base on the potential role of social protection systems to channel anticipatory action assistance to large sections of a given population in anticipation of a forecasted shock. Indeed, progress in this area is being promoted as a potential "game-changer" of how the sector addresses the risks faced by climate vulnerable populations.

Above all, the sustainability of anticipatory action requires creating ownership and capacity at the country level. This entails supporting governments to integrate anticipatory action within national disaster risk management policies, processes and financial instruments, as well as empowering local partners, communities and all first responders to implement anticipatory action by having in place the necessary resources and mechanisms. Policies, legal frameworks and protocols on accessing funds for anticipatory action are missing in several countries. Generating evidence of anticipatory action's impacts and benefits is crucial for improving the quality of programming, and for advocating for the institutionalization of the approach. To this end, any evidence generated must be accurate, transparent, and based on sound methodologies. Overall, a better understanding of the political disincentives and barriers to government engagement in anticipatory action is crucial.

There is greater scope for collaboration and recognition of mutually reinforcing overlaps between development, humanitarian, climate and peace actors and activities. For anticipatory action to scale up, it should be systematically integrated into building disaster and climate risk management for resilience to crises for people and countries.

4.3 COMBINING PREVENTATIVE CONTROL AND ANTICIPATORY ACTION – THE CASE OF DESERT LOCUSTS IN THE HORN OF AFRICA

The desert locust upsurge that occurred in the greater Horn of Africa in 2020 and 2021 was among the worst such crises to strike the region ever recorded. It represented an unprecedented threat to food security and livelihoods, with the potential to cause widespread suffering, displacement and conflict. On that occasion, a set of risk-informed interventions that included preventative and anticipatory actions were undertaken to address the outbreak, which are deemed to have averted losses to a

BOX 13

METHODOLOGY TO ESTIMATE AVOIDED LOSSES FROM RISK-INFORMED DESERT LOCUST INTERVENTION

Based on the experience of implementing the desert locust control operation upsurge in the greater Horn of Africa in 2020–2021, a new living methodology was developed to calculate the return on investment of FAO's risk-informed intervention, using various considerations and assumptions.

Swarm and hopper bands consumption requirements per hectare are estimated considering the average density of swarms and bands. Reports from the field provided details about the nature of the control operation (air and ground) as well as the ratio of hoppers to swarms. Based on this information, every time one hectare is treated, there are around 30 tonnes of green matter and vegetation that is not consumed by desert locusts (protected). To assess the direct averted losses and impacts on productive livelihoods (farmers, agropastoralists and pastoralists), assumptions regarding the source of productive green matter and vegetation consumed by the desert locusts were formulated. Following these assumptions and some considerations derived from the literature, it is possible to calculate how much one hectare of desert locusts (hoppers and swarms) can destroy over their life cycle (i.e. reflecting mobility) in rangeland and farmland.

This reasoning allows estimating the crop loss averted by harvest time, the values of the crop secured, the number of people meeting their annual cereal needs and the number of pastoral households able to feed their livestock.

A more detailed description of the methodology to calculate avoided losses from risk-informed locust intervention can be found in **Technical annex 5**.

Source: Authors' own elaboration.

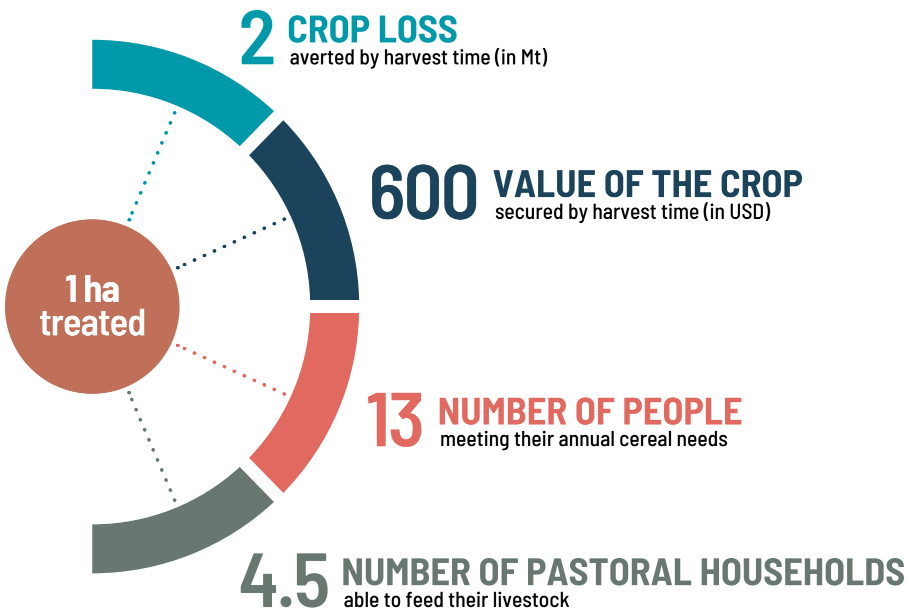
significant extent, especially in terms of cereals and livestock production. That experience is reported and analysed here, with a view to provide an example that can be scaled up in response to future outbreaks.

It should be noted that the Horn of Africa, where the 2020–2021 outbreak took place, is exposed to a variety of hazards. The risk-informed actions analysed in this section overlayed in parts of the region with flood, droughts, and conflict and/or insecurity, which also took a heavy toll in terms of economic losses. Together, these disasters – some linked to or exacerbated by the impacts of climate change – continue to deepen the exposure and vulnerabilities of people, systems and economies, and result in high levels of acute food insecurity across the region.[as,243]

as According to the 2021 IGAD Regional Focus of the Global Report on Food Crisis, 12.6 million people faced high levels of acute food insecurity (Integrated Food Security Phase Classification [IPC] Phase 3 or worse)[42] in Ethiopia (8.6 million), Kenya (1.9 million) and Somalia (2.1 million) during 2020. Given the underlying disaster risk profile of the Horn of Africa, risk-informed action to address hazards of all kinds is imperative to safeguard livelihoods and food security.

In general, desert locust risk management requires a preventive control strategy based on monitoring of habitats of the involved species in key periods of their development. This allows early detection of increases in the number of insects and behavioural changes. In the Horn of Africa, the desert locust prevention and anticipatory action plan was launched on 24 January 2020, and extended until June 2022. The plan had two main objectives. First, scaling up surveillance and control, to reduce the impact on crop production and the rangeland carrying capacity. Second, anticipatory livelihood interventions were implemented based on the expectation that some outspread of desert locusts would still occur despite the monitoring operations. These interventions are deemed to have prevented households from reaching a condition of high food insecurity – corresponding to Phase 3+ of the International Phase Classification (IPC) – and consequently engaging in undesirable coping strategies, asset depletion and atypical movements with their livestock herds in search of pasture.

FIGURE 44
OUTCOME OF INTERVENTION PER HECTARE TREATED



Source: Authors' own elaboration based on FAO data.

The timely and accurate early warning and forecasting information provided by FAO's Desert Locust Information Service (DLIS) throughout the upsurge allowed the risk-informed strategies to be deployed. Under the L3[at] Locust Emergency, the DLIS collaborated with a wide team of professionals, which included academics along with research and private sector partners. This team generated 16 innovations that were integrated into the DLIS and the national locust programmes to further improve monitoring and early warning. In addition, drones were employed to survey the locusts in several countries with the support of the Desert Locust Regional Commissions in the central and western regions of the Horn of Africa. Efforts were complemented by ground surveillance teams of government officials, which played a critical role in accessing remote areas and providing early detection of locusts, especially during the so-called "hopper band stage".[au]

As a result, 2.3 million ha of affected area was treated in the Horn of Africa and Yemen. It is estimated that for every hectare of desert locust infested land that is surveyed and controlled, an estimated 2 tonnes of grain are protected at an average value of USD 600. Pasture requirements for 4.5 tropical livestock units were also secured, as shown in FIGURE 44. The commercial value of the overall averted cereal and milk losses, after treating 2.3 million ha, was estimated at USD 1.77 billion. With this result and based on the methodology presented in **Technical annex 5**, at scale and risk-informed desert locust control interventions provide a return on investment of 1:15. This means that USD 1 invested in the intervention averted an estimated USD 15 of losses in the greater Horn of Africa.

From May 2020 to the end of 2021, through an investment of close to USD 90 million, FAO completed the delivery of livelihood packages reaching over 305 000 farming and livestock households (TABLE 7). Crop farmers received farming inputs and cash activities, while agropastoralists and pastoralists received feed and fodder inputs and cash.

These collective efforts by FAO and partners averted 4.5 million tonnes of crop losses, saved 900 million litres of milk production, and secured food for nearly 42 million people. In addition, control in arid and semiarid lands have allowed pastoral and agropastoral households to enjoy adequate access to grazing areas for their ruminants. Converted into tropical livestock units and yearly milk productivity per tropical livestock unit, FAO estimates that the control intervention maintained over 3 million tropical livestock units. As with other anticipatory action mechanisms, the outcome analysis of interventions is expressed in terms of averted livelihoods impacts and losses.

It is worth recalling also that the upsurge in desert locusts was not the only disaster affecting the Horn of Africa in 2020–2021. Farmers in the Horn of Africa were already suffering from other disasters such as

at Sudden onset, large-scale disasters and crises that require a corporate response.

au This is the stage at which flightless juvenile individuals aggregate into coherent, aligned swarms, which are referred to as hopper bands.

TABLE 7
SUMMARY OF ACTIONS AND OUTCOMES FOR THE 2020–2021 DESERT LOCUST EMERGENCY

	ANIMAL FEED AND MINERAL BLOCK PROVISION	FARMING PACKAGES	CASH TRANSFERS
Actions implemented	749 500 animals fed	230 132 tonnes of grain produced	USD 14 million
Outcome derived	≥ 85 000 children under 5 years of age are milk-secure for one year	USD 69 million commercial value of produce, sufficient to provide cereal and create 149 927 self-reliant households for over one year	Meeting basic requirements of 107 500 households (average three months)

Source: Authors' own elaboration.

floods, droughts and storms, along with the COVID-19-related restrictions that limited access to agricultural inputs and decrease of planted areas (as presented in **section 3.2.1**).

The results show that without the preventative control of a desert locust upsurge, the maize and sorghum production in 2020 and 2021 might have been even lower. This has also called for a multihazard disaster risk reduction approach to ensure that the interventions implemented on the ground address the interconnected nature of disaster risks and their cascading impacts.

The overall lesson learned is that risk-informed action in the case of the locust upsurge has limited considerably the potential negative impact of the shock on agrifood systems and the associated livelihoods. It resulted in reduced damage to crops and rangelands, reduced pesticide sprays that have negative impacts on human health and the environment, and lowered financial costs. This approach facilitates a reduction in the occurrence and intensity of locust outbreaks and prevents them from developing into major upsurges or plagues. Over decades, this strategy has proven to be the most effective, making it possible to act before a significant increase in desert locust populations can occur. For such transboundary plant pests, this strategy also needs to be coupled with global or regional cooperation.

It should also be noted that continued support is required in the Horn of Africa to address future desert locust upsurges if countries are to count on a sustainable monitoring and control systems such as the one deployed in the 2020–2021 outbreak. Moreover, more frequent surveys lower the risk of unnoticed breeding. During years when conditions are not favourable to the breeding of locusts, such as drought years, it is still necessary to maintain the capacity of countries to prepare for the potential of a shock related to desert locusts, even in the face of competing priorities such as droughts and floods.

The risk of unnoticed breeding is particularly high in the areas of the region that cannot be surveilled due to security reasons, like most of Yemen and parts of Somalia. This calls for aggressive and wide-reaching campaigns against the desert locust. If pastoralists are not protected from hazards such as desert locusts or drought, these hazards will ravage rangelands and animals. Thus, steps should be taken to institutionalize ongoing surveillance and build measures to address future outbreaks, building on the success of the risk-informed action presented in this section on disaster risk reduction strategies, as well as plans in countries where there is high risk of desert locust outbreaks in the future. ■

PAKISTAN
Flood victims making their way to dry land.
©FAO/Asim Hafeez

PART 5
CONCLUSIONS

The growing frequency and severity of disaster events are producing unprecedented levels of damage and loss in agriculture around the world. These negative impacts cascade down value chains to affect agrifood systems across multiple dimensions, compromising food security and undermining the sustainability of the agriculture sector. The increasingly globalized and interconnected nature of agrifood systems, and the heavy reliance of agriculture on weather and climate conditions amplify its vulnerability and exposure to the growing threat of climate change, crises such as the recent COVID-19 health pandemic and ongoing conflict situations. Facing up to these challenges – and advancing towards the goals of the Sendai Framework for Disaster Risk Reduction, the 2030 Agenda for Sustainable Development, and the Paris Agreement on Climate Change – requires policies and strategies that are grounded in data and adopt a multihazard and proactive approach to reducing disaster risk in agriculture.

A key theme running across all sections of the report is the **need for improved data and information on the impacts of disasters in agriculture**. Investment in enhanced data monitoring, reporting, and collection methodologies and tools is an essential first step in building national capacities to understand and reduce disaster risks in agriculture and agrifood systems. This report has advanced the knowledge base by providing a first global estimate of the impact of disasters on crops and livestock production. Nearly USD 3.8 trillion, amounting to an average of USD 123 billion per year or 5 percent of the global agricultural GDP, was lost due to disasters affecting agriculture over the past three decades. Production losses translate into reduced nutrient availability around the world, with a loss of dietary energy estimated at 148 kcal per person per day on average. This figure represents a significant setback in ensuring food security and nutrition for all, and in building inclusive, resilient and sustainable agricultural livelihoods.

The gradual but steady rise in the amount of world production lost annually in tonnes is most stark for countries with the most vulnerable populations. Low-income countries and SIDS have been hit the hardest, as shown by the extent of losses experienced in terms of share of agricultural GDP. There is an urgent need for additional support to be provided for enhancing the resilience of agriculture in these contexts and across the world, starting with better and more locally relevant information on the magnitude and dimensions of disaster impacts in agriculture and related food systems. Results generated through probabilistic modelling using secondary data, as done for the global assessment of losses in this report, should ideally be substituted by harmonized information on disaster losses collected at the national and subnational scale.

Sector and subsector specific approaches for assessing vulnerability and exposure, evaluating impacts and reducing risks are essential. The same hazard, for example a plant or animal disease, can produce negative effects in crops, livestock, forestry, and fisheries and aquaculture subsectors along totally different trajectories and timelines. Estimates of livestock losses in the wake of the 2016–2017 drought in Somalia, and a ground level assessment of the impact of the fall armyworm infestation both serve to underline the detailed quantification of losses that is possible in the crops and livestock sector when data are more readily available and scaled down to local contexts and hazards. However, even in subsectors with better information access, there is a need to develop standardized tools for measuring the impact of disasters to assess direct damage and loss, build capacity at various levels, support coordination mechanisms for prevention and response, and scale up these loss estimations to a national or global scale. Data recording must also extend over timescales that take production cycles into account and disentangle the multiyear effects of disasters, as demonstrated by the evaluation of livestock losses in Somalia.

The vast and often remote space occupied by the forestry and fisheries subsectors, and the diversity of their ecological stocks, requires different approaches to valuing assets and calculating impacts than those employed for crops or livestock. These two subsectors suffer from a lack of comprehensive information on their production, assets, activities and livelihoods, and are frequently overlooked in post-disaster impact evaluations and needs assessments. Currently, there is no systematic approach for monitoring the disasters and emergencies that affect fisheries and aquaculture and forestry, or for tracking subsequent damage and loss. Although data and statistics are improving, the lack of standardized methodologies and tools for data collection prevents the formulation of even general estimates of disaster impacts in these two subsectors, which are critical for sustaining the food security and livelihoods of millions of people around the world and whose health is essential for maintaining biodiverse ecosystems and mitigating climate change.

Emerging technologies and advances in remote sensing applications offer new avenues towards improving information on disaster impacts in agriculture. The increasing precision and cost effectiveness of earth observation systems, satellite imagery and computing power offered by machine learning and artificial intelligence platforms can supplement national statistics and conventional data collection tools, such as surveys to provide improved information on the hazards, exposure, vulnerabilities and risks driving disaster impacts. To feed into the monitoring of progress towards the 2030 Agenda and Sendai Framework, promoting and strengthening data reporting for the Sendai Framework C2 indicator on direct economic losses in agriculture, corresponding to indicator 1.5.2 of the SDGs, will also provide a systematic and comprehensive database for disaster losses in agriculture.

A second key conclusion of this report is the **need to develop and mainstream multisectoral and multihazard disaster risk reduction approaches into policy and programming at all levels**. Disaster impacts are worsened by multiple drivers and overlapping crises that produce cascading and compounding effects and worsen the exposure and vulnerability of people, ecosystems, and economies and weaken coping capacity. As described in this report, factors such as climate change, the COVID-19 pandemic, the African swine fever epidemic and armed conflicts, all result in the amplification of disaster risk and impacts in agriculture. Unpacking the different ways and degrees to which each of these risk drivers triggers damage and loss and produce negative and cascading effects on agricultural production, value chains and food security reveals the interconnected nature of risks affecting agriculture. Designing risk reduction strategies and interventions for specific hazard contexts must first involve a deeper consideration of the overall risk landscape, including interdependencies existing across sectors and boundaries.

In the case of climate change, the use of attribution science methodologies provides new information on the degree to which climate change is exacerbating losses in agriculture. Assessments undertaken for Argentina, Kazakhstan, Morocco and South Africa confirmed that climate change has increased the occurrence of yield anomalies significantly, from slightly more likely in Morocco to being multiplied by a factor of ten in South Africa. Similarly, restrictions put in place in response to the COVID-19 pandemic provided another example of a global crisis that had long lasting negative effects on agricultural production and food security. Despite some transportation exemptions, restrictions during the planting season such as stay-at-home orders and trade limitations made it much more likely for farmers to report difficulty in obtaining agricultural inputs in surveyed countries. Much in the same way, although the ASF outbreak was largely a localized event in China, it affected the production and prices of pig meat and live animals in various countries across the world. Another underlying driver of disaster risk is the growing incidence of armed conflict around the world. Not only do conflicts result in direct damage and loss to agriculture and food systems, but they also undermine development progress and exacerbate disaster risk. As with climate change and pandemics, armed conflicts produce long-term negative effects that can spill over to regional or global scales.

Effective strategies for reducing disaster and climate risk must, therefore, adopt a holistic, system-wide view of the different drivers and impact pathways that produce losses in agrifood systems. This is particularly relevant in countries that have many vulnerable people or communities, have less developed capacities or resources to prepare for or respond to disasters, or where fluctuations in agricultural production can easily threaten food security. The knock-on effects of climate change, the COVID-19 pandemic, the ASF epidemic, and armed conflicts on the agriculture sector underscore the need for approaches that are truly multisectoral, multihazard and preventive, taking into consideration co-benefits and trade-offs between interventions. However, lack of understanding of the interconnected and systemic risks and the related data continues to be a challenge. It is also very important to gain a better understanding of the benefits of disaster risk reduction actions in agriculture, and to build a robust evidence base of interventions and measures that can be scaled up and further promoted.

As documented in **Part 4** of the report, there is a limited but growing body of evidence on the **need for investments in resilience that provide benefits in reducing disaster risk in agriculture** and improve agricultural production and livelihoods. Context and location-specific farm-level disaster risk reduction good practices are cost effective solutions to enhance the resilience of livelihoods and agriculture against natural and biological hazards. The case studies presented in this part demonstrate that not only do good practices reduce disaster risks, but they also display significant additional benefits. The limited evidence available suggests that technical solutions, anticipatory actions, and livelihood protection measures implemented for risk management in agriculture yield significant benefits. However, these solutions have not yet been widely adopted or scaled up. This calls for urgent action to foster the adoption of available innovations, promoting the generation of more scalable disaster risk management solutions, and enhancing early warning to inform anticipatory actions.

There are two suitable and complementary pathways for scaling up farm-level disaster risk reduction good practices in agriculture. The first is at a smaller and incremental scale, through farmer-to-farmer replication, which requires lower investment and less institutional support. The second pathway is through larger-scale efforts in which government and private sector support is needed to promote the uptake of good practices widely and swiftly. Both scenarios require incentives and capacity building for farmers, which can be deployed simultaneously. Crucially, both pathways depend on good infrastructure as well as an enabling environment. This means that new initiatives, incentives and investments aimed at meeting those critical needs for scaling up are necessary.

Unlocking the full potential of anticipatory action requires looking beyond triggers of natural hazards and investing in integrated systems that can respond in a multihazard context. To make them focused and effective, these systems need standardized quantitative and qualitative tools for subnational, national and global data collection. Risk information systems, including agroclimate services, risk analysis, risk monitoring and early warning systems to enable anticipatory action must be improved to scale up disaster risk reduction interventions. Investments must be made to strengthen the capacity of countries at the national and local levels on these systems and services, from monitoring and data collection to dissemination of actionable alerts and advice to end users, and to enable and empower farmers to make risk-informed decision and actions. Timely advice and early warning on climate information can help farmers to prepare for and respond to climate impacts. It is estimated that early warning systems, including in the food and agriculture sectors, can save lives and assets that are worth up to seven times their cost. Advanced technology and innovation create new opportunities for the dissemination of alerts and advisories to farmers and rural communities to ensure the information reaches the most vulnerable, including women, girls and youth. International cooperation and partnerships at all levels are required to establish global monitoring, risk assessment and early warning systems.

Monitoring risks in the agricultural sector is another crucial aspect of risk reduction that requires greater attention and coordination. At the farm, subnational, national and international levels, strengthened surveillance, monitoring and rapid diagnostics would have prevented significant losses in the case of most slow-onset events, such as the drought in Somalia, the fall armyworm infestation, the COVID-19 pandemic and the ASF epidemic. The risk-informed desert locust intervention in East Africa highlights the successful outcomes that can be achieved through coordinated monitoring, early warning and international action. Such risk-informed actions are deemed to have averted over 4.5 million tonnes of crop losses and secured cereal requirements for 30.6 million people. The intervention provides important lessons for mitigating the impacts of future desert locust upsurges and preventing and/or mitigating negative household coping mechanisms and food security deterioration.

Though not yet comprehensive, the available evidence suggests a set of interventions that can be undertaken to improve disaster impact assessments and to step up disaster risk reduction actions at all levels. National, sectoral and local disaster risk reduction strategies are a cornerstone for achieving inclusive and resilient agriculture, and the United Nations system can be an important collaborator in mainstreaming disaster risk reduction in national and sectoral policies, programmes and funding mechanisms. The General Assembly of the United Nations has recognized that sustainable and predictable financing for disaster risk reduction is imperative. To strengthen the business case for investment in approaches that prevent and reduce risk, alongside targeted and standalone investments in disaster risk reduction, mechanisms should be developed for budget tagging and tracking expenditures within and across sectors.

Documenting good practices in DRR, including their integration in development and humanitarian interventions is essential towards building a robust evidence base on risk-informed solutions. Testing the benefits of proactive DRR good practices and modelling their benefits under both hazard and non-hazard scenarios through calculating their benefit–cost ratios is an important step towards their promotion. As demonstrated in this report, the practices identified yield added benefits of USD 3.6 under hazard conditions and USD 4.3 under non-hazard conditions. As such, they have significant benefits even in the absence of a hazard and should be systematically documented and promoted. It is therefore imperative that multihazard disaster risk reduction is integrated into agricultural policies and extension services, as well as national and local disaster risk reduction strategies. ■

TECHNICAL ANNEXES

TECHNICAL ANNEX 1
LOSS AND DAMAGE CALCULATIONS FROM POST DISASTER NEED ASSESSMENTS

Post disaster needs assessments (PDNAs) are available online and were downloaded from PreventionWeb,[av] ReliefWeb,[aw] the Global Facility for Disaster Reduction and Recovery (GFDRR)[ax] and World Bank[ay] websites. Those utilized in this report as data sources span from 2007 to 2022.

In particular, data was retrieved from 88 post disaster assessment exercises conducted in 60 countries across seven regions and subregions, as follows: Africa, 30; Asia, 24; Caribbean, 10; eastern Europe, 8; Near East, 1; Oceania, 10; and South America, 5. The data cover eight hazard types: cyclone, 4; drought, 7; earthquake, 9; flood, 32; multihazard, 6 (including – *La Niña*, 1); storm, 23; tsunami, 1; and volcanic activity, 3. This pool of PDNAs included different assessment types, particularly damage loss and needs assessments, post disaster needs assessments and rapid damage and needs assessments.

av See Prevention Web. 2023. Post-Disaster Needs Assessments (PDNA). In: *Prevention Web*. [Cited June 2023]. https://recovery.preventionweb.net/build-back-better/post-disaster-needs-assessments/country-pdnas

aw See Relief Web. 2023. Reports only. In: *Relief Web*. [Cited June 2023]. https://reliefweb.int/updates?view=reports

ax See GFDRR (Global Facility for Disaster Reduction and Recovery). 2023. Post Disaster Needs Assessment. In: *GFDRR*. [Cited June 2023]. www.gfdrr.org/en/post-disaster-needs-assessments

ay See World Bank. 2023. The World Bank Open Knowledge Repository. In: *World Bank*. [Cited June 2023]. https://openknowledge.worldbank.org/home

PDNAs produce damage and loss estimates by economic sector, which makes it possible to compare impacts across the economy. All reported damage and loss values were converted to USD for 2017 (either from current USD or local currency unit) using consumer price index data from the World Bank.

To calculate the total agricultural losses caused by disaster types, damage and loss values reported were summed up and aggregated by hazard category. The industrial accidents reported did not include impact values for the agricultural sector and thus are not displayed as a category in the results.

The share of agricultural losses in productive sector losses corresponds to the reported damage and loss in agriculture for all PDNAs divided by the total reported damage and loss for all the productive sectors of all PDNAs (including agriculture, industry, commerce and trade, and tourism) by disaster category.

Similarly, the share of agricultural losses on total losses is calculated by dividing the reported damage and loss in agriculture for all PDNAs by the total reported damage and loss of all PDNAs by disaster category.

A subsector breakdown of the reported damage and loss was provided for 50 PDNAs, which accounts for 56 percent of the sample. For this subsample, damage and loss by agricultural subsector were aggregated in 2017 USD to compute the respective shares.

TECHNICAL ANNEX 2
ESTIMATING GLOBAL LOSSES FROM SECONDARY DATA

Estimates of the losses resulting from disasters in crops and livestock from 1991 to 2021 were developed using a counterfactual production scenario specific to disaster years. This scenario is then compared to reported production to assess the impact of the disasters.

Data source

Four data sources are used to estimate the different parameters of the models.

- *Disaster data*: The occurrence of disasters is taken from the EM-DAT database, which provides the most comprehensive coverage of historical disaster events. The disasters recorded in this database meet the criteria of either ten or more dead, 100 or more injured, a declaration of a state of emergency, or a call for international assistance. The analysis includes all scales of disaster events – small, medium, and large – falling under the following hazard categories: storm, flood, drought, extreme temperature, insect infestation, wildfire, earthquake, landslide, mass movement and volcanic activity. The global count for these disasters was 10 190 events from 1991 to 2021.
- *Production and price data*: Nationally aggregated annual production, yield, area harvested for crops and number of animals for livestock, and price data was taken from FAOSTAT for 197 countries or areas. A total of 186 items are included in the analysis, divided into 11 commodity groups: cereals, legumes, coffee, tea, cocoa and spice crops, fruits and nuts, oilseeds, roots and tubers, sugar crops, tobacco, rubber and fibre crops, and vegetables, as well as the key livestock products commodities of meat and meat products, milk and eggs.
- Agricultural total factor productivity data from 1991–2020 was retrieved from the United States Department of Agriculture.

Production in the counterfactual scenario for disaster years builds production values under the assumption that disasters had not occurred. Yield values are imputed from the yield time series by country of more than 12 700 commodities drawn from FAOSTAT. Yield values in disaster years are substituted with counterfactuals based on the disaster events reported in EMDAT.

The analysis primarily uses a list of matrices that contain yield time series with the reported value of non-disaster years and yield for disaster years removed, $Yield\ (j,t,i{\cdot}d)$ where j are countries or areas, t are years (1991–2021), i are the commodities and d=0, which is non-disaster years. Three interpolation techniques are used to compute the counterfactual yields for the disaster years, depending on the number of non-disaster years for each time series.

- For time series with more than five years without disasters in 1991–2021, this applies to 58 percent of the sample, missing yield values are estimated by interpolating non-disaster year yields. A structural model fitted by maximum likelihood with Kalman smoothing is used for this computation. The structural model decomposes the time series into state–space model components, first through a measurement equation of the yield variable defining the state vector α:

$$yield_t = F_t\, \alpha_t + S_t\, \varepsilon_t, \quad \varepsilon_t \sim i.i.d.N(0,V_\varepsilon)$$

With α the vector of m state variables of dimension (m x 1), F_t and S_t are fixed coefficient matrices of dimensions N x m and N x r, r being the dimensions of the disturbance vector, and ε_t a r x 1 vector with zero mean and covariance matrix V_ε.

The state vector can then be described in a state equation as follows:

$$\alpha_{t+1} = G_t\, \alpha_t + R_t\, \eta_t, \quad \eta_t \sim i.i.d\ N(0,W_\eta)$$

With G_t an m x m matrix and R_t an m x g matrix of fixed coefficients, g being the dimensions of the disturbance vector, and η_t a g x 1 vector of mean zero and covariance matrix W_η.

The recursive Kalman filter allows for the model to be estimated in an iterative manner with the following equation:

$$\alpha_{t+1} = \alpha_t + K_t\,(yield_t - F_t'\, \alpha_t)$$

The Kalman gain (K_t) balances uncertainty between past observations and new information. If past observations are uncertain, K_t approaches one to give more weight to new information. If the difference between observed and estimated variables is unstable, K_t approaches zero.

- For time series with fewer than five years without disasters over 1991–2021:
  - Estimation is based on country clusters – this applies to 39 percent of the sample. Countries are grouped into 20 groups derived from dynamic time warping based on agricultural total factor productivity (TFP) growth and factor analysis based on yield levels for all commodities. The cluster tendency of the data was assessed using the Hopkins statistic.[244] A hierarchical clustering on principal component is conducted on the ten principal components resulting from the factor analysis conducted on 196 variables for 197 countries. Using the Ward criterion, countries are grouped together incrementally, while the growth of within-inertia corresponding to the last term in the following equation is minimized to form the most homogeneous clusters possible:

$$\sum_{k=1}^{K}\sum_{c=1}^{C}\sum_{j=1}^{N_c}(v_{jck} - \overline{v}_k)^2 =$$

$$= \sum_{k=1}^{K}\sum_{c=1}^{C} I_c(\overline{v}_{ck} - \overline{v}_k)^2 +$$

$$+ \sum_{k=1}^{K}\sum_{c=1}^{C}\sum_{j=1}^{N_c}(v_{jck} - \overline{v}_{ck})^2$$

v is the value of the variable k, from the 10 principal components variables, for the country j of the cluster c.

For each cluster c, each item i, and each year t, an average annual yield change rate is calculated:

$$Yield\ change\ rate_{cit} =$$

$$= \frac{\sum_{j=1}^{N_c}(yield_{ijt} - yield_{ij(t-1)})/yield_{ij(t-1)}}{n}$$

Where N_c is the number of countries in each cluster c.

Starting from the yields of 1990, this change rate is then applied to each country and each item to build a counterfactual time series from 1991 to 2021. The estimated counterfactual yield is calculated as follows for item i, country j and year t:

$$\hat{y}_{ijt} = \hat{y}_{ij(t-1)} \times (1 + Yield\ change\ rate_{cit})$$

  - Five countries were the only observation in their cluster (China, Guyana, Mexico, Peru and Uzbekistan). In these cases it was estimated using an ordinary least square regression model based on total factor productivity and lagged yield, following the equation:

$$yield_{ijt} = a \times yield_{ij(t-1)} + b \times agTFP_{jt} + u_{ijt}$$

$yield_{ijt}$ is the yield of for item i, country j, at time t
$agTFP_{jt}$ is the agricultural TFP of country j, at time t
U_{ijt} is the error term

Predictors estimated are used to compute the counterfactual yield time series as follows:

$$\hat{y}_{ijt} = \hat{a} \times \hat{y}_{ij(t-1)} + \hat{b} \times agTFP_{jt}$$

Once the counterfactual has been estimated, a yield deviation is calculated by the difference between the estimated counterfactual yield and the reported yield value in FAOSTAT.

To identify variability from non-disaster-related effects and remove background noise in yield variation, null distributions are computed by country and by item. Simulations were run on 10 000 simulated disaster matrices to build distributions of estimated yield deviations. Yield deviations under the 5 percent quantile of the distribution were removed from the estimated losses.

From yield losses to production losses, yields of a given year are multiplied by either the number of ha harvested, the number of animals slaughtered for meat products, or the number of laying or milking animals.

Production losses in values are obtained by multiplying tonnes by producer prices in FAOSTAT, expressed as 2017 purchasing power parity USD. Challenges arose from the earlier period of the time series in the 1990s when price reporting was less reliable than today. Without country prices, subregional medians, regional medians or world medians are used (12 percent of missing prices). When the local prices are three times higher than the world median, the world median is used.

TECHNICAL ANNEX 2A
ATTRIBUTION OF THE LOSSES TO DISASTER EVENTS

Losses are estimated per year per country and disaggregated by items. However, 85 percent of the disaster years considered are multidisaster years. To attribute these losses to different hazards taking place in the same year, a mixed effects regression model was used, with the positive production losses for each item in each country in each year as the dependent variable, year, and the number of each type of disaster as fixed effects and item and country as random effects as follows:

$$y_{ijt} = \beta_0 + \beta_1 x_t + \beta_2 x_{2jt} + \beta_3 x_{3jt} + \beta_4 x_{4jt} + \beta_5 x_{5jt} +$$
$$+ \beta_6 x_{6jt} + \beta_7 x_{7jt} + \beta_8 x_{8jt} + y_i + y_j + \varepsilon_{ijt} \quad (1)$$

Where y_{ijt} is the production loss of item i in country j and year t; the β_i are the fixed effect parameters; x_t is the year t with t from 1991 to 2021; x_{2jt} is the number of droughts in country j and year t; x_{3jt} is the number of floods in country j and year t; x_{4jt} is the number of storms in country j and year t; x_{5jt} is the number of earthquakes in country j in year t; x_{6jt} is the number of extreme temperatures in country j and year t; x_{7jt} is the number of landslides in country j and year t; x_{8jt} is the number of wildfires in country j and year t; y_i is the random effect for commodity i; y_j is the random effect country for j; and ε_{ijt} are the residuals, which are independent and normally distributed. The parameters of the model are estimated using restricted maximum likelihood.

Insect infestation, land movement and volcanic eruptions were deleted from the attribution exercise because there were too few observations (38, 19 and 151, respectively) in EM-DAT compared to the other types of events. However, these types of disasters were included in the loss estimation using the counterfactual models in **Technical annex 2**. The parameters of each type of event were used as weights to attribute production losses of each item in each country during each year to each type of disaster that happened in the country that year as follows:

$$w_{djt} = \frac{\beta_d X_{djt}}{\sum_{d=2}^{8} \beta_d X_{djt}}$$

Where w_{dt} is the weight for disaster type d in country j and year t; β_d is the model (1) parameter for disaster type d; and X_{djt} is the number of disasters of type d in country j and year t. Then the loss for item i in country j in year t due to disaster type d was calculated as:

$$l_{ijdt} = L_{ijt} w_{djt}$$

Where L_{ijt} are the total losses for item i in country j and year t.

Those losses were added over items, countries and years to obtain the total losses by type of disaster:

$$L_d = \sum_i \sum_j \sum_t l_{ijdt}$$

which was divided by the total number of disasters of that type, to obtain the average loss per disaster of each type:

$$a_d = \frac{L_d}{\sum_j \sum_t X_{jdt}}$$

Finally, this average loss per disaster of each type a_d was calculated as a percentage p_d of the average total losses of all types of disasters:

$$p_d = \frac{a_d}{\sum_d a_d} \times 100$$

TECHNICAL ANNEX 3
CLIMATE ATTRIBUTION DATA AND METHODS

Full details on the four case studies (soy yields in Argentina, wheat yields in Kazakhstan and Morocco, and maize yields in South Africa) are published in a companion supplement technical paper. This section presents the data and methods used for **section 3.1**.

The attribution results presented are based on comparing observed yield records with estimated counterfactual and factual crop yield distributions. Factual yields are the yields simulated for climate as it has actually been evolving, while counterfactual yields are those simulated for climate as it might have been without greenhouse gas increases and other anthropogenic climate forcing factors. To that purpose, we build a statistical, multivariate crop yield model based on the observed crop yield data in the full length of their available record[245] and observationally-derived climate data (20CRv3–W5E5).[246,247]

The modelling approach is constructed as to be generally applicable across case study countries or crops. For that, a pool of potentially relevant climate indices is determined (TABLE 8). This selection is informed by expert judgement including biophysiological factors and statistical crop modelling experience together with literature input.[248,249,250] These indices are calculated for growing seasons specific to the sub-region and crop with the highest production at the gridded scale of available climate data (1.4 x 1.4-degree resolution). From all data (observationally-based climate indices and crop yields), anomalies are taken with respect to a non-linear trend to account for the confounding influence of agricultural management changes such as fertilizer application. The variables to be used for the linear regression model are then selected in a two-step process similar to Laudien *et al.*[251] First, interdependency among the regression variables is removed by discarding those correlated by +/-0.7 or more with another variable that has a higher correlation with the yield data. The thus-reduced pool of variables is passed onto a Lasso regression that selects up to five variables that best explain the yield data. A linear fit gives the model parameters, and an out-of-sample validation is performed.

The statistical yield model is then applied to a set of factual and counterfactual climate data, taken from the Detection and Attribution Model Intercomparison Project (DAMIP)[252] component of the Coupled Model Intercomparison Project Phase 6 (CMIP6). A set of historical simulations include historical changes of both anthropogenic (greenhouse gases, ozone, aerosols, land use, etc.) and natural (solar irradiance, volcanic aerosol) climate forcing factors. A set of hist–nat simulations include only historical changes of the natural factors, while the anthropogenic ones are kept at pre-industrial levels. The 50 historical and 50 hist–nat simulations from DAMIP's only large ensemble with daily data availability, the sixth version of the Model for Interdisciplinary Research on Climate (MIROC6)[253] are for this purpose bias-corrected with the ISIMIP3 method (v3.0.2).[254] Model evaluation[255,256] shows no conspicuous biases beyond what is commonly accepted in climate impact modelling studies. For the case study regions specifically, precipitation in northern Kazakhstan has been shown to be well represented by the model);[257] for precipitation in Morocco the same is true at least at the coast and in the north,[258] which is the region of interest here. Earlier versions of the same model have been used to provide datasets for impact attribution studies,[259,260] including agriculture.[261,262]

MIROC6's equilibrium climate sensitivity (ECS) and Transient Climate Response (TCR) are with 2.60 °C and 1.58 °C at the lower side of the CMIP6 spread of 3.78 °C +/- 1.12 °C (ECS) and 1.98 °C +/- 0.48 °C (TCR) (mean +/- one standard deviation).[263] More importantly, it is within the IPCC's likely range for ECS of 2.5 °C to 5.1 °C (central value: 3.4 °C; very likely range: 2.1 °C to 7.7 °C) that is the best estimate to date, assessed based on multiple lines of evidence. It is slightly below the assessed likely range of 1.6 °C to 2.7 °C (central value: 2.0 °C) but within the very likely range of 1.3 °C to 3.1 °C. The model's total aerosol effective radiative »

TABLE 8

POOL OF CLIMATE INDICES USED FOR THE STATISTICAL CROP MODELLING, WHICH IS THEN REDUCED BASED ON INDEPENDENCE AND EXPLANATORY POWER

gdd{0,8,10}degC30degC	degree-days above a crop-specific baseline temperature (T_base) and below an optimum temperature (T_opt) summed over all days in the growing season. T_base = 8deg (maize), T_base = 0deg (wheat), T_base = 10deg (soy).; T_opt=30degC
n5daydry	number of events (dry spells) with 5 or more consecutive dry days (dry day:=day with precipitation amount <0.5 mm) per growing season (seven-day dry spell counts only once, not three times)
n5daywet	number of events with 5 or more consecutive wet days (wet day:=day with precipitation amount >=0.5 mm) per growing season (seven-day events count only once, not thrice)
ncverywet	maximum number of consecutive days in the growing season with precipitation amount >= 50 mm/day
ncxdry	maximum number of consecutive days (dry spells) in the growing season with precipitation amount < 0.5 mm
ndry	number of days per growing season with precipitation amount <0.5 mm/day (dry days)
nfrost	number of days per growing season with daily minimum near-surface temperature below 0degC (frost day)
nprge30mm	number of days per growing season with precipitation amount >=30 mm/day
nprge50mm	number of days per growing season with precipitation amount >=50 mm/day
nprgtp95	number of days per growing season with precipitation > its 95th percentile for that day of the year across the reference period
nprlt15mm	number of days per growing season with precipitation amount <15 mm/day
nprlt5mm	number of days per growing season with precipitation amount <5 mm/day
nTgt30degC	number of days per growing season with daily-mean temperature above 30 °C (very hot days)
nTNgtp95	number of days per growing season with daily minimum near-surface temperature > its 95th percentile for that day of the year across the reference period
nTNltp05	number of days per growing season with daily minimum near-surface temperature < its 5% percentile for that day of the year across the reference period
nTXgtp95	number of days per growing season with daily maximum near-surface temperature > its 95th percentile for that day of the year across the reference period
nTXltp05	number of days per growing season with daily maximum near-surface temperature < its 5th percentile for that day of the year across the reference period
pr5x	maximum daily-average precipitation amount during any consecutive five-day period centred within the growing season
prstd	standard deviation of precipitation across all days in the growing season
prsum	precipitation amount summed over all days in the growing season
prwetmean	rainfall intensity, defined as the ratio between the total growing-season rainfall (prsum) and the number of rainy days (rainy day:=day with precipitation amount >= 0.5 mm)
Tmean	growing-season average of daily-mean near-surface temperature
TNstd	standard deviation of daily minimum near-surface temperatures across all days in the growing season
TX5x	maximum daily maximum near-surface temperature during any consecutive five-day period centred within the growing season
TXstd	standard deviation of daily maximum near-surface temperatures across all days in the growing season

Source: Authors' own elaboration.

» forcing is with -0.99 W/m^2 well within the CMIP6 spread of -1.23 W/m^2 +/- 0.48 W/m^2 (mean +/- 5-95 percent confidence range) as well as within the IPCC's assessed range of -2.0 W/m^2 to -0.6 W/m^2 (central value: −1.3 W/m^2) (medium confidence).[264] Together, these numbers imply that the model response to greenhouse gases and other forcing factors is plausible. The global temperature response at the lower end implies further that the attribution results obtained might be biased low rather than high, meaning they provide more conservative estimates.

The 50 simulations in either experiment vary among each other in terms of internal climate variability, i.e. they each have different weather realized, and together give a picture of the climate with and without greenhouse gases and other anthropogenic climate forcings. The factual climate model data is processed in the same way as the observationally derived climate data. The counterfactual climate model data is processed analogously, only that in the percentile-based thresholds, these thresholds for the computation of indices are taken from the respective factual climate data, and, similarly, that anomalies for the counterfactual indices are computed with respect to the non-linear trend in the respective factual rather than the counterfactual data. Using the variable selection and model parameters from the observationally derived statistical model gives the distributions of factual and counterfactual yields.

TECHNICAL ANNEX 4
METHODOLOGICAL NOTE ON THE COST-BENEFIT ANALYSIS CALCULATION

This note aims at presenting the different calculation methods used for the section in **Part 4** on the benefit cost analysis and to demonstrate that the three approaches – preventative/risk reduction, anticipatory action (AA) and risk-informed action to curb the spread of desert locust (preventative and AA) – complement one another for building resilience. FAO has developed methodologies to calculate the benefit of farm-level disaster risk reduction good practice and anticipatory action interventions across a range of its programmes. While these methodologies are still being developed to include a wider range of programmatic activities, they provide an overview of the steps and structures of FAO's benefit cost analysis methods for analysing farm-level DRR good practices and AA interventions.

Section 1: Methodology assessing the benefits of disaster and climate risk reduction good practices based on FAO's 2019 publication, *Disaster risk reduction at farm level: Multiple benefits, no regrets*

Summary: The cost–benefit analysis (CBA) process calculates and compares the benefits and costs of suggested DRR good practice technologies for agriculture (crop, livestock, fisheries and forestry) and existing local technologies over time based on primary farm-level data collected on agricultural on a seasonal basis. On each farm, both the DRR suggested good practice technology and the existing local technology are monitored in different adjacent plots simultaneously. Plots that were not affected by hazards during the monitored period are the non-hazard scenario, whereas plots that were affected by hazards during the monitored period are part of the hazard scenario. Data collected at the farm level for the CBA include costs such as inputs, labour, maintenance and capital costs, and benefits, i.e. the gross value of production. The CBA compares the net benefits, i.e. the net return on investment in the suggested DRR good practice technology and existing local technology, over an observed period of analysis and then extrapolates these over a longer time (in this context, 11 years).

A three-step process was conducted to assess the benefits of the disaster and climate risk reduction good practices, including data collection, field-level appraisal and scaling up analysis.

Step 1: Data collection

The first step was to collect certain baseline data, which involved conducting background desk research on the target villages, households and their agricultural production activities, in addition to information on the hazard exposure, and extreme weather events and disasters that have affected them over the last five years. It also involved selecting target DRR practices, which were identified by a team of experts who also identified sites for the initial pre-selection and the villages to be involved in the study, based on local agroecological zones. These were then validated, which included identifying the households interested in participating in the field testing.

Selected study field plots of the participating farmers were divided into two parts of which one was used to test the innovative DRR good practice, while the other served as a control plot, on which the previously used farming practice was implemented, unchanged. In some cases, due to unavailability of land or in the case of perennial crops, the control plot was established on a nearby field, which had the same site conditions as the one on the DRR test plot to ensure that the conditions were the same for testing both the traditional as well as the good practice.

The performance on both the test and control plots was analysed season by season during non-hazard years (when no hazards occurred) and was compared to the performance under hazard conditions (when one or more hazards occurred). In this way, practices could be identified that:

- performed best under hazard conditions; and
- performed at least as well, in the absence of hazards, as the conventional agronomic practices used previously.

Step 2: Field-level appraisal through cost-benefit analysis

The second step was to create the CBA, which quantitatively evaluated the net benefits (feasibility and effectiveness) derived from the new DRR good practice as compared to the previously used practice, under both hazard and non-hazard conditions. CBA involved assigning a monetary value to the costs, added benefits, and avoided costs associated with implementing both the good practice and the previously used practice, under both hazard and non-hazard conditions. The valuation of unpriced goods or services, such as family labour or open-access water resources, was estimated by using prices of marketed goods as substitutes. TABLE 9 shows that the types of costs and benefits varied depending on the type of practice.

The BCR was used to compare practices and to indicate the relationship between the costs and benefits, which is expressed as a ratio of the discounted present value of benefits to the discounted present value of costs.

TABLE 9
COSTS AND BENEFITS

COSTS	BENEFITS
Upfront capital costs (e.g. costs of machinery and materials, costs of installing equipment/structures)	Revenues from agricultural production
Operations and maintenance costs	Value of agricultural assets, i.e. livestock
Input costs (e.g. labour, energy, water, fertilizers, pesticides, seeds, feed)	

Source: Authors' own elaboration.

The net returns were also evaluated through calculating the net present value (NPV) of both the good practice and the previously used or common practice, which was then compared to evaluate the added benefits (such as increased productivity) and avoided damage and losses achieved by the good practice. An appraisal period of 11 years was used, applying a 10 percent discount rate with a 5 percent and 15 percent sensitivity check. In general, on the one had, a positive NPV indicates that the present value of benefits outweighed the present value of costs over the assessed period. On the other hand, a negative NPV shows that the upfront and running costs are not fully repaid by the benefits accrued over time. A practice is considered more profitable when its NPV is higher.

Besides the quantitative analysis of the field level appraisal, a qualitative analysis was also conducted of the social and environmental co-benefits of the good practice as perceived by farmers. This information was gathered through semi-structured interviews and, when feasible, focus group discussions. The topics covered included the socioeconomic feasibility of the practice, its sustainability, and the associated social and environmental benefits. These benefits encompassed reduced vulnerability, increased income and livelihood opportunities, the potential to alleviate temporary food shortages during and after disasters, and enhanced nutrition. The discussions also explored whether these benefits helped mitigate adverse environmental impacts. In this way, additional benefits, unintended impacts and barriers were qualitatively identified and assessed, which may not become known if only quantitative evaluation is undertaken.

Step 3: Scaling up analysis

The third step that was undertaken as part of the FAO 2019 study, involved assessing the scaling up potential of selected good practices. For this, customized simulation models through the system dynamics methodology were used to simulate the potential impacts of scaling up three highly promising good practices. Through the system dynamics approach, biophysical variables can be integrated in monetary models and vice versa. This helps to better understand the dynamic non-linear behaviour of complex systems over time based on key causal relationships and feedback loops across its indicators. The simulation models that were developed were based on the findings from the field-level appraisals and context-specific potential barriers (e.g. agroecological and socioeconomic constraints) were also considered.

The simulation models were established for two main scenarios: i) the good practice scaling up scenario that assumes that the assessed DRR good practice is widely adopted by the farmers; and ii) a business-as-usual scenario is introduced during the simulation period of 11 years, functioning as though only the previously used practice by farmers was used without any other DRR good practice. In addition, three hazard frequency scenarios were simulated: i) a low-hazard frequency, where hazards recur every three years; ii) a medium-high-hazard frequency, considers hazards returning every two years; and iii) a high-hazard frequency, which assumes the hazards recur yearly.

Section 2: Anticipatory action benefit-cost analysis methodology

This note presents the calculation methods used for the benefit–cost analysis from the implementation of anticipatory action interventions. FAO has developed frameworks for calculating the direct benefits from AA interventions across a range of its programmes. While these methodologies are still being developed to include a wider range of programmatic activities, this methodology provides an overview of the steps and structures of FAO's benefit–cost analysis methods for AA.

The main output of the benefit–cost analysis is the benefit–cost ratio of the anticipatory action intervention. The BCR measures the ratio between the direct benefits resulting from anticipatory actions and the costs of designing and implementing the anticipatory actions, all expressed in present monetary values. Therefore, the BCR provides a summary of the value for money of acting before the occurrence of a forecasted hazard to prevent or mitigate its impact on the livelihoods of affected communities. To conduct this, FAO gathers quantitative data through structured interviews with beneficiary and control households, the counterfactuals between the two samples are used to form the bases of outcomes from AA interventions that then follow a range of formulas calculating added benefits and avoided losses from the intervention. The key steps to calculate the BCR of an anticipatory action project are summarized here.

Step 1: Data collection

The benefit–cost analysis of AA projects is based on primary data collected at the household level for both control and beneficiary samples. The differences between these two sample populations forms the basis of the calculation of benefits of the analysis.

There are several actions that are implemented to ensure the accuracy of the data collected.

1. Samples for beneficiary and control groups are collected and are stratified along several social, demographic and economic characteristics to ensure that the control and sample populations are as close as possible, to avoid any bias in data collection that may skew the results. Statistical tests are performed to confirm the comparability of the samples.
2. The timing of data collection is important to ensure that the most accurate data are collected, and the type of intervention that is being implemented is also accounted for and is representative of the project outcomes.
3. Prior to the calculation, data are reviewed to assess any inaccuracies that may arise from the enumerators. Assessing these issues early can greatly assist the quality of the analysis and remove or limit any data collection errors that might hinder the analysis.

Step 2: Calculating the costs of the interventions

The valuation of project costs per beneficiary household is a fundamental step in the calculation of the benefit–cost ratio of anticipatory actions. All the costs related to the analysed activities are accounted for, including direct costs (e.g. procurement) as well as logistics, administrative and other support costs. Project costs are calculated based on reported project expenditures detailed on FAO's financial reporting systems available on the Field Programme Management Information System (FPMIS).

Two categories of costs are considered:

a. programme costs, which include the costs of purchased items, logistics and letters of agreement with implementing partners; and
b. support costs, which are the running costs of project implementation, including administrative costs, field monitoring, general operating expenses and technical support services, among others.

Step 3: Calculating the benefits of anticipatory actions

The benefit–cost analysis only focuses on the direct benefits of the anticipatory actions, i.e. benefits derived directly from FAO's assistance.

Two types of direct benefits should be analysed:

1. added benefits: early actions determine an increase in agricultural output or an increase in the value of agricultural output; and
2. avoided losses: early actions prevent or reduce damage and losses caused by hazards on agricultural assets and/or output.

The benefits are calculated by analysing the differences in outcome variables between beneficiary and control groups. Statistical tests are performed to evaluate the significance of the observed differences.

Importantly, qualitative data are also collected – through focus group discussions and key informant interviews – and analysed to gain an in-depth understanding of the perceptions of affected communities; triangulate the quantitative findings; assess the strengths and weaknesses of the decision-making and operational procedures followed to link early warnings with anticipatory actions; and derive fundamental insights for improving future programming.

Example: the methodology used to calculate avoided losses of animal mortality

The example outlines the steps taken to calculate the avoided losses of animal mortality.

Calculate the total number of goats owned by each household. The number should include goats owned before the start of the project interventions plus goats purchased during the project.

$$\text{Animal}_{\text{total}} = \text{animal}_{t_o} + \text{animal}_{\text{bought}}$$

For each household, calculate the mortality rate (MR) of goats by dividing the reported number of goats that died due to drought by the total number of goats owned:

$$\text{MR}_{\text{animal}} = \frac{\text{animal}_{\text{dead}}}{\text{animal}_{\text{total}}}$$

Calculate the average mortality rate of goats for the whole beneficiary sample and for the whole control sample. Note: households that do not own goats should not be included in the calculation of average goat mortality rates.

Calculate the difference in average goat mortality rates between beneficiary and control samples.

$$\text{DMR}_{\text{animal}} = \text{MR}_{\text{animal}_{\text{benef}}} - \text{MR}_{\text{animal}_{\text{control}}}$$

Calculate the total additional number of goats that survived (or died) throughout the project duration. Multiply by the total number of goats owned by beneficiary households.

$$\text{TotalDMR}_{\text{animal}} = \text{DMR}_{\text{animal}} \times \sum_{b=1}^{n} \text{animal}_{\text{total}_b}$$

Calculate the value of the additional number of goats that survived (or died) throughout the project duration using the average market price of goats during the project implementation period.

$$\text{ValueTotalDMR}_{\text{animal}} = \text{TotalDMR}_{\text{animal}} \times \text{p}_{\text{animal}}$$

Calculate the value of saved animals per household.

$$\text{ValueTotalDMR}_{\text{animal}}\text{perHH} = \frac{\text{ValueTotalDMR}_{\text{animal}}}{\text{n. of sampled beneficiary HHs}}$$

Step 4: The benefit–cost ratio

The BCR is calculated as the ratio between total costs per beneficiary household and the sum of all statistically significant added benefits and avoided losses calculated based on replies from beneficiary and control households.

TABLE 10

COSTS AND BENEFITS PER HOUSEHOLD

COSTS PER HOUSEHOLD	
Project costs	245.5
Support costs	39.3
Total costs	284.8
BENEFITS PER HOUSEHOLD	
Avoided loss of herd value (body conditions)	1 110
Animals saved (adult)	778
Animals saved (newborn)	57
Avoided loss of cashmere production value	37
Increased milk production	26
Total benefits	2 008
Benefit-cost ratio	7.1
"Worst-case" scenario	5.1
"Best-case" scenario	12.1

Source: Authors' own elaboration.

Sensitivity analysis is performed by altering some of the key assumptions adopted in the BCR calculations and assessing the results variation. In particular, worst-case and best-case scenarios are simulated.

TABLE 10 provides an example of how this would be calculated given a project's costs and total accumulated benefits and avoided losses.

TECHNICAL ANNEX 5 METHODOLOGY TO CALCULATE AVOIDED LOSSES FOR RISK-INFORMED DESERT LOCUST INTERVENTION

Based on the experience of implementing the desert locust control operation, a new living methodology was developed to calculate the return on investment of FAO's risk-informed interventions, using various considerations and assumptions. The FAO Locust Handbook and FAO-Desert Locust Forecasting Manual were consulted for desert locust food requirements and the average density of the swarms and bands. The control operation profile derived from these sources was used to determine the size of the swarms, infested areas and areas treated and avoided losses of green matter/vegetation because of areas protected.

Desert locust food requirements (FAO-locust handbook and FAO-DL forecasting manual):

- 1 adult consumption (lifetime) = 60 gr of green matter/vegetation
- 1 hopper consumption (lifetime) = 3.7 gr of green matter/vegetation

Considering the average density of swarms and bands (Desert Locust Forecasting Manual and FAO Desert Locust Guidelines I Biology and Behaviour), it is estimated that the consumption requirements per hectare are:

- Swarm consumption (lifetime)/ha = 36 tonnes of green matter/vegetation
- Hopper bands consumption (lifetime)/ha = 4 tonnes of green matter/vegetation

Control operation profile:
Reports from the field provided details about the nature of the control operation (air and ground) as well as the ratio of hoppers to swarms. Two years of control operation reports indicated that 80 percent of hectares treated were infested with immature and mature swarms, while 20 percent of areas treated were infested with hoppers at various stages (from instar 1 to 5).

Based on this information, every time we treat one hectare, there are around 30 tonnes of green matter and vegetation that is not consumed by desert locusts (protected).

The productive green matter:
In order to estimate losses and impacts affecting the productive livelihoods of farmers, agropastoralists and pastoralists, we need to introduce (adopt) the concept of productive green matter and vegetation. We considered productive vegetation to be any palatable species (for animals) in the rangeland and/or farms and any species directly used as food (for humans).

- Assumption 1. It is estimated that during their lifetime, desert locusts will get only 50 percent of their dietary requirements from productive green matter and vegetation, while the remaining half will come from the leaves of unpalatable or non-food producing species.
- Assumption 2. Looking at the land cover averages in the areas where desert locusts have been most present during the current upsurge, it is estimated that of the total productive green matter and vegetation consumed, 70 percent comes from rangeland and 30 percent from farmland.

From desert locust consumption to rangeland and crop losses:
Following these assumptions and the considerations that will follow, it is possible to calculate how much one hectare of desert locusts (hoppers and swarms) can destroy over their life cycle in rangeland and farmland.

Consideration 1. Average productivity value for rangeland at 0.75 T/ha in East Africa.[265]

Consideration 2. Cropland protected in the Horn of Africa, applying 3 tonnes/ha as average green forage yield ratio and considering a ratio leaf/stalks of 0.49.

Consideration 3. Average production of cereals (major crops in arid and semi-arid land areas): 1.3 tonnes and an estimated 50 percent reduction in yield due to desert locust.

Consideration 4. 1 TLU/ha carrying capacity of rangeland and an estimated 60 percent in the reduction of carrying capacity due to desert locusts. Sixty percent reduction (in the case of a desert locust infestation) is estimated taking into consideration field observations.

Consideration 5. 4.5 TLU/HH is used as an average in the region.

Consideration 6. USD 300 is used as an average price per tonne of cereal.

Consideration 7. 150 kg is used as average cereals requirement per person/year. ■

GLOSSARY

Agricultural assets: The volume of stored inputs and production (seeds, fertilizer, feed, stored crops and livestock produce, harvested fish, stored wood, etc.) as well as machinery and equipment used in crop and livestock farming, forestry, and fisheries and aquaculture. It encompasses a wide array of items, including but not limited to: tractors, balers, combine harvesters, threshers, fertilizer distributors, ploughs, root or tuber harvesting machines, seeders, soil machinery, irrigation facilities, tillage implements, track-laying tractors, milking machines, dairy machines, specialized wheeled equipment, portable chainsaws, fishing vessels, fishing gear, aquaculture feeders, pumps, aerators and support vessels for aquaculture.

Agricultural production loss: Declines in the volume of crop, livestock (and also fisheries and aquaculture and forestry) production resulting from a disaster, as compared to pre-disaster expectations.

Agrifood systems: Systems that encompass the primary production of food and non-food agricultural products, as well as in food storage, aggregation, post-harvest handling, transportation, processing, distribution, marketing, disposal and consumption. Within agrifood systems, food systems comprise all food products that originate from crop and livestock production, forestry, fisheries and aquaculture, and from other sources such as synthetic biology, that are intended for human consumption.

Anthropogenic climate forcings: Short for human-induced forcings that influence the climate system's internal dynamics. Anthropogenic forcings include emissions of greenhouse gases, aerosols, ozone-depleting substances and land-use change.[139]

Attribution: The process of evaluating the relative contributions of multiple causal factors to a change or event with an assessment of confidence.[139]

Biological hazards: Hazards of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins and bioactive substances. Examples include bacteria, viruses or parasites, as well as venomous wildlife and insects, poisonous plants and mosquitoes carrying disease-causing agents.

Climate: Climate is usually defined as the average weather, but it is more rigorously defined as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years.[139]

Climate change: Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties that persist for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.[139] In its Article 1, the United Nations Framework Convention on Climate Change defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Climate change adaptation: In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to the expected climate and its effects.[139]

Climate resilience: The capacity of social, economic and environmental systems to cope with current or expected climate variability and changing average climate conditions, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.[139]

Climate variability: Variations in the mean state and other statistics (standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Climatological disasters: A disaster caused by long-lived, meso- to macro-scale atmospheric processes ranging from intraseasonal to multidecadal climate variability.[1]

Coping capacity/capacity to cope: The ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks.[1]

Damage: The monetary value of the total or partial destruction of physical assets and infrastructure in disaster affected areas, expressed as replacement and/or repair costs. In agriculture, damage is considered in relation to standing crops, farm machinery, irrigation systems, livestock shelters, fishing vessels, pens and ponds, etc.[1]

Disaster: A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental loss and impacts.[1]

Disaster risk: The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. The definition of disaster risk reflects the concept of hazardous events and disasters as the outcome of continuously present conditions of risk.[1]

Disaster risk reduction: The policy objective of disaster risk management. DRR strategies and plans are designed with the objective of preventing the emergence of new disaster risks, reducing existing risks and effectively managing any remaining risks. These efforts collectively enhance resilience and align with the overarching aim of promoting sustainable development.[1]

Displacement: Situations where people are forced or obliged to leave their homes or places of habitual residence due to a disaster or to avoid the impact of an immediate and foreseeable natural hazard. This displacement occurs because individuals who are exposed to a natural hazard are in a situation where they are exceptionally vulnerable and lack the resilience necessary to withstand the impacts of that hazard. It is the effects of natural hazards, including the adverse impacts of climate change, that may overwhelm the resilience or adaptive capacity of an affected community or society, thus leading to a disaster that potentially results in displacement. Disaster displacement may take the form of spontaneous flight, an evacuation ordered or enforced by authorities, or an involuntary planned relocation process. This displacement can take place within a single country, referred to as internal displacement, or it can extend across international borders, known as cross-border disaster displacement.[266]

Early-warning system: An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities, systems and processes that enable individuals, communities, governments, businesses and others to take timely action to reduce the effects of disaster in advance of hazardous events.[1]

Extreme event (extreme weather event or climate extreme event): An event that is rare at a particular place and time of year. Definitions of rare vary, but the occurrence of an extreme weather event would be at a value of a weather or climate of weather variable above or below a threshold value near the upper or lower ends of the range of observed values of the variable. By definition, the characteristics of extreme weather may vary from place to place. When a pattern of extreme weather persists for a season or longer, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g. drought or heavy rainfall over a season).[139]

Food chain crises: Threats to the human food chain such as transboundary plant, forest, animal, aquatic and zoonotic pests and diseases, food safety events, radiological and nuclear emergencies, dam failures, industrial pollution, oil spills, etc. These have the potential to significantly affect food security, livelihoods, human health, national economies and global markets.[268]

Food insecurity: A situation that exists when people lack secure access to enough safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution or inadequate use of food at the household level. Food insecurity, poor conditions of health and sanitation, and inappropriate care and feeding practices are the major causes of poor nutritional status. Food insecurity may be chronic, seasonal or transitory.[267]

Food security: A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, four food security dimensions can be identified: food availability, economic and physical access to food, food utilization and stability over time.[268]

Geophysical disasters: Disasters that originate from the Earth's internal processes, such as earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud flows. Hydrological and meteorological factors are important to some of these processes. Tsunamis are difficult to categorize because they are triggered by undersea earthquakes and other geological events, but they essentially become an oceanic process that is manifested as a coastal water-related hazard.[1]

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be natural, anthropogenic or socionatural in origin. Natural hazards are predominantly associated with natural processes and phenomena.[1]

Hunger: An uncomfortable or painful physical sensation caused by insufficient consumption of dietary energy.[268]

Hydrological disasters: Disasters caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater.[1]

Loss: The change in economic flows occurring due to a disaster. In agriculture, loss may include declines in crop production, decline in income from livestock products, increased input prices, reduced overall agricultural revenues and higher operational costs and increased unexpected expenditures to meet immediate needs in the aftermath of a disaster.[1]

Loss and Damage, and losses and damage: The term Loss and Damage (capitalized) refers to political debate under the UNFCCC following the establishment of the Warsaw Mechanism on Loss and Damage in 2013, which is to "address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change." Losses and damage (lowercase) refer broadly to harm from (observed) impacts and (projected) risks and can be economic or non-economic. In this report, the term loss and damage refers to the definition of damage and losses as described individually in this glossary.[5]

Meteorological disasters: Events caused by short-lived and/or small- to meso-scale atmospheric processes (in the spectrum from minutes to days).[1]

Micronutrients: Vitamins, minerals and other substances that are required by the body in very small but specific amounts. Micronutrients are measured in milligrams or micrograms.[268]

Migration: The movement of a person or a group of people, either across an international border or within a state. It is a population movement, encompassing any kind of movement of people, whatever its length, composition and causes. It includes migration of refugees, displaced persons, economic migrants and persons moving for other purposes, including family reunification.[269]

Mitigation (of disaster risk and disaster): The efforts aimed at reducing the potential adverse impacts of a hazardous event, including those caused by human activities. This reduction is achieved through actions that target the reduction of hazard, exposure and vulnerability.[1]

Preparedness: The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of a likely, imminent or current disaster.[1]

Prevention: Activities and measures to avoid existing and new disaster risks. Disaster prevention expresses the concept and intention to completely avoid potential adverse impacts of hazardous events.[1]

Projection: A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.[5]

Recovery: Restoring or improving the livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities of a disaster-affected community or society, aligning to the principles of sustainable development and "build back better" to avoid or reduce future disaster risk.[1]

Rehabilitation: The restoration of basic services and facilities for the functioning of a community or a society affected by a disaster.[1]

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.[1]

Residual risk: The disaster risk that remains even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained. The presence of residual risk implies a continuing need to develop and support effective capacities for emergency services, preparedness, response and recovery, together with socioeconomic policies such as safety nets and risk transfer mechanisms, as part of a holistic approach.[1]

Severe food insecurity: The level of severity of food insecurity at which people have likely run out of food, experienced hunger and, at the most extreme, gone for days without eating, putting their health and wellbeing at grave risk, based on the Food Insecurity Experience Scale.[268]

Slow-onset disaster: A disaster that emerges gradually over time. Slow-onset disasters could be associated with drought, desertification, sea-level rise, epidemic diseases, etc.[1]

Societal hazard: Hazards brought about entirely or predominantly by human activities and choices, that have the potential to endanger exposed populations and environments. They are derived from sociopolitical, economic activity, cultural activity, human mobility and the use of technology, but also by societal behaviour – either intentional or unintentional.[3]

Sudden-onset disaster: A disaster triggered by a hazardous event that emerges quickly or unexpectedly. Sudden-onset disasters could be associated with earthquakes, volcanic eruptions, flash floods, chemical explosions, critical infrastructure failures, transport accidents, etc.[1]

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.[1]

NOTES

1 **General Assembly of the United Nations**. 2017. *Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction*. Seventy-first session Agenda item 19 (c) Sustainable development: disaster risk reduction. New York, United Nations. https://digitallibrary.un.org/record/852089?ln=en

2 **EM-DAT**. 2023. Disasters in numbers 2022. In: *CRED*. Brussels. https://cred.be/sites/default/files/2022_EMDAT_report.pdf

3 **UNDRR (United Nations Office for Disaster Risk Reduction) & ISC (International Science Council).** 2020. *Hazard Definition & Classification Review. Technical Report*. Geneva, UNDRR and Paris, ISC. www.preventionweb.net/media/47681/download?startDownload=true

4 **General Assembly of the United Nations**. 2016. *Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction*. Seventy-first session Agenda item 19 (c) Sustainable development: disaster risk reduction. New York, United Nations. https://digitallibrary.un.org/record/852089?ln=fr

5 **IPCC (Intergovernmental Panel on Climate Change).** 2022. *Climate Change 2022 Impacts, Adaptation and Vulnerability*. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama, eds. pp. 3056. Cambridge, UK and New York, USA, Cambridge University Press. doi.org.10.1017/9781009325844

6 **Conforti, P., Markova, G. & Tochkov, D**. 2020. *FAO's Methodology for Damage and Loss Assessment in Agriculture*. FAO Statistics Division Working Paper Series/19-17. Rome, FAO. http://www.fao.org/3/ca6990en/CA6990EN.pdf.

7 **Holleman, C., Rembold, F., Crespo, O. & Conti, V.** 2020. *The impact of climate variability and extremes on agriculture and food security – An analysis of the evidence and case studies*. Background paper for The State of Food Security and Nutrition in the World 2018. FAO Agricultural Development Economics Technical Study No. 4. Rome, FAO. doi.org/10.4060/cb2415en

8 **World Bank**. 2022. *Pakistan: Flood Damages and Economic Losses Over USD 30 billion and Reconstruction Needs Over USD 16 billion – New Assessment*. In: *The World Bank*. Washington, DC. [Cited May 2023]. www.worldbank.org/en/news/press-release/2022/10/28/pakistan-flood-damages-and-economic-losses-over-usd-30-billion-and-reconstruction-needs-over-usd-16-billion-new-assessme

9 **NCEI (National Centers for Environmental Information)**. 2020. U.S. Billion-dollar Weather and Climate Disasters, 1980–present (NCEI Accession 0209268). In: *NOAA*. Washington, DC. [Cited 13 May 2023]. doi.org/10.25921/stkw-7w73

10 **IOM (International Organization for Migration).** 2021. Corredor seco Honduras 2021: Línea base vulnerabilidad y sequía. In: *IOM*. Grand-Saconnex, Switzerland. [Cited 5 May 2022]. https://dtm.iom.int/reports/l%C3%ADnea-base-vulnerabilidad-y-sequ%C3%ADa-corredor-seco-honduras-noviembre-2020

11 **WFP (World Food Programme).** 2021. *Charting a New Regional Course of Action: The Complex Motivations and Costs of Central American Migration*. Rome. www.wfp.org/publications/complex-motivations-and-costs-central-american-migration

12 **UNHCR (United Nations High Commissioner for Refugees).** 2021. Cambio climático, otro factor que provoca desplazamiento en Honduras. In: *UNHCR*. Geneva. [Cited November 2021]. www.acnur.org/noticias/stories/cambio-climatico-otro-factor-que-provoca-desplazamiento-en-honduras

13 **Netherer, S., Panassiti, B., Pennerstorfer, J. & Matthews, B.** 2019. Acute Drought Is an Important Driver of Bark Beetle Infestation in Austrian Norway Spruce Stands. *Frontiers in Forests and Global Change*, 2: 39. doi.org/10.3389/ffgc.2019.00039

14 **Valadez, M. & de la Lama, G.M.** 2023. Heat Stress in Cattle. *Animal Behaviour and Welfare Cases*. [Cited 31 March 2023]. doi.org/10.1079/abwcases.2023.0005

15 **Thornton, P., Nelson, G., Mayberry, D. & Herrero, M.** 2022. Impacts of heat stress on global cattle production during the 21st century: a modelling study. *The Lancet Planetary Health*, 6(3): e192–e201. doi.org/10.1016/S2542-5196(22)00002-X

16 **Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S. & Cassman, K.G.** 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences*, 101(27): 9971–9975. doi.org/10.1073/pnas.0403720101

17 **Schlenker, W. & Roberts, M.J.** 2009. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences*, 106(37): 15594–15598. doi.org/10.1073/pnas.0906865106

18 **Fernie, E., Tan, D.K.Y., Liu, S.Y., Ullah, N. & Khoddami, A.** 2022. Post-Anthesis Heat Influences Grain Yield, Physical and Nutritional Quality in Wheat: A Review. *Agriculture*, 12(6): 886. doi.org/10.3390/agriculture12060886

19 **Bishop, J., Bell, T., Huang, C. & Ward, M.** 2021. *Fire on the Farm: Assessing the impacts of the 2019–2020 bushfires on food and agricultures in Australia*. World Wildlife Fund for Nature (WWF). https://assets.wwf.org.au/image/upload/v1/website-media/resources/WWF_Report-Fire_on_the_Farm_converted

20 **Banca d'Italia.** 2022. *Gli effetti del cambiamento climatico sull'economia italiana*. Questioni di Economia e Finanza. No. 728. Rome. www.bancaditalia.it/pubblicazioni/qef/2022-0728/QEF_728_22.pdf

21 **Brás, T.A., Seixas, J., Carvalhais, N. & Jägermeyr, J.** 2021. Severity of drought and heatwave crop losses tripled over the last five decades in Europe. *Environmental Research Letters*, 16(6): 065012. doi.org/10.1088/1748-9326/abf004

22 **IFRC (International Federation of Red Cross and Red Crescent Societies).** 2022. Mozambique: Tropical Cyclones Idai and Kenneth – Emergency Appeal n° MDRMZ014, Final Report. In: *ReliefWeb*. [Cited July 2023]. https://reliefweb.int/report/mozambique/mozambique-tropical-cyclones-idai-and-kenneth-emergency-appeal-ndeg-mdrmz014-final-report

23 **EU Science Hub.** 2023. The EU 2022 wildfire season was the second worst on record. In: *European Commission*. [Cited 10 March 2023]. https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/eu-2022-wildfire-season-was-second-worst-record-2023-05-02_en

24 **You, S., Liu, T., Zhang, M., Zhao, X., Dong, Y., Wu, B., Wang, Y., Li, J., Wei, X. & Shi, B.** 2021. African swine fever outbreaks in China led to gross domestic product and economic losses. *Nature Food*, 2021(10): 802–808. doi.org/10.1038/s43016-021-00362-1

25 **WFP (World Food Programme).** 2022. *Pakistan Country Brief, October 2022*. Rome. https://reliefweb.int/report/pakistan/wfp-pakistan-country-brief-october-2022

26 **FAO.** 2023. Türkiye earthquakes: initial assessment indicates losses of more than 20 percent in food production. In: *FAO*. Rome. [Cited 10 March 2023]. www.fao.org/newsroom/detail/turkiye-earthquakes-initial-assessment-indicates-losses-of-more-than-20-percent-in-food-production/en

27 **Asian Development Bank.** 2021. *Asian Development Outlook 2021 Update: Transforming Agriculture in Asia*. Manila. www.adb.org/sites/default/files/publication/726556/ado2021-update.pdf

28 **African Development Bank Group.** 2016. *Feed Africa: Strategy for Agricultural Transformation in Africa. 2016–2025*. Abidjan. www.afdb.org/en/documents/document/feed-africa-strategy-for-agricultural-transformation-in-africa-2016-2025-89888

29 FAO, IFAD, UNICEF, WFP & WHO. 2023. *The State of Food Security and Nutrition in the World 2023: Urbanization, agrifood systems transformations and healthy diets across the rural-urban continuum*. Rome, FAO. doi.org/10.4060/cc3017en

30 Kunbhar, Z. 2022. Floods after drought devastate Sindh's Agriculture. In: *The Third Pole*. [Cited 26 August 2022]. www.thethirdpole.net/en/food/floods-after-drought-devastate-sindh-agriculture/

31 Government of Pakistan. 2022. *Pakistan Meteorological Department: Drought Alert-1 (16 May 2022)*. In: Reliefweb. [Cited May 2023]. https://reliefweb.int/report/pakistan/pakistan-meteorological-department-drought-alert-i-16-may-2022

32 Mushtaq, F., Ali, M., Ghosh, A., Jalal, R., Asghar, A., Dadhich, G., Chiozza, F. *et al.* 2022. *A rapid geospatial flood impact assessment in Pakistan*. Rome, FAO. https://www.fao.org/geospatial/resources/detail/en/c/1629466/

33 Government of Pakistan. 2022. *Pakistan Floods 2022: Post-Disaster Needs Assessment*. In: Reliefweb. [Cited May 2023]. https://reliefweb.int/report/pakistan/pakistan-floods-2022-post-disaster-needs-assessment

34 Kugelman, M. 2022. Foreign Policy, Pakistan's Flood Crisis Could Become a Food Crisis. *Foreign Policy*. 8 September 2022. https://foreignpolicy.com/2022/09/08/pakistan-floods-food-security-crisis/

35 IRC (International Rescue Committee). 2023. *Six months on since the Pakistan floods, 8.6 million people are facing hunger: IRC calls for world leaders to address the imbalance of climate change*. In: IRC. [Cited May 2023]. www.rescue.org/press-release/six-months-pakistan-floods-86-million-people-are-facing-hunger-irc-calls-world

36 IPC (Integrated Food Security Phase Classification). 2022. *Khyber Pakhtunkhwa, Pakistan: IPC Acute Food Insecurity Analysis July – December 2022*. In: Reliefweb. [Cited May 2023]. https://reliefweb.int/report/pakistan/khyber-pakhtunkhwa-pakistan-ipc-acute-food-insecurity-analysis-july-december-2022-published-december-30-2022

37 IDMC (Internal Displacement Monitoring Centre). 2023. *2023 Global Report on Internal Displacement*. Geneva, IDMC. www.internal-displacement.org/global-report/grid2023/

38 IFRC (International Federation of Red Cross and Red Crescent Societies). 2022. *Central America: Hurricanes Eta & Iota – Final Report (MDR43007)*. IFRC. https://reliefweb.int/report/guatemala/central-america-hurricanes-eta-iota-final-report-mdr43007

39 Ruiz Soto, A.G., Bottone, R., Waters, J., Williams, S., Louie, A. & Wang, Y. 2021. *Charting a New Regional Course of Action: The Complex Motivations and Costs of Central American Migration*. Migration Policy Institute. www.migrationpolicy.org/sites/default/files/publications/mpi-wfp-mit_migration-motivations-costs_final.pdf

40 Rubi, M. & Gaynor, T. 2021. In Honduras, climate change is one more factor sparking displacement. In: *UNHCR*. Geneva. [Cited March 2023]. https://www.unhcr.org/news/stories/honduras-climate-change-one-more-factor-sparking-displacement

41 ILO. 2023. Employment by sex and age (thousands) – Annual. In: *ILOSTAT*. Geneva. [Cited March 2023]. www.ilo.org/shinyapps/bulkexplorer53/?lang=en&segment=indicator&id=EMP_TEMP_SEX_AGE_NB_A

42 Botreau, H. & Cohen, M.J. 2019. *Gender inequalities and food insecurity: Ten years after the food price crisis, why are women farmers still food-insecure?* Oxfam. http://hdl.handle.net/10546/620841

43 FAO. 2021. *The impact of disasters and crises on agriculture and food security: 2021*. Rome. doi.org/10.4060/cb3673en

44 Government of Pakistan. 2023. Introduction. In: *Pakistan Bureau of Statistics*. [Cited March 2023]. www.pbs.gov.pk/content/agriculture-statistics#:~:text=It%20contributes%20about%2024%20percent,source%20of%20foreign%20exchange%20earnings

45 ILO. 2023. Employment by sex and age (thousands) – Annual. In: *ILOSTAT*. Geneva. [Cited March 2023]. www.ilo.org/shinyapps/bulkexplorer53/?lang=en&segment=indicator&id=EMP_TEMP_SEX_AGE_NB_A

46 Chowdhury, J.R., Parida, Y. & Agarwal, P. 2022. How flood affects rural employment in India: A gender analysis. *International Journal of Disaster Risk Reduction*, 73: 102881. doi.org/10.1016/j.ijdrr.2022.102881

47 UNDP (United Nations Development Programme). 2023. Multidimensional Vulnerability Index. In: *UNDP*. New York. [Cited July 2023]. https://data.undp.org/sids/app/vulnerability/mvi-index/spider

48 Maino, R. & Emrullahu, D. 2022. Climate Change in sub-Saharan Africa Fragile States: Evidence from Panel Estimations. *IMF Working Papers*, 2022(054): 1. doi.org/10.5089/9798400204869.001

49 Molua, E.L. 2009. An empirical assessment of the impact of climate change on smallholder agriculture in Cameroon. *Global and Planetary Change*, 67(3–4): 205–208. doi.org/10.1016/j.gloplacha.2009.02.006

50 Mazhin, SA., Farrokhi, M., Noroozi, M., Roudini, J., Hosseini, S.A., Motlagh, M.E., Kolivand, P. & Khankeh, H. Worldwide disaster loss and damage databases: A systematic review. *J Educ Health Promot*. 2021 Sep 30;10:329. doi: 10.4103/jehp.jehp_1525_20. PMID: 34761015; PMCID: PMC8552254 https://doi.org/10.4103%2Fjehp.jehp_1525_20

51 UNDRR. 2016. *Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction*. UNDRR. www.preventionweb.net/publication/report-open-ended-intergovernmental-expert-working-group-indicators-and-terminology

52 Abbade, E.B. 2015. Environmental impacts of food supply and obesogenic severity worldwide. *British Food Journal*, 117(12): 2863–2879. doi.org/10.1108/BFJ-12-2014-0404

53 WMO (World Meteorological Organization). 2023. Economic costs of weather-related disasters soars but early warnings save lives. In: *WMO*. Geneva. March 2023. https://public.wmo.int/en/media/press-release/economic-costs-of-weather-related-disasters-soars-early-warnings-save-lives

54 Jones, R.L., Guha-Sapir, D. & Tubeuf, S. 2022. Human and economic impacts of natural disasters: can we trust the global data? *Scientific Data*, 9(1): 572. doi.org/10.1038/s41597-022-01667-x

55 CRED (Centre for Research on the Epidemiology of Disasters) & UNDRR. 2018. *Economic Losses, Poverty & Disasters 1998-2017*. https://reliefweb.int/report/world/economic-losses-poverty-disasters-1998-2017

56 UNDRR. 2022. *Global Assessment Report on Disaster Risk Reduction – Our World at Risk: Transforming Governance for a Resilient Future*. Geneva. www.undrr.org/GAR2022

57 FAO. 2018. *The impact of disasters and crises on agriculture and food security 2017*. Rome. https://www.fao.org/3/I8656EN/i8656en.pdf

58 World Bank & FAO. 2018. *Rebuilding Resilient and Sustainable Agriculture in Somalia (Overview). Somalia Country Economic Memorandum Volume 1*. Rome, FAO. https://www.fao.org/documents/card/en?details=I8842EN%2f

59 IPPC Secretariat. 2021. *Scientific review of the impact of climate change on plant pests – A global challenge to prevent and mitigate plant pest risks in agriculture, forestry and ecosystems*. FAO on behalf of the IPPC Secretariat. doi.org/10.4060/cb4769en

60 Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A. & Tamò, M. 2016. First Report of Outbreaks of the Fall Armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. *PLOS ONE*, 11(10): e0165632. doi.org/10.1371/journal.pone.0165632

61 Kenis, M., Benelli, G., Biondi, A., Calatayud, P.-A., Day, R., Desneux, N., Harrison, R.D. *et al.* 2022. Invasiveness, biology, ecology, and management of the fall armyworm, Spodoptera frugiperda. *Entomologia Generalis*, 102198. doi.org/10.1127/entomologia/2022/1659

62 Montezano, D.G., Specht, A., Sosa-Gómez, D.R., Roque-Specht, V.F., Sousa-Silva, J.C., Paula-Moraes, S.V., Peterson, J.A. & Hunt, T.E. 2018. Host Plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. *African Entomology*, 26(2): 286–300. https://doi.org/10.4001/003.026.0286

63 Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y. *et al*. 2017. Fall Armyworm: Impacts and Implications for Africa. *Outlooks on Pest Management*, 28(5): 196–201. doi.org/10.1564/v28_oct_02

64 Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colemenarez, Y., Corniani, N. *et al*. 2017. *Fall armyworm: impacts and implications for Africa*. Evidence Note. 2. CABI. www.invasive-species.org/wp-content/uploads/sites/2/2019/02/FAW-Evidence-Note-October-2018.pdf

65 Chimweta, M., Nyakudya, I.W., Jimu, L. & Bray Mashingaidze, A. 2020. Fall armyworm [*Spodoptera frugiperda* (J.E. Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. *International Journal of Pest Management*, 66(2): 142–154. doi.org/10.1080/09670874.2019.1577514

66 Baudron, F., Zaman-Allah, M.A., Chaipa, I., Chari, N. & Chinwada, P. 2019. Understanding the factors influencing fall armyworm (*Spodoptera frugiperda* J.E. Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. *Crop Protection*, 120: 141–150. doi.org/10.1016/j.cropro.2019.01.028

67 Overton, K., Maino, J.L., Day, R., Umina, P.A., Bett, B., Carnovale, D., Ekesi, S., Meagher, R. & Reynolds, O.L. 2021. Global crop impacts, yield losses and action thresholds for fall armyworm (*Spodoptera frugiperda*): A review. *Crop Protection*, 145: 105641. doi.org/10.1016/j.cropro.2021.105641

68 Davis, F.M., Ng, S.S. & Williams, W.P. 1992. Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. *Technical bulletin – Mississippi Agricultural and Forestry Experiment Station (USA)*, 186:9.

69 Murray, D.A.H., Clarke, M.B. & Ronning, D.A. 2013. *The Current and Potential Costs of Invertebrate Pests in Grain Crops*. Grains Research and Development Corporation. https://grdc.com.au/__data/assets/pdf_file/0026/159281/grdcreportcurrentpotentialcostsinvertebratepests-feb2013pdf.pdf-QR-code-editpdf.pdf

70 Zacarias, D.A. 2020. Global bioclimatic suitability for the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), and potential co-occurrence with major host crops under climate change scenarios. *Climatic Change*, 161(4): 555–566. doi.org/10.1007/s10584-020-02722-5

71 Ramasamy, M., Das, B. & Ramesh, R. 2022. Predicting climate change impacts on potential worldwide distribution of fall armyworm based on CMIP6 projections. *Journal of Pest Science*, 95(2): 841–854. doi.org/10.1007/s10340-021-01411-1

72 Tambo, J.A., Kansiime, M.K., Rwomushana, I., Mugambi, I., Nunda, W., Mloza Banda, C., Nyamutukwa, S., Makale, F. & Day, R. 2021. Impact of fall armyworm invasion on household income and food security in Zimbabwe. *Food and Energy Security*, 10(2): 299–312. doi.org/10.1002/fes3.281

73 Deshmukh, S., Pavithra, H.B., Kalleshwaraswamy, C.M., Shivanna, B.K., Maruthi, M.S. & Mota-Sanchez, D. 2020. Field Efficacy of Insecticides for Management of Invasive Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on Maize in India. *Florida Entomologist*, 103(2): 221–227. doi.org/10.1653/024.103.0211

74 Grande, F., Ueda, Y., Masangwi, S., Moltedo, A., Brivio, R., Selek, A., Vannuccini, S., Tayyib, S. & Holmes, B. 2023. *Global Nutrient Conversion Table for FAO Supply Utilization Accounts*. Rome, FAO.

75 Institute of Medicine. 1997. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. Washington, DC., The National Academies Press. https://nap.nationalacademies.org/catalog/5776/dietary-reference-intakes-for-calcium-phosphorus-magnesium-vitamin-d-and-fluoride

76 Institute of Medicine. 1998. *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline*. Washington, DC., The National Academies Press. https://nap.nationalacademies.org/catalog/6015/dietary-reference-intakes-for-thiamin-riboflavin-niacin-vitamin-b6-folate-vitamin-b12-pantothenic-acid-biotin-and-choline

77 Institute of Medicine. 2000. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, DC., The National Academies Press. https://nap.nationalacademies.org/catalog/9810/dietary-reference-intakes-for-vitamin-c-vitamin-e-selenium-and-carotenoids

78 Institute of Medicine. 2001. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. Washington, DC., The National Academies Press. https://nap.nationalacademies.org/catalog/10026/dietary-reference-intakes-for-vitamin-a-vitamin-k-arsenic-boron-chromium-copper-iodine-iron-manganese-molybdenum-nickel-silicon-vanadium-and-zinc

79 FAO. 2020. *Global Forest Resources Assessment: 2020 Key Findings*. Rome. www.fao.org/3/CA8753EN/CA8753EN.pdf

80 Bond, W.J., Woodward, F.I. & Midgley, G.F. 2005. The global distribution of ecosystems in a world without fire. *New Phytologist*, 165(2): 525–538. doi.org/10.1111/j.1469-8137.2004.01252.x

81 Bowman, D.M.J.S., Balch, J.K., Artaxo, P., Bond, W.J., Carlson, J.M., Cochrane, M.A., D'Antonio, C.M. et al. 2009. Fire in the Earth System. *Science*, 324(5926): 481–484. doi.org/10.1126/science.1163886

82 FAO. 2018. *The State of the World's Forests 2018: Forest pathways to sustainable development*. Rome. www.fao.org/publications/card/fr/c/I9535EN

83 FAO & UNEP (United Nations Environment Programme). 2020. *The State of the World's Forests 2020: Forests, biodiversity and people*. Rome, FAO and Nairobi, UNEP. doi.org/10.4060/ca8642en

84 Doerr, S.H. & Santín, C. 2016. Global trends in wildfire and its impacts: perceptions versus realities in a changing world. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1696): 20150345. doi.org/10.1098/rstb.2015.0345

85 Giglio, L., Randerson, J.T., Van Der Werf, G.R., Kasibhatla, P.S., Collatz, G.J., Morton, D.C. & DeFries, R.S. 2010. Assessing variability and long-term trends in burned area by merging multiple satellite fire products. *Biogeosciences*, 7(3): 1171–1186. doi.org/10.5194/bg-7-1171-2010

86 van Lierop, P., Lindquist, E., Sathyapala, S. & Franceschini, G. 2015. Global forest area disturbance from fire, insect pests, diseases and severe weather events. *Forest Ecology and Management*, 352: 78–88. doi.org/10.1016/j.foreco.2015.06.010

87 GWIS (Global Wildfire Information System). 2022. Country Profile. In: *GWIS*. [Cited January 2023]. https://gwis.jrc.ec.europa.eu/apps/country.profile

88 Chuvieco, E., Roteta, E., Sali, M., Stroppiana, D., Boettcher, M., Kirches, G., Storm, T. *et al.* 2022. Building a small fire database for Sub-Saharan Africa from Sentinel-2 high-resolution images. *Science of The Total Environment*, 845: 157139. doi.org/10.1016/j.scitotenv.2022.157139

89 UNEP & GRID-Arendal. 2022. *Spreading like Wildfire: The Rising Threat of Extraordinary Landscape Fires*. www.unep.org/resources/report/spreading-wildfire-rising-threat-extraordinary-landscape-fires

90 IPCC. 2019. *Special Report: Climate Change and Land*. Special Report. Geneva. www.ipcc.ch/srccl/

91 Flannigan, M.D., Krawchuk, M.A., De Groot, W.J., Wotton, B.M. & Gowman, L.M. 2009. Implications of changing climate for global wildland fire. *International Journal of Wildland Fire*, 18(5): 483. doi.org/10.1071/WF08187

92 **Boschetti, L., Sparks, A., Roy, D.P., Giglio, L. & San-Miguel-Ayanz, J.** 2020. GWIS national and sub-national fire activity data from the NASA MODIS Collection 6 Burned Area Product in support of policy making, carbon inventories and natural resource management, developed under NASA Applied Sciences grant #80NSSC18K0400. Using the NASA Polar Orbiting Fire Product Record to Enhance and Expand the Global Wildfire Information System (GWIS). https://gwis.jrc.ec.europa.eu/apps/country.profile/downloads

93 **European Commission, Joint Research Centre.** 2022. *Pan-European wildfire risk assessment.* EU Publications. https://data.europa.eu/doi/10.2760/9429

94 **Bowman, D.M.J.S., Williamson, G.J., Abatzoglou, J.T., Kolden, C.A., Cochrane, M.A. & Smith, A.M.S.** 2017. Human exposure and sensitivity to globally extreme wildfire events. *Nature Ecology & Evolution*, 1(3): 1–6. doi.org/10.1038/s41559-016-0058

95 **FAO**. 2019. *FAO Strategy on Forest Fire Management*. Rome. www.fao.org/forestry/49772-0e64392e1b16124967bab33b6cbd84417.pdf

96 **Haubrock, P.J., Turbelin, A.J., Cuthbert, R.N., Novoa, A., Taylor, N.G., Angulo, E., Ballesteros-Mejia, L.** et al. 2021. Economic costs of invasive alien species across Europe. *NeoBiota*, 67: 153–190. doi.org/10.3897/neobiota.67.58196

97 **USDA (United States Department of Agriculture) Forest Service**. 2009. *Major Forest Insect and Disease Conditions in the United States: 2009 Update*. USDA Forest Service FS-952. www.fs.usda.gov/foresthealth/publications/ConditionsReport_2009.pdf

98 **Pimentel, D., Lach, L., Zuniga, R. & Morrison, D.** 2000. Environmental and Economic Costs of Nonindigenous Species in the United States. *BioScience*, 50(1): 53. [0053:EAECON]2.3.CO;2. https://entnemdept.ufl.edu/Hodges/als4161/Secure/PDF%20Files/Articles/Environmental_and_Economic.pdf

99 **Fei, S., Morin, R.S., Oswalt, C.M. & Liebhold, A.M.** 2019. Biomass losses resulting from insect and disease invasions in US forests. *Proceedings of the National Academy of Sciences*, 116(35): 17371–17376. doi.org/10.1073/pnas.1820601116

100 **Turner, J.A., Buongiorno, J., Zhu, S., Prestemon, J.P., Li, R. & Bulman, L.S.** 2007. Modelling the impact of the exotic forest pest Nectria on the New Zealand forest sector and its major trading partners. *New Zealand Journal of Forestry Science*, 37(3): 383–411. www.srs.fs.usda.gov/pubs/ja/ja_turner009.pdf

101 **Williams, F., Eschen, R., Harris, A., Djeddour, D., Pratt, C., Shaw, R.S., Varia, S. *et al.*** 2010. *The economic cost of invasive non-native species on Great Britain*. Wallingford, CABI. www.cabi.org/VetMedResource/ebook/20123122024

102 **Commonwealth of Australia**. 2018. *Australia's State of the Forests Report 2018*. Canberra, Department of Agriculture and Water Resources, ABARES. https://www.agriculture.gov.au/abares/forestsaustralia/sofr/sofr-2018

103 **Wills, A.J. & Farr, J.D.** 2017. Gumleaf skeletoniser *Uraba lugens* (Lepidoptera: Nolidae) larval outbreaks occur in high rainfall Western Australian jarrah (*Eucalyptus marginata*) forest after drought: *Uraba lugens* dryness index. *Austral Entomology*, 56(4): 424–432. doi.org/10.1111/aen.12255

104 **Cameron, N.L., Carnegie, A.J., Wardlaw, T., Lawson, S. & Venn, T.** 2018. Economic appraisal of Sirex Wood Wasp (*Sirex noctilio*) control in Australian pine plantations. *Australian Forestry*, 81(1): 37–45. doi.org/10.1080/00049158.2018.1430436

105 **Nahrung, H.F. & Carnegie, A.J.** 2020. Non-native Forest Insects and Pathogens in Australia: Establishment, Spread, and Impact. *Frontiers in Forests and Global Change*, 3: 37. doi.org/10.3389/ffgc.2020.00037

106 **Mota, M.M. & Vieira, P., eds.** 2008. *Pine Wilt Disease: A Worldwide Threat to Forest Ecosystems.* Dordrecht, Springer Netherlands. doi.org/10.1007/978-1-4020-8455-3

107 **Forest Agency**. 2020. *Annual Report on Forest and Forestry in Japan*. Tokyo, Japan. www.maff.go.jp/e/data/publish/attach/pdf/index-208.pdf

108 **Natural Resources Canada**. 2020. *The State of Canada's Forests. Annual Report 2020*. Ottawa, Canada Forest Service. https://cfs.nrcan.gc.ca/publications?id=40219

109 **Gomez, D.F., Sathyapala, S. & Hulcr, J.** 2020. Towards Sustainable Forest Management in Central America: Review of Southern Pine Beetle (Dendroctonus frontalis Zimmermann) Outbreaks, Their Causes, and Solutions. *Forests*, 11(2): 173. doi.org/10.3390/f11020173

110 **Billings, R.** 2015. *Second evaluation of a major pine beetle outbreak in Honduras and recommendations for direct control*. Unpublished Report. USDA Forest Service/International Programs and US Agency for International Development.

111 **Billings, R.** 2019. *Technical assistance visit to the Dominican Republic to evaluate and make recommendations for direct control of an outbreak of the pine bark beetle Ips calligraphus*. Unpublished Report. College Station, Texas, USDA Forest Service/International Programs, Texas Forest Service.

112 **Jiménez G., A.A., Cordón Cabrera, P.R. & Agramonte, J.E.** 2022. Fluctuación poblacional de Ips calligraphus en pinares de la vertiente norte de la cordillera Central, República Dominicana. *Novitates Caribaea*, (20): 137–154. doi.org/10.33800/nc.vi20.314

113 **Hernández Paz, M.** 1975. *El gorgojo de la corteza, plaga principal de los pinares*. Corporación Hondureña de Desarrollo Forestal.

114 **Billings, R.** 1982. *Evaluation and recommendations for control of the 1982 outbreak of Dendroctonus in the pine forests of Honduras*. Unpublished Report. Lufkin, Texas, United States Department of Agriculture (USDA) Office of International Cooperation and Development/United States Agency for International Development (USAID).

115 **Macias Sámano, J.E., Billings, R.F. & Espino Mendoza, V.** 2017. *Guía para implementar el método de cortar y dejar y la franja de contención como medios de control del gorgojo descortezador del pino, Dendroctonus frontalis, en Centroamérica y México*. Washington, D.C. and Tegucigalpa, Honduras, Instituto Nacional de Conservación y Desarrollo Forestal, Areas Protegidas y Vida Silvestre (Tegucigalpa, Honduras) and USDA Forest Service, International Programs.

116 **Billings, R., Clarke, S.R., Espino Mendoza, V., Cordon Cabrera, P., Melendez Figueroa, B., Ramon Campos, J. & Baeza, G.** 2004. Bark beetle outbreaks and fire: A devastating combination for central America's pine forests. *Unasylva*, 55: 10–15. https://www.fao.org/3/y5507e/y5507e05.htm

117 **Paveglio, T.B., Brenkert-Smith, H., Hall, T. & Smith, A.M.S.** 2015. Understanding social impact from wildfires: advancing means for assessment. *International Journal of Wildland Fire*, 24(2): 212. doi.org/10.1071/WF14091

118 **Walz, Y., Janzen, S., Narvaez, L., Ortiz-Vargas, A., Woelki, J., Doswald, N. & Sebesvari, Z.** 2021. Disaster-related losses of ecosystems and their services. Why and how do losses matter for disaster risk reduction? *International Journal of Disaster Risk Reduction*, 63: 102425. doi.org/10.1016/j.ijdrr.2021.102425

119 **FAO.** 2022. *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*. Rome. doi.org/10.4060/cc0461en

120 **Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F.** 2018. *Impacts of climate change on fisheries and aquaculture. Synthesis of current knowledge, adaptation and mitigation options*. FAO Fisheries and Aquaculture Technical Paper. T627. Rome, FAO. www.fao.org/3/i9705en/i9705en.pdf

121 **Hampton, I., Githaiga-Mwicigi, J., Lamberth, S., Pitcher, G.C., Pretorius, M., Van Der Lingen, C. & Yemane, D.** 2017. *Report of the DAFF Workshop on Adaptation to Climate Change in the South African Marine Fisheries and Marine Aquaculture Sectors, 11–12 October 2016*. Sea Point, Cape Town, DAFF Research Aquarium. https://www.fao.org/3/cc2822en/cc2822en.pdf

122 Ortega-Cisneros, K., Cochrane, K.L., Rivers, N. & Sauer, W.H.H. 2021. Assessing South Africa's Potential to Address Climate Change Impacts and Adaptation in the Fisheries Sector. *Frontiers in Marine Science*, 8. www.frontiersin.org/articles/10.3389/fmars.2021.652955

123 Karlson, B., Andersen, P., Arneborg, L., Cembella, A., Eikrem, W., John, U., West, J.J. *et al.* 2021. Harmful algal blooms and their effects in coastal seas of Northern Europe. *Harmful Algae*, 102: 101989. doi.org/10.1016/j.hal.2021.101989

124 DFFE (Department of Forestry, Fisheries and the Environment). 2019. *National Climate Change Adaptation Strategy, Republic of South Africa.* DFFE. www.dffe.gov.za/sites/default/files/docs/nationalclimatechange_adaptationstrategy_ue10november2019.pdf

125 van Diemen, E. 2022. Situation Red Alert issued to recover live rock lobster after mass red tide walkout. In: *Daily Maverick*. [Cited July 2023]. www.dailymaverick.co.za/article/2022-03-04-situation-red-alert-issued-to-recover-live-rock-lobster-after-mass-red-tide-walkout/

126 Cockcroft, A.C. 2001. Jasus lalandii "walkouts" or mass strandings in South Africa during the 1990s: an overview. *Marine and Freshwater Research*, 52(8): 1085. doi.org/10.1071/MF01100

127 Cockcroft, A.C. & Payne, A.I.L. 1999. A cautious fisheries management policy in South Africa: the fisheries for rock lobster. *Marine Policy*, 23(6): 587–600. https://doi.org/10.1016/S0308-597X(98)00045-1

128 Eggers, J., Cochrane, K. & Sauer, W. 2022. Estimating the economic income and social contributions derived from the South African west coast rock lobster fishery. *African Journal of Marine Science*, 44(3): 255–269. doi.org/10.2989/1814232X.2022.2104926

129 Philippines Office of Civil Defense and Humanitarian Country Team. 2019. *Typhoon Kammuri (Tisoy) Joint Rapid Assessment of Impact and Needs*. www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/documents/files/191211_typhoon_kammuri_tisoy_rapid_assessment_report_rev.pdf

130 Philippines Office of Civil Defense and Humanitarian Country Team. 2020. *Super Typhoon Goni (Rolly) Humanitarian Needs and Priorities*. https://reliefweb.int/attachments/50a2637e-bfcb-3452-ab40-4a7c0a99cd32/PHL-TyphoonGoni-HumanitariannNeedsPriorities-201109.pdf

131 FAO. 2022. *Philippines: Damages and needs assessment of families affected by Super Typhoon Rai ("Odette") in selected provinces of Region VIII and Region XIII*. Rome. doi.org/10.4060/cc0207en

132 Philippines Office of Civil Defense and Humanitarian Country Team. 2022. *Consolidated Needs Assessment Report Revision: Super Typhoon Rai (Odette)*. https://reliefweb.int/attachments/810f3297-b89d-3088-b589-6ecb34cc58c8/2022%20Consolidated%20Needs%20Assessment%20Report%20Revision%20-%20Super%20Typhoon%20Rai%20-%20Philippines%20%281%29.pdf

133 Tonga Statistics Department. 2023. National Accounts. In: *Tonga Statistics Department*. [Cited June 2023]. https://tongastats.gov.to/statistics/economics/national-accounts/

134 World Bank. 2023. Agriculture, forestry, and fishing, value added (constant 2015 US$) – Tonga. In: *World Bank*. Washington, DC. [Cited June 2023]. https://data.worldbank.org/indicator/NV.AGR.TOTL.KD?locations=TO

135 Tonga Statistics Department. 2023. Agriculture Census. In: *Tonga Statistics Department*. [Cited June 2023]. https://tongastats.gov.to/census/agriculture-census/

136 Tonga Statistics Department. 2023. Household Income and Expenditure Survey. In: *Tonga Statistics Department*. [Cited June 2023]. https://tongastats.gov.to/survey/hies-survey/

137 IPCC. 2019. *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, eds. Geneva. www.ipcc.ch/srccl/

138 IPCC. 2022. Cross Working Group Attribution. Hope, P., W. Cramer, M. van Aalst, G. Flato, K. Frieler, N. Gillett, C. Huggel, J. Minx, F. Otto, C. Parmesan, J. Rogelj, M. Rojas, S.I. Seneviratne, A. Slangen, D. Stone, L. Terray, R. Vautard, and X. Zhang. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*- H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama, eds. p 149–152. Cambridge, UK and New York. Cambridge University Press. https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf

139 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*. pp. 423–553. Cambridge, UK and New York, Cambridge University Press. https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf

140 FAO. 2023. Crops and livestock products. In: *FAOSTAT*. Rome. [Cited June 2023]. www.fao.org/faostat/en/#data/QCL

141 Gillett, N.P., Shiogama, H., Funke, B., Hegerl, G., Knutti, R., Matthes, K., Santer, B.D. *et al.* 2016. The Detection and Attribution Model Intercomparison Project (DAMIP v1.0) contribution to CMIP6, *Geoscientific Model Development*, 9, 3685–3697. doi.org/10.5194/gmd-9-3685-2016

142 Heath, M. 2022. Argentina soy belt drought awakens ghost of 2018 production "disaster". In: *Reuters*. 10 February 2022. [Cited 16 May 2023]. www.reuters.com/business/environment/argentina-farm-belt-drought-awakens-ghost-2018-soybean-disaster-2022-02-10/

143 Bureau of National Statistics Kazakhstan. 2022. *Statistics of agriculture, forestry, hunting and fisheries*. https://stat.gov.kz

144 North Africa Post. 2019. Morocco's Central bank expects fewer wheat yield in 2019. In: *North Africa Post*. Rabat. [Cited 17 March 2023]. https://northafricapost.com/29126-moroccos-central-bank-expects-fewer-wheat-yield-in-2019.html

145 FAO. 2023. Crops and Livestock Products. In: *FAOSTAT*. Rome. [Cited June 2023]. www.fao.org/faostat/en/#data/QCL

146 CRED. Emergency Events Database (EM-Dat), the international Disaster Database. In: *CRED*. [Cited 17 March 2023]. https://www.emdat.be/

147 Cisse, G. & McLeman, R. 2022. Health, Wellbeing, and the Changing Structure of Communities. In: H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama, eds. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter07.pdf

148 FAO, IFAD, UNICEF, WFP & WHO. 2023. *The State of Food Security and Nutrition in the World 2023. Urbanization, agrifood systems transformation and healthy diets across the rural–urban continuum* https://www.fao.org/documents/card/en/c/cc3017en

149 FAO, IFAD, UNICEF, WFP & WHO. 2020. *The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets*. Rome, FAO. www.fao.org/documents/card/en/c/ca9692en

150 FAO. 2021. *Niger | Moyens d'existence agricoles et sécurité alimentaire dans le cadre de la covid-19*. Rome. doi.org/10.4060/cb4622fr

151 Ranjan Jena, P., Kalli, R. & Chandra Tanti, P. 2022. Impact of Covid-19 on Agricultural System and Food Prices: The Case of India. In: U. Bacha, ed. *Rural Health*. IntechOpen. https://doi.org/10.5772/intechopen.98905

152 FAO. 2021. *Agricultural livelihoods and food security in the context of COVID-19: Results from household surveys in 11 countries with high pre-existing levels of food insecurity – Cross-country monitoring report. May 2021*. Rome. doi.org/10.4060/cb4747en

153 FAO 2020. *Second Rapid Assessment of Food and Nutrition Security in the Context of COVID-19 in Bangladesh: May – July 2020*. Dhaka. doi.org/10.4060/cb1018en

154 FAO. 2020. *National agrifood systems and COVID-19 in Liberia. Effects, policy responses and long term implications*. Rome. doi.org/10.4060/cb2114en

155 FAO. 2021. *Liberia | Agricultural livelihoods and food security in the context of COVID-19: Monitoring Report – January 2021*. Rome. doi.org/10.4060/cb3618en

156 FAO & WFP. 2020. *Covid-19 impacts on agri-food value chains: Libya*. Cairo, FAO and WFP. doi.org/10.4060/cb3089en

157 FAO & WFP. 2021. *Myanmar | Agricultural livelihoods and food security in the context of COVID-19: Monitoring report – May 2021*. Rome, FAO and WFP. doi.org/10.4060/cb5218en

158 FAO & WFP. 2022. *Myanmar | Shocks, agricultural livelihoods and food security. Monitoring report, June 2022*. Rome, FAO and WFP. doi.org/10.4060/cc0562en

159 FAO. 2021. *Sierra Leone | Agricultural livelihoods and food security in the context of COVID-19: Monitoring report – May 2021*. Rome. doi.org/10.4060/cb4396en

160 FAO, IFAD & WFP. 2020. *South Sudan, COVID-19 Impacts Assessment Results on Agriculture and Food Security in South Sudan*. Rome, FAO. https://www.fao.org/3/cb0208en/CB0208EN.pdf

161 FAO. 2021. *The Sudan | Food supply, agricultural livelihoods and food security in the context of COVID-19: Monitoring Report – January 2021*. Rome. doi.org/10.4060/cb2262en

162 FAO. 2021. *Bolivarian Republic of Venezuela | Agricultural livelihoods and food security in the context of COVID-19: Monitoring Report – January 2021*. Rome. doi.org/10.4060/cb3178en

163 FAO. 2021. *Yemen – Shocks, agricultural livelihoods and food security. Monitoring report, December 2021*. Rome. doi.org/10.4060/cb7844en

164 FAO. 2021. *Impact of COVID-19 on the delivery of veterinary services and animal disease reporting: May–June 2020/June–August 2020*. Rome. doi.org/10.4060/cb5649en

165 Mthembu, B.E., Mkhize, X. & Arthur, G.D. 2022. Effects of COVID-19 Pandemic on Agricultural Food Production among Smallholder Farmers in Northern Drakensberg Areas of Bergville, South Africa. *Agronomy*, 12(2): 531. https://doi.org/10.3390/agronomy12020531

166 Ahmed, J.U., Akter, S. & Majumder, K.A. 2021. Impact of COVID-19 on agricultural production and distribution in South Asia. *World Food Policy*, 7(2): 168–182. doi.org/10.1002/wfp2.12032

167 Rahman, M.T., Akter, S., Rana, M.R., Sabuz, A.A. & Jubayer, M.F. 2022. How COVID-19 pandemic is affecting achieved food security in Bangladesh: A perspective with required policy interventions. *Journal of Agriculture and Food Research*, 7: 100258. doi.org/10.1016/j.jafr.2021.100258

168 GNAFC (Global Network Against Food Crises). 2020. *Food Crises and Covid-19: Emerging Evidence and Implications. An analysis of acute food insecurity and agri-food systems during COVID-19 pandemic*. Technical Note. Rome, Technical Support Unit (TSU) of the Global Network Against Food Crises. https://reliefweb.int/report/world/food-crises-and-covid-19-emerging-evidence-and-implications-technical-note

169 Varshney, D., Roy, D. & Meenakshi, J.V. 2020. Impact of COVID-19 on agricultural markets: assessing the roles of commodity characteristics, disease caseload and market reforms. *Indian Economic Review*, 55(S1): 83–103. doi.org/10.1007/s41775-020-00095-1

170 OECD (Organisation for Economic Co-operation and Development). 2020. *Covid-19 and the food and agriculture sector: Issues and policy responses*. Paris. www.oecd.org/coronavirus/policy-responses/covid-19-and-the-food-and-agriculture-sector-issues-and-policy-responses-a23f764b/

171 FAO. 2022. *Pakistan. DIEM – Data in Emergencies Monitoring brief, round 3 Results and recommendations June 2022*. Rome. https://www.fao.org/documents/card/en?details=CC0783EN

172 FAO. 2022, Lebanon, DIEM – Data in Emergencies Monitoring brief, round 2 Results and recommendations June 2022. Rome. https://www.fao.org/documents/card/en/c/cc0932en

173 FAO. 2020. Food Security in Iraq – Impact of COVID-19, Rome. https://www.wfp.org/publications/food-security-iraq-impact-covid-19

174 FAO. 2021. *Agricultural livelihoods and food security in the context of COVID-19*. Rome. doi.org/10.4060/cb4747en

175 FAO. 2021. *Somalia | Agricultural livelihoods and food security in the context of COVID-19*. Rome. doi.org/10.4060/cb2947en

176 Sánchez-Cordón, P.J., Montoya, M., Reis, A.L. & Dixon, L.K. 2018. African swine fever: A re-emerging viral disease threatening the global pig industry. *The Veterinary Journal*, 233: 41–48. doi.org/10.1016/j.tvjl.2017.12.025

177 WOAH. 2022. *African Swine Fever (ASF) — Situation Report 8, 2022*. Paris. www.oie.int/app/uploads/2022/03/asf-report8.pdf

178 Normile, D. 2019. African swine fever marches across much of Asia. *Science*, 364(6441): 617–618. doi.org/10.1126/science.364.6441.617

179 FAO. 2020. *Report on African Swine Fever (ASF) in Asia and the Pacific. Thirty-fifth Session of the FAO Regional Conference for Asia and the Pacific (APRC 35)*. Rome. https://www.fao.org/documents/card/en/c/NB742EN/

180 Frezal, C., Gay, S.H. & Nenert, C. 2021. *The Impact of the African Swine Fever outbreak in China on global agricultural markets*. OECD Food, Agriculture and Fisheries Papers 156. Paris, OECD. doi.org/10.1787/96d0410d-en

181 Zhao, J., Bai, Z. & Ma, L. 2019. China needs long-term solutions for African Swine Fever. *Science Bulletin*, 64(20): 1469–1471. doi.org/10.1016/j.scib.2019.08.015

182 Song, H., Li, J. & Jin, Z. 2023. Nonlinear dynamic modeling and analysis of African swine fever with culling in China. *Communications in Nonlinear Science and Numerical Simulation*, 117: 106915. doi.org/10.1016/j.cnsns.2022.106915

183 Zhang, P., Nie, T., Ma, J. & Chen, H. 2022. Identification of suitable areas for African swine fever occurrence in China using geographic information system-based multi-criteria analysis. *Preventive Veterinary Medicine*, 209: 105794. doi.org/10.1016/j.prevetmed.2022.105794

184 USDA. 2022. *Livestock and Poultry: World Markets and Trade*. Washington, DC., USDA Foreign Agricultural Service. https://usda.library.cornell.edu/concern/publications/73666448x?locale=en

185 Guberti, V., Khomenko, S., Masiulis, M. & Kerba S. 2022. *African swine fever in wild boar – Ecology and biosecurity. Second edition.* FAO Animal Production and Health Manual No. 28. Rome, FAO, WOAH and European Commission. https://www.fao.org/3/cc0785en/cc0785en.pdf

186 Rozstalnyy, A., Roche, X., TagoPacheco, D., Kamata, A., BeltranAlcrudo, D., Khomenko, S., Lockhart, C. *et al.* 2022. *Qualitative risk assessment for African swine fever virus introduction: Caribbean, South, Central and North Americas*. FAO Animal Production and Health Papers No 18. Rome, FAO. https://doi.org/10.4060/cb8748en

187 FAO. 2021. FAO Statistical Yearbook – World Food and Agriculture. Rome. doi.org/10.4060/cb4477en

188 Jean-Pierre, R.P., Hagerman, A.D. & Rich, K.M. 2022. An analysis of African Swine Fever consequences on rural economies and smallholder swine producers in Haiti. *Frontiers in Veterinary Science*, 9. https://www.frontiersin.org/articles/10.3389/fvets.2022.960344/full

189 Casal, J., Tago, D., Pineda, P., Tabakovski, B., Santos, I., Benigno, C., Huynh, T., Ciaravino, G. & Beltran-Alcrudo, D. 2022. Evaluation of the economic impact of classical and African swine fever epidemics using OutCosT, a new spreadsheet-based tool. *Transboundary and Emerging Diseases*, 69(5): e2474–e2484. https://doi.org/10.1111/tbed.14590

190 Mason-D'Croz, D., Bogard, J.R., Herrero, M., Robinson, S., Sulser, T.B., Wiebe, K., Willenbockel, D. & Godfray, H.C.J. 2020. Modelling the global economic consequences of a major African swine fever outbreak in China. *Nature food*, 1(4): 221–228. doi.org/10.1038/s43016-020-0057-2

191 Nguyen-Thi, T., Pham-Thi-Ngoc, L., Nguyen-Ngoc, Q., Dang-Xuan, S., Lee, H.S., Nguyen-Viet, H., Padungtod, P. *et al.* 2021. An Assessment of the Economic Impacts of the 2019 African Swine Fever Outbreaks in Vietnam. *Frontiers in Veterinary Science*, 8. www.frontiersin.org/articles/10.3389/fvets.2021.686038

192 Savioli, G., Ahmadi, B.V., Muñoz, V., Rosso, F. & Schuppers, M. 2022. A methodology to assess indirect economic impacts of animal disease outbreaks: A case of hypothetical African swine fever outbreak in Switzerland. *Transboundary and Emerging Diseases*, 69(5): e1768–e1786. https://doi.org/10.1111/tbed.14512

193 PRIO (Peace Research Institute Oslo). 2020. Trends in Armed Conflict, 1946–2019. Oslo. https://www.prio.org/publications/12756

194 Murray, V., Abrahams, J., Abdallah, C., Ahmed, K., Angeles, L., Benouar, D., Brenes Torres, A., Chang Hun, C., Cox, S., Douris, J., Fagan, L., Fra Paleo, U., Han, Q., Handmer, J., Hodson, S., Khim, W., Mayner, L., Moody, N., Moraes, L. L. O.; Nagy, M., Norris, J., Peduzzi, P., Perwaiz, A., Peters, K., Radisch, J., Reichstein, M., Schneider, J., Smith, A., Souch, C., Stevance A-S., Triyanti, A., Weir, M., & Wright, N. 2021. *Hazard Information Profiles: Supplement to UNDRR-ISC Hazard Definition & Classification Review: Technical Report*. Geneva, United Nations Office for Disaster Risk Reduction; Paris, International Science Council. https://www.preventionweb.net/publication/hazard-information-profiles-hips

195 UNDRR (United Nations Office for Disaster Risk Reduction). 2023. *GAR Special Report: Measuring Resilience for the Sustainable Development Goals. Geneva.* https://www.undrr.org/gar/gar2023-special-report

196 UNDRR. 2019. *Global Assessment Report on Disaster Risk Reduction 2019*. Geneva. https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019

197 UNDRR. 2023. *The Report of the Midterm Review of the Implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030*. Geneva. https://www.undrr.org/publication/report-midterm-review-implementation-sendai-framework-disaster-risk-reduction-2015-2030

198 General Assembly of the United Nations. 2023. *Main findings and recommendations of the midterm review of the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030.* Seventy-seventh session, 690. https://www.undrr.org/publication/report-main-findings-and-recommendations-midterm-review-implementation-sendai-framework

199 Peters, K. 2022. *Evidence of positive progress on Disaster Risk Reduction in the Humanitarian-Development-Peace nexus: Thematic report to inform the Mid-Term Review of the Sendai Framework.* https://sendaiframework-mtr.undrr.org/publication/thematic-study-evidence-positive-progress-disaster-risk-reduction-humanitarian

200 Peters, L. 2021. Beyond disaster vulnerabilities: An empirical investigation of the causal pathways linking conflict to disaster risks. International Journal of Disaster Risk Reduction, 55:102092. https://www.sciencedirect.com/science/article/pii/S2212420921000583?casa_token=YZnxgGpfocMAAAAA:pNqonePbjM2CZoKMKKvu9ufQEXHV2R9NTbptQV1_q1utaDOd04qGHO_X4k8Y3K221NB3aCbYSfQ

201 Zaman, S., Sammonds, P., Ahmed, B. & Rahman, T. 2020. Disaster risk reduction in conflict contexts: Lessons learned from the lived experiences of Rohingya refugees in Cox's Bazar, Bangladesh. *International Journal of Disaster Risk Reduction*, 50: 101694. https://doi.org/10.1016/j.ijdrr.2020.101694

202 Nemeth, S., & Lai, B.. 2022. When do natural disasters lead to negotiations in a civil war? *Journal of Peace Research* 59 (1): 28–42. https://doi.org/10.1177/00223433211061952

203 Gaillard, J.-C., Clavé, E., & Kelman, I. 2008. Wave of peace? Tsunami disaster policy in Aceh, Indonesia. *Geoforum* 39 (1): 511–526. https://www.sciencedirect.com/science/article/abs/pii/S0016718507001662

204 Caso, N., Hilhorst, D., Mena, R., & Papyrakis, E. 2023. Does disaster contribute to armed conflict? A quantitative analysis of disaster–conflict co-occurrence between 1990 and 2017. International Journal of Development Issues. https://www.emerald.com/insight/content/doi/10.1108/IJDI-01-2023-0015/full/html

205 Mach, K. J., Kraan, C.M., Adger, W. N., Buhaug, H., Burke, M., Fearon, J. D. , *et al.* 2019. Climate as a risk factor for armed conflict. *Nature* 571 (7764): 193–197. https://doi.org/10.1038/s41586-019-1300-6

206 von Uexkull, N., Croicu, M., Fjelde, H., & Buhaug, H. 2016. Civil conflict sensitivity to growing-season drought. *Proceedings of the National Academy of Sciences* 113 (44): 12391–12396. https://www.pnas.org/doi/abs/10.1073/pnas.1607542113

207 Arai, T. 2012. Rebuilding Pakistan in the aftermath of the floods: Disaster relief as conflict prevention. *Journal of Peacebuilding & Development*, 7 (1): 51–65. https://www.jstor.org/stable/48603409

208 Ide, T. 2023. *Catastrophes, Confrontations, and Constraints: How Disasters Shape the Dynamics of Armed Conflicts*. MIT Press. https://doi.org/10.7551/mitpress/14970.001.0001

209 Mercy Corps & ACAPS. 2020. *Yemen: Food supply chain. Thematic report.* https://reliefweb.int/report/yemen/yemen-food-supply-chain-thematic-report-16-december-2020

210 European Union, World Bank, United Nations. 2019. Guidance for PDNA in Conflict Situations. https://www.undp.org/publications/pdna-guidance-integrating-conflict-sensitivity

211 European Union, World Bank, United Nations (2019). "GUIDANCE FOR PDNA IN CONFLICT SITUATIONS." Available at: https://www.undp.org/publications/pdna-guidance-integrating-conflict-sensitivity

212 UNDRR (2023). GAR Special Report: Measuring Resilience for the Sustainable Development Goals. Geneva. Available at: https://www.undrr.org/gar/gar2023-special-report

213 State Statistics Service of Ukraine. 2020. The official portal. In: *Government of Ukraine*. [Cited June 2023]. www.ukrstat.gov.ua/

214 USDA. 2022. *Ukraine Agricultural Production and Trade*. Washington, DC., USDA Foreign Agricultural Service. www.fas.usda.gov/sites/default/files/2022-03/Ukraine-Ag-Production-Trade.pdf

215 Kyiv School of Economics. 2021. *Assessing the role of small farmers and households in agriculture and the rural economy and measures to support their sustainable development.* Kyiv. https://kse.ua/wp-content/uploads/2021/02/KSE-Smallholders.pdf

216 **FAO**. 2022. Ukraine: Impact assessment results (September to October 2022). Data in Emergencies Hub. In: *FAO*. Rome. [Cited 12 July 2023]. https://data-in-emergencies.fao.org/apps/c5e28e7c958b4748bb806e1fe28ccf7b/explore

217 **Conflict Observatory.** 2022. Ukraine's Crop Storage Infrastructure Post-Invasion Impact Assessment. In: *Conflict Observatory*. [Cited June 2023]. https://hub.conflictobservatory.org/portal/apps/sites/#/home/pages/grain-1

218 **UNEP**. 2022. *The Environmental Impact of the Conflict in Ukraine: A Preliminary Review*. Nairobi. https://www.unep.org/resources/report/environmental-impact-conflict-ukraine-preliminary-review

219 **Turton, S., Sineat, Y. & Nitta, Y.** 2019. African swine fever wipes out Asia's backyard pig farmers. In: *Nikkei Asia*. [Cited 17 May 2023]. https://asia.nikkei.com/Business/Agriculture/African-swine-fever-wipes-out-Asia-s-backyard-pig-farmers

220 **Coughlan de Perez, E., van Aalst, M., Deva, C., van den Hurk, B., Jongman, B., Klose, T., Linnerooth-Bayer, J. & Suarez, P.** 2014. *Managing the risk of extreme events in a changing climate – trends and opportunities in the disaster-related funding landscape*. Input paper prepared for the Global Assessment Report on Disaster Risk Reduction 2015. The Hague, Red Cross/Red Crescent Climate Centre. https://www.climatecentre.org/wp-content/uploads/Managing-the-risk-of-extreme-events-in-a-changing-climate.pdf

221 **Pappenberger, F., Cloke, H.L., Parker, D.J., Wetterhall, F., Richardson, D.S. & Thielen, J.** 2015. The monetary benefit of early flood warnings in Europe. *Environmental Science & Policy*, 51: 278–291. https://doi.org/10.1016/j.envsci.2015.04.016

222 **Costella, C., Jaime, C., Arrighi, J., Coughlan de Perez, E., Suarez, P. & van Aalst, M.** 2017. Scalable and sustainable: How to build anticipatory capacity into social protection systems. *IDS Bulletin*. Vol. 48 No. 4. https://bulletin.ids.ac.uk/index.php/idsbo/article/view/2885

223 **Baig, S.P., Rizvi, A., Josella, M. & Palanca-Tan, R.** 2015. *Cost and Benefits of Ecosystem Based Adaptation: The Case of the Philippines*. Gland, Switzerland, International Union for Conservation of Nature (IUCN). https://portals.iucn.org/library/sites/library/files/documents/2016-009.pdf

224 **FAO & UNHCR.** 2018. *Cost-benefit analysis of forestry interventions for supplying woodfuel in a refugee situation in the United Republic of Tanzania*. Rome, FAO. https://www.fao.org/3/ca0164en/CA0164EN.pdf

225 **Seekao, C. & Pharino, C.** 2018. Cost-benefit analysis of shrimp farming's flood risk reduction strategies in Thailand. *Journal of Flood Risk Management*, 11: S805–S816. https://doi.org/10.1111/jfr3.12259

226 **Asha, N., Kikulwe, E., Nowakunda, K., Ajambo, S. & Naziri, D.** 2015. *Technical report: Structure of the Cooking Banana Value Chain in Uganda and Opportunities for Value Addition and Postharvest Losses Reduction*. CGIAR. www.rtb.cgiar.org/wp-content/uploads/2015/08/RPS/2/3.pdf

227 **FAO.** 2017. *Benefits of Farm-Level Disaster Risk Reduction Practices in Agriculture – Preliminary Findings*. Rome. www.fao.org/3/a-i7319e.pdf

228 **FAO.** 2019. *Disaster risk reduction at farm level: Multiple benefits, no regrets. Results from cost-benefit analyses conducted in a multi-country study, 2016-2018*. Rome. www.fao.org/3/ca4429en/CA4429EN.pdf

229 **FAO.** 2021. *Anticipatory action: Changing the way we manage disasters*. Rome. www.fao.org/3/cb7145en/cb7145en.pdf

230 **FAO.** 2018. *Mongolia: Impact of early warning action. Protecting herder livelihoods ahead of dzud winter*. Rome. www.fao.org/publications/card/en/c/CA2181EN/

231 **FAO.** 2019. *Colombia: Impact of early warning action. Boosting food security and social cohesion on the frontline of the migration crisis*. Rome. www.fao.org/publications/card/en/c/CA6818EN/

232 **FAO.** 2018. *Early warning early action in Sudan*. Rome. https://www.fao.org/3/i9383en/I9383EN.pdf

233 **FAO.** 2018. *Horn of Africa: Impact of early warning early action. Protecting pastoralist livelihoods ahead of drought*. Rome. www.fao.org/documents/card/en/c/CA0227EN

234 **FAO.** 2019. *Madagascar: Impact of Early Warning Early Action. Protecting farming livelihoods from drought and food insecurity*. Rome. www.fao.org/documents/card/en/c/CA3933EN/

235 **FAO.** 2019. *The Sudan: Impact of Early Warning Early Action. Protecting agropastoralist livelihoods ahead of drought*. Rome. www.fao.org/3/ca4653en/ca4653en.pdf

236 **Kumar, A.** 2022. Connecting anticipatory action and disaster risk reduction: perspectives from UNDRR. In: *UNDRR*. Geneva. [Cited June 2023]. www.preventionweb.net/news/connecting-anticipatory-action-and-disaster-risk-reduction-perspectives-undrr

237 **UNDRR.** 2023. Disaster Risk Management. In: *UNDRR*. Geneva. [Cited June 2023]. www.undrr.org/terminology/disaster-risk-management

238 **Anticipation Hub.** 2021. A step forward for anticipatory action at COP26. In: *Anticipation Hub*. [Cited June 2023]. www.anticipation-hub.org/news/a-step-forward-for-anticipatory-action-at-cop26

239 **IFRC, FAO, WFP, OCHA & Start Network.** 2021. *Enabling Anticipatory Action at Scale Policy Brief for Donor Governments*. www.anticipation-hub.org/Documents/Policy_Papers/AATF_Policy_Brief_for_Donor_Governments_May_2021.pdf

240 **International Movement.** 2022. *Power of Humanity. Council of Delegates of the International Red Cross and Red Crescent Movement*. Geneva. https://rcrcconference.org/app/uploads/2022/05/09_CoD22-Anticipatory-action-Background-document-FINAL-EN.pdf

241 **Levine, S., Wilkinson, E., Weingärtner, L. & Mall, P.** 2021. *Anticipatory action for livelihood protection. A collective endeavour*. Working Paper 580. Overseas Development Institute. https://cdn.odi.org/media/documents/202006_odi_anticipatory_action_for_livelihood_protection_wp_final.pdf

242 **Scott, Z.** 2022. Finance for Early Action: Tracking commitments, trends, challenges and opportunities. REAP (Risk-informed Early Action Partnership). www.insdevforum.org/wp-content/uploads/2022/06/20220613_Finance-for-Early-Action_FINAL-1-1.pdf

243 **Khim, W.** 2020. *Disaster risk reduction in times of COVID-19: What have we learned?* Rome, FAO. https://doi.org/10.4060/cb0748en

244 **Lawson, R.G. & Jurs, P.C.** 1990. New index for clustering tendency and its application to chemical problems. *Journal of Chemical Information and Computer Sciences*, 30(1): 36–41. https://doi.org/10.1021/ci00065a010

245 **FAO**. 2023. Crops and livestock products. In: *FAOSTAT*. Rome. [Cited June 2023]. www.fao.org/faostat/en/#data/QCL

246 **Lange, S., Mengel, M., Treu, S. & Büchner, M.** 2022. ISIMIP3a atmospheric climate input data (v1.0). In: *ISIMIP*. [Cited July 2023]. doi.org/10.48364/ISIMIP.982724

247 **Frieler, K., Volkholz, J., Lange, S., Schewe, J., Mengel, M., del Rocío Rivas López, M.** et al. 2023. Scenario set-up and forcing data for impact modelevaluation and impact attribution within the third round of the Inter-Sectoral Model Intercomparison Project (ISIMIP3a). Preprint. *EGUsphere*. doi.org/10.5194/egusphere-2023-281

248 **Laudien, R., Schauberger, B., Makowski, D. & Gornott, C.** 2020. Robustly forecasting maize yields in Tanzania based on climatic predictors. *Scientific Reports*, 10(19650). doi.org/10.1038/s41598-020-76315-8

249 Chemura, A. Nangombe, S., Gleixner, S., Chinyoka, S. & Gornott, C. 2022. Changes in Climate Extremes and Their Effect on Maize (Zea mays L.) Suitability Over Southern Africa. *Frontiers in Climate*, 4: 890210. doi.org/10.3389/fclim.2022.890210

250 Sultan, B., Defrance, D. & Iizumi, T. 2019, Evidence of crop production losses in West Africa due to historical global warming in two crop models. *Scientific Reports*, 6.9.2019: 12834. doi.org/10.1038/s41598-019-49167-0

251 Laudien, R., Schauberger, B., Makowski, D. & Gornott, C. 2020. Robustly forecasting maize yields in Tanzania based on climatic predictors. *Scientific Reports*, 10(19650). doi.org/10.1038/s41598-020-76315-8

252 Gillett, N.P., Shiogama, H., Funke, B., Hegerl, G., Knutti, R., Matthes, K., Santer, B.D. *et al.* 2016. The Detection and Attribution Model Intercomparison Project (DAMIP v1.0) contribution to CMIP6, *Geoscientific Model Development*, 9, 3685–3697. doi.org/10.5194/gmd-9-3685-2016

253 Tatebe, H., Ogura, T., Nitta, T., Komuro, Y., Ogochi, K., Takemura, T., Sudo, K. *et al.* 2019. Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6. *Geoscientific Model Development*, 12(7): 2727–2765. doi.org/10.5194/gmd-12-2727-2019

254 Lange, S. 2019. Trend-preserving bias adjustment and statistical downscaling with ISIMIP3BASD (v1.0). *Geoscientific Model Development*, 12, 3055–3070. doi.org/10.5194/gmd-12-3055-2019

255 Tatebe, H., Ogura, T., Nitta, T., Komuro, Y., Ogochi, K., Takemura, T., Sudo, K. *et al.* 2019. Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6. *Geoscientific Model Development*, 12(7): 2727–2765. doi.org/10.5194/gmd-12-2727-2019

256 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*. pp. 423–553. Cambridge, UK and New York, Cambridge University Press. https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf

257 Guo, H. Bao, A., Chen, T., Zheng, G., Wang, Y., Jiang, L. & De Maeyer, P. 2021. Assessment of CMIP6 in simulating precipitation over arid Central Asia. *Atmospheric Research*, 252, 105451. doi.org/10.1016/J.ATMOSRES.2021.105451

258 Mesgari, E., Hosseini, S.A., Hemmesey, M.S., Houshyar, M. & Partoo, L.G. 2022. Assessment of CMIP6 models' performances and projection of precipitation based on SSP scenarios over the MENAP region. *Journal of Water and Climate Change*, 13(10): 3607. doi.org/10.2166/wcc.2022.195

259 Iizumi, T., Shiogama, H., Imada, Y., Hanasaki, N., Takikawa, H. & Nishimori, M. 2018. Crop production losses associated with anthropogenic climate change for 1981–2010 compared with preindustrial levels. *International Journal of Climatology*, 38(14): 5405–5417. doi.org/10.1002/joc.5818

260 Ishii, M. & Mori, N. 2020. d4PDF: large-ensemble and high-resolution climate simulations for global warming risk assessment. *Progress in Earth and Planetary Science*, 7: 58. doi.org/10.1186/s40645-020-00367-7

261 Iizumi, T., Shiogama, H., Imada, Y., Hanasaki, N., Takikawa, H. & Nishimori, M. 2018. Crop production losses associated with anthropogenic climate change for 1981–2010 compared with preindustrial levels. *International Journal of Climatology*, 38(14): 5405–5417. doi.org/10.1002/joc.5818

262 Sultan, B., Defrance, D. & Iizumi, T. 2019, Evidence of crop production losses in West Africa due to historical global warming in two crop models. *Scientific Reports*, 6.9.2019: 12834. doi.org/10.1038/s41598-019-49167-0

263 Flynn, C.M. & Mauritsen, T. 2020. On the climate sensitivity and historical warming evolution in recent coupled model ensembles. Atmospheric Chemistry and Physics, 20, 7829–7842. doi.org/10.5194/acp-20-7829-2020

264 **Forster, P. *et al.*** 2021. The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In: V. Masson-Delmotte, *et al.*, eds. Climate Change 2021: The Physical Science Basis. Cambridge, UK, Cambridge University Press.

265 **Meshesha, D.T., Moahmmed, M. & Yosuf, D.** 2019. Estimating carrying capacity and stocking rates of rangelands in Harshin District, Eastern Somali Region, Ethiopia. *Ecology and Evolution*, 9(23): 13309–13319. doi.org/10.1002/ece3.5786

266 **The Nansen Initiative.** 2015. *The Nansen Initiatve. Global Consultation. Conference Report : Geneva, 12-23 October 2015*. https://www.eda.admin.ch/dam/eda/en/documents/aussenpolitik/menschenrechte-menschliche-sicherheit/2017-und-aelter/Nansen-GCR2015-screen.pdf.

267 **FAO, IFAD, UNICEF, WFP & WHO.** 2022. *The State of Food Security and Nutrition in the World 2022. Repurposing food and agricultural policies to make healthy diets more affordable*. Rome, FAO. doi.org/10.4060/cc0639en

268 **FAO, IFAD, UNICEF, WFP & WHO. 2020.** *The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets*. Rome, FAO. www.fao.org/documents/card/en/c/ca9692en

269 **IOM (International Organization of Migration)**. 2017. *World Migration Report 2018*. IOM World Migration Report. United Nations. https://doi.org/10.18356/f45862f3-en

2023

THE IMPACT OF DISASTERS ON AGRICULTURE AND FOOD SECURITY

AVOIDING AND REDUCING LOSSES THROUGH INVESTMENT IN RESILIENCE

Disasters are resulting in unprecedented levels of destruction across the world. These shocks and disruptions affect the functioning and sustainability of agricultural production and threaten the livelihoods of millions of people reliant on agrifood systems. Reducing the impact of disasters on agriculture requires a better understanding of their negative impacts on agriculture and necessitates an investigation into the underlying risks that make agriculture vulnerable to the effects of disasters.

This report provides an assessment of losses caused by disasters in agricultural production over the past three decades and delves into the diverse threats and impacts affecting the crops, livestock, forestry, and fisheries and aquaculture subsectors. These impacts are amplified by underlying factors and vulnerabilities created by social and environmental conditions such as climate change, global pandemics and epidemics, and conflict situations, which can generate disastrous outcomes and produce cascading effects across agrifood systems. Facing up to these challenges demands new approaches to risk reduction and response mechanisms. This publication provides examples of actions and strategies for investing in resilience and proactively addressing risks in agriculture. It demonstrates ways to mainstream disaster risk reduction into agricultural practices and policies and calls for a deeper understanding of the context in which these solutions are implemented.

ISBN 978-92-5-138194-6

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CC7900EN/1/10.23