



Food and Agriculture
Organization of the
United Nations

2021

The impact of disasters and crises
on agriculture and food security



2021
**The impact of disasters and crises
on agriculture and food security**

Required citation:

FAO. 2021. *The impact of disasters and crises on agriculture and food security: 2021*.

Rome. <https://doi.org/10.4060/cb3673en>

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Dashed lines on maps represent approximate border lines for which there may not yet be full agreement. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

ISBN 978-92-5-134071-4

© FAO, 2021.



Some rights reserved. This work is made available under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 IGO licence (CC BY-NC-SA 3.0 IGO; <https://creativecommons.org/licenses/by-nc-sa/3.0/igo/legalcode>).

Under the terms of this licence, this work may be copied, redistributed and adapted for non-commercial purposes, provided that the work is appropriately cited. In any use of this work, there should be no suggestion that FAO endorses any specific organization, products or services. The use of the FAO logo is not permitted. If the work is adapted, then it must be licensed under the same or equivalent Creative Commons licence. If a translation of this work is created, it must include the following disclaimer along with the required citation: "This translation was not created by the Food and Agriculture Organization of the United Nations (FAO). FAO is not responsible for the content or accuracy of this translation. The original [Language] edition shall be the authoritative edition."

Disputes arising under the licence that cannot be settled amicably will be resolved by mediation and arbitration as described in Article 8 of the licence except as otherwise provided herein. The applicable mediation rules will be the mediation rules of the World Intellectual Property Organization <http://www.wipo.int/amc/en/mediation/rules> and any arbitration will be conducted in accordance with the Arbitration Rules of the United Nations Commission on International Trade Law (UNCITRAL).

Third-party materials. Users wishing to reuse material from this work that is attributed to a third party, such as tables, figures or images, are responsible for determining whether permission is needed for that reuse and for obtaining permission from the copyright holder. The risk of claims resulting from infringement of any third-party-owned component in the work rests solely with the user.

Sales, rights and licensing. FAO information products are available on the FAO website (www.fao.org/publications) and can be purchased through publications-sales@fao.org. Requests for commercial use should be submitted via: www.fao.org/contact-us/licence-request. Queries regarding rights and licensing should be submitted to: copyright@fao.org.

Cover photograph

Farmer inspects her crop ruined by desert locust swarms, Ethiopia 2020 ©FAO/Petterik Wiggers



		INTRODUCTION		PART I	
		Agriculture on the proving grounds	1	More disasters, more impact on agriculture	23
Foreword	xxii	2010-2019 the most turbulent decade	2	Chapter I	25
Acknowledgements	xxv	Disasters steady on the rise	4	Proving the case: measurement and evidence 2008–2018	
Abbreviations and acronyms	xxvi	Exceptions are the new rule	9	Chapter II	47
		Biological hazards: pest and disease outbreaks	10	Disasters and forests: unpacking a complex relationship	
		The heat is on	12	Chapter III	63
		Global 2030 Agenda – one decade left	15	Impact of disasters on fisheries and aquaculture	
		Quest continues for disaggregated data	16		
		From governance of evidence to governance of action	18		
		Time to act	21		



© REUTERS/Daniel Mercadio

PART II

Focus on food chain crises

Chapter IV

Agriculture in the face of a pandemic: COVID-19 impacts on food production

Chapter V

Animal health at the crossroads: bridging theory, assessment and policy

Chapter VI

Locusts, a legendary pest with a present-day toll: lessons from Madagascar

77

79

93

113

PART III

Towards the future of damage and loss monitoring

Chapter VII

Extreme exposure: a clearer picture of agriculture in the climate crisis

Chapter VIII

From farm to space: exploring remote sensing applications for disaster impact analysis in agriculture

133

135

157

CONCLUSION

The road to 2030: risk-resilient development pathways for agriculture

177

APPENDICES

187

Technical annex

FAO's damage and loss assessment methodology

188

Glossary

198

References

202



Extreme weather events

India 2019 Though common here, dust storms have become more frequent, intense and deadly, such as this one which struck Prayagraj, killing many.





Climate change

Barrow, Alaska, United States of America 2016 Sea ice is melting earlier and faster than ever before, leading to mass migration of the walruses, sea lions and fish upon which the indigenous Iñupiat people depend.





Desert locusts

Kenya 2020 Swarms of the ravenous pest invaded countries across the Greater Horn of Africa, the Arabian Peninsula and Southwest Asia, menacing food security and agricultural livelihoods.







COVID-19

Indonesia 2020 Measures to control the global pandemic including mask-wearing, social distancing and handwashing disrupted daily life.



Flooding

South Sudan, 2019 Heavy rains submerged whole communities that were already facing a humanitarian crisis.





© Subrata Biswas/Climatepeace



© Pedro Arnesre/Climatepeace

TOP: Drought-sticken pond, India 2016 | BOTTOM: Drought, Spain 2017

At no other point in history has agriculture been faced with such an array of familiar and unfamiliar risks, interacting in a hyperconnected world and a precipitously changing landscape. The growing frequency and intensity of disasters, along with the systemic nature of risk, are jeopardizing our entire food system.

Agriculture underpins the livelihoods of over 2.5 billion people worldwide. Given the sector's innate interactions with the environment, its direct reliance on natural resources for production, and its significance for national socio-economic development, urgent and ambitious action is needed to build more resilient agricultural systems.



©FAO/Marco Longari



©FAO/Sasha Cuvinsky

TOP: Fish farming, United Republic of Tanzania 2015 / BOTTOM: Cyclone Pam aftermath, Vanuatu 2015



© Kran Ridley/Greenpeace



© Ulet Ifansasti/Greenpeace

TOP: Mega fire, Australia 2020 | BOTTOM: Forest fire, Indonesia 2019

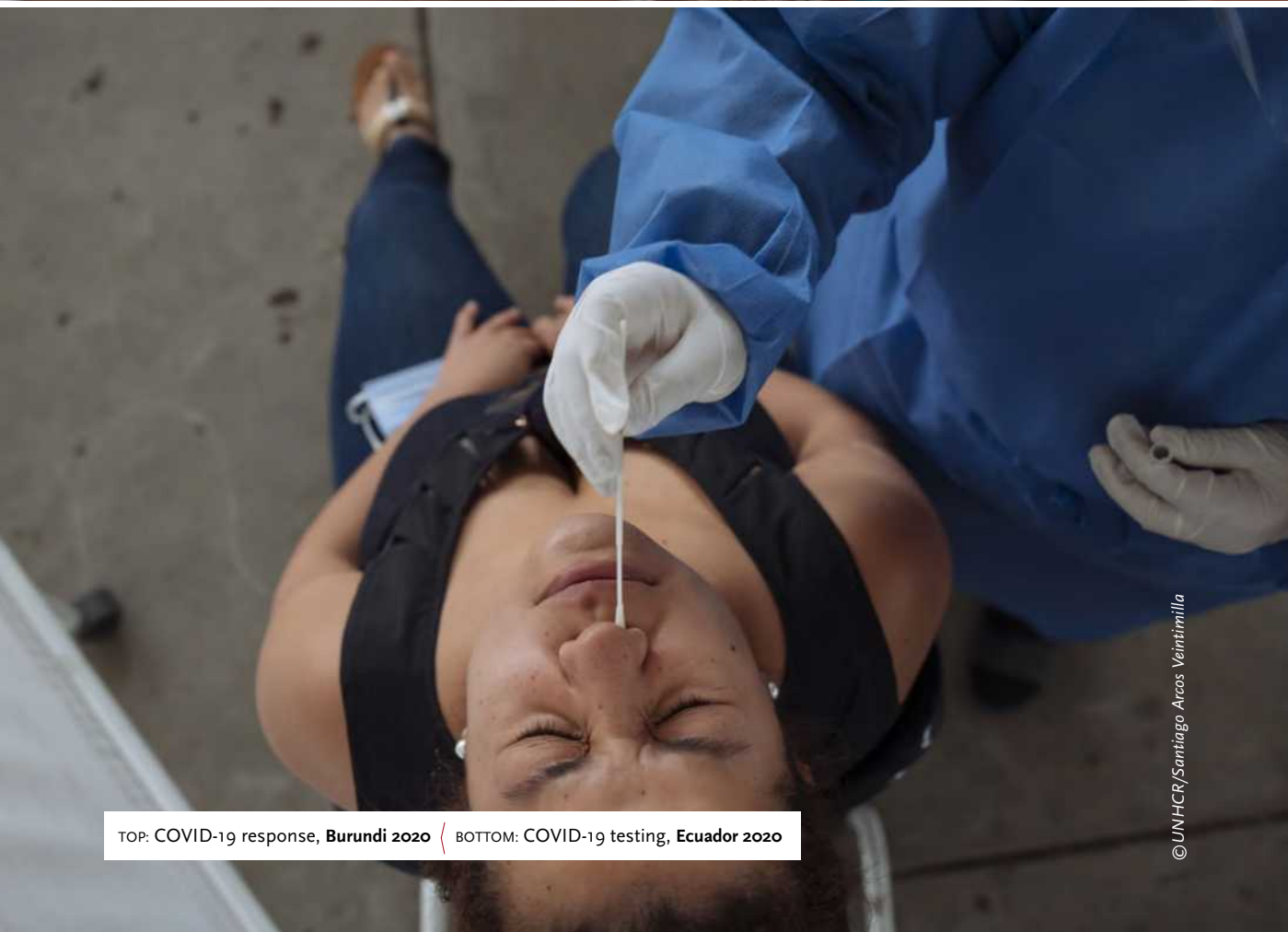
Hazardous events need not devolve into full-blown disasters; risks need not become insurmountable.

Disaster risk can be reduced and managed.

As the COVID-19 pandemic strains food supply chains around the world, a sound evidence base on disaster impacts on agriculture and food security will be key to implementing tailored and effective resilience policies, tracking progress toward global goals, and targeting investment to reinforce agriculture's crucial role in achieving the future we want.



© UNICEF/UNI349559/Nijimbere



© UNHCR/Santiago Arcos Veintimilla

TOP: COVID-19 response, Burundi 2020 | BOTTOM: COVID-19 testing, Ecuador 2020

Foreword

As the third edition of the Food and Agriculture Organization of the United Nations' (FAO) report on *The Impact of disasters and crises on agriculture and food security* is released, global disaster risk governance is facing a critical period. While capping off a decade of exacerbated disaster loss, exceptional global heat, retreating ice and rising sea levels, 2020 has also added new – and unprecedented – challenges. The COVID-19 pandemic is the most widespread and devastating disease event in recent history. Its economic and social impacts have disrupted nearly all aspects of life; agricultural livelihoods have been particularly hard hit. Meanwhile, vast swarms of desert locusts have been ravaging crops and grazing land, further menacing the food security of already vulnerable populations; megafires have carpeted large areas of forests and arable land, while other areas were submerged under record floods.

Agriculture is facing an array of both familiar and unfamiliar risks, interacting in a hyperconnected world and a precipitously changing landscape. Disaster risk is becoming increasingly compound, interconnected and interacting, causing shifts in the frequency and intensity of hazards. This is not without the fingerprint of climate change, which is materializing into decade-old predictions much sooner than envisaged.

The upheaval set in motion by COVID-19 may push even more families and communities into deeper distress. Disaster impact is pervasive and requires immediate efforts to better assess and understand its dynamics, so that it may be reduced and managed in integrated and innovative ways. The urgency and importance of doing so have never been greater.

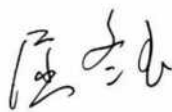
This report constitutes a further step towards bridging persistent knowledge gaps and fostering a better understanding of how agriculture is affected by disasters. Extreme events such as drought, floods, storms, tsunamis, wildfires, pest and disease outbreaks exert a heavy toll on agriculture and all its sectors: crops, livestock, forestry, fisheries and aquaculture. Their growing frequency and intensity, along with the systemic nature of risk, are jeopardizing our agri-food systems. Least developed countries and lower-income countries are often among the most affected, with cascading consequences for value chains, food security and even national economies. Increased risk exposure has become the 'new normal' and the impact of climate change is set to exacerbate these challenges even further.

Proactive risk reduction is imperative in our joint efforts to design a sustainable future. Potentially hazardous events do not need to devolve into full-blown disasters and risks need not become insurmountable. Despite innate exposure and impending risks, disaster impact is ultimately contingent on the ability of communities to anticipate, cope with, resist and recover from shocks. Resilience and disaster risk reduction therefore must become an essential and integral part of modern agri-food systems.

We are living at a time that demands ambitious collective measures. The 'Decade of Action' to achieve the Sustainable Development Goals is a clarion call for accelerating sustainable solutions to all the world's greatest challenges, ranging from hunger, poverty and inequality to climate change and the finance gap. The Sendai Framework for Disaster Risk Reduction has set the global agenda for developing disaster risk reduction (DRR) strategies, making risk-informed policy decisions to reduce disaster loss, and allocating resources to prevent emerging risks. In this context, the ability of governments, international organizations, civil society and the private sector to operate and cooperate in fragile and disaster-prone contexts is a defining feature for meeting global targets and achieving resilience and sustainability. The UN and its partners must collaborate to ensure innovative disaster risk management.

Both national and local capacities must be strengthened to cope with increasing risks and recurring shocks. A culture of systematic disaster impact monitoring and assessment must be created to enable and supply effective DRR policy and action. As resources become increasingly scarce, this will provide the evidence needed to effectively target our investments in resilience, preparedness and mitigation.

As we enter the Decade of Action and progress towards the global targets of the Sendai Framework, we offer the international community the messages of this report to embrace and act upon. Agriculture absorbs a disproportionate share of disaster impacts, many of which are borne directly by smallholders, whose activities underpin national economies and help feed the planet. Establishing a more holistic and ambitious disaster-resilience framework for agriculture is therefore a cornerstone for better production, better nutrition, a better environment and a better life.



QU Dongyu
Director-General
Food and Agriculture Organization of the United Nations

Acknowledgements

This third report on *The impact of disasters and crises on agriculture and food security* is the outcome of extensive cross-departmental collaboration within the Food and Agriculture Organization of the United Nations (FAO) to enhance the resilience of agriculture-based livelihoods to disasters, extreme events and crises. Significant technical inputs and advice were provided by various divisions and offices within the Organization, from the Natural Resources and Sustainable Production Stream, the Economic and Social Development Stream, the Office of Emergencies and Resilience and the Office of Climate Change, Biodiversity and Environment. In addition, FAO country and regional offices provided invaluable support in gathering national-level data where available.

Production of this report was coordinated by the Statistics Division of FAO and supervised by Stephan Baas, Piero Conforti and Shukri Ahmed, with Galimira Markova as lead coordinating author.

Central to the development of the report were the technical papers prepared and technically reviewed by the following FAO experts:

Galimira Markova and Piero Conforti for Introduction and Chapter I with key inputs from Sarah Graf; key inputs on nutrition from Nancy Aburto, Darana Souza, Patrizia Fracassi and Victoria Padula de Quadros;

Daowei Zhang, Peter Moore, Norbert Winkler, Shiroma Sathyapala, Yuka Makino, Elaine Springgay, Xia Zuzhang and Arturo Gianvenuti for Chapter II;

Robert Ulric Lee, Florence Poulain, Stefania Savore, Matthew Walsh, Anton Ellenbroek and Felix Marttin for Chapter III;

Galimira Markova for Chapter IV;

Julio Pinto, Ludovic Plee and Alejandro Acosta for Chapter V;

Mario Zappacosta and Yanyun Li for ASI infobox and Cristina Coslet for ASF infobox;

Shawn McGuire, Catherine Constant, Chikelu Mba, Shoki Aldobai, Annie Monard, Alexandre Latchininsky, Andrea LoBianco and Galimira Markova for Chapter VI;

Natalia Alekseeva, Stephan Baas, Galimira Markova, Hideki Kanamaru, Janek Toepper, Makie Yoshida, Mariko Fujisawa, Olga Buto, Sarah Graf, Cecilia Jones and Elisa Di Stefano for Chapter VII;

Neil Marsland, Oriane Turot, Josselin Gauny, Matieu Henry and Matthew Walsh for Chapter VIII;

Galimira Markova and Piero Conforti for the Technical annex.

Overall production, editing and design supervised by George Kourous; report editing and design support by Laurie Olsen; overall map guidance from Anneta BouSaleh; African swine fever map by Akiko Kamata; design and layout by Claudia Neri assisted by Elisa Stagnoli.

Unless otherwise stated, all figures used in the publication are from FAO.

Abbreviations and acronyms

50x2030 Initiative	50x2030 Initiative to Close the Agricultural Data Gap
AGRISurvey	Agricultural Integrated Survey Programme
AI	Artificial intelligence
Aoi	Area of interest
ASF	African swine fever
ASIS	Agriculture Stress Index System
BSE	Bovine spongiform encephalopathy
CAR-SPAW-RAC	Regional Activity Centre for the Protocol Concerning Specially Protected Areas and Wildlife for the Wider Caribbean Region (UNEP – Caribbean Environment Programme)
CEPAL	Comisión Económica para América Latina y el Caribe
CFSAM	Crop and food security assessment mission
CONEVAL	Consejo Nacional de Evaluación de la Política de Desarrollo Social
COP	Conference of the Parties
CRED	Centre for Research on the Epidemiology of Disasters
DEM	Digital elevation model
DHS	Demographic and Health Surveys
DGPS	Differential global positioning systems
DL	Damage and loss
DRM	Disaster risk management
DRR	Disaster risk reduction
EM-DAT	Emergency Events Database (maintained by CRED)
EMPRES-i	Emergency Prevention System (EMPRES-i) (maintained by FAO)
ENSOMD	Enquête Nationale sur le Suivi des Objectifs du Millénaire pour le Développement (Madagascar)
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
FCC	Food Chain Crises Management Framework
FMD	Foot-and-mouth disease
FSC	Food Security Cluster
FSIN	Food Security Information Network
GACC	China Customs Statistics
GAR	Global Assessment Report on Disaster Risk Reduction (UNDRR)
GDP	Gross domestic product
GEMP	Good emergency management practice
GFDRR	Global Facility for Disaster Reduction and Recovery
GFW	Global Forest Watch
GHG	Greenhouse gas
GIEWS	Global Information and Early Warning System (FAO)
GISTEMP	Global Surface Temperature Analysis (maintained by NASA-GISS)
GIS	Geographic information system
GISS	Goddard Institute for Space Studies
GIT	Geospatial information technology
GAUL	Global administrative unit layer
GCM	Global climate models
GLC	Global land cover
GNAFC	Global Network Against Food Crises
HIC	High-income country
HIHI	Hand-in-Hand Initiative
HOT	Humanitarian OpenStreetMap Team
IACC	United Nations Interagency Coordination Group on Antimicrobial Resistance
ICT	Information and communications technologies
IDP	Internally displaced people
IEAG	United Nations Secretary-General's Independent Expert Advisory Group
IFAD	International Fund for Agricultural Development
IFRC	International Federation of the Red Cross
ILO	International Labour Organization

INSTAT	Institute National de la Statistique (Madagascar)
IPCC	Intergovernmental Panel on Climate Change
IPC/CH	Integrated Food Security Phase Classification/Cadre Harmonisé
IPPC	International Plant Protection Convention
IOM	International Office of Migration
IUCN	International Union for Conservation of Nature and Natural Resources
IUFRO	International Union of Forest Research Organizations
LDC	Least developed country
LCML	Land classification meta language
LIC	Low-income country
LMC	Locusta migratoria capito
LMIC	Lower-middle-income country
LSD	Lumpy skin disease
MAEP	Ministère de l'Agriculture, de l'Elevage et de la Pêche (Madagascar)
MARA	Ministry of Agriculture and Rural Affairs (China)
MDPI	Multidisciplinary Digital Publishing Institute
MIRA	Multi-Cluster/Sector Initial Rapid Assessment
MODIS	Moderate Resolution Imaging Spectroradiometer
MOSAICC	Modelling System for Agricultural Impacts of Climate Change
NASA	National Aeronautics and Space Administration (United States)
NDVI	Normalized difference vegetation index
NGO	Non-governmental organization
OIE	Office International des Epizooties (World Organisation for Animal Health)
PA	Paris Agreement
PDNA	Post-disaster needs assessment
PPE	Personal protective equipment
PPP	Purchasing power parity
PPR	Peste des petits ruminants
RSS	Remote sensing survey
SDG	Sustainable Development Goals
SDI	Spatial data infrastructure
SFDRR	Sendai Framework for Disaster Risk Reduction 2015–2030
SFM	Sendai Framework Monitor
SIDS	Small Island Developing States
SPOT	Satellite Pour l'Observation de la Terre
TAD	Transboundary animal disease
UMIC	Upper-middle-income country
UN	United Nations
UNDP	UN Development Programme
UNDRR	UN Office for Disaster Risk Reduction
UNEP	UN Environment Programme
UNESCAP	UN Economic and Social Commission for Asia and the Pacific
UNFCCC	UN Framework Convention on Climate Change
UNHCR	UN High Commissioner for Refugees
UNISDR	UN International Strategy for Disaster Risk Reduction
UNOCHA	UN Office for the Coordination of Humanitarian Affairs
VHI	Vegetation health index
WAHIS	World Animal Health Information System (maintained by OIE)
WFP	World Food Programme
WHO	World Health Organization
WIM	Warsaw International Mechanism for Loss and Damage Associated with Climate Change Impacts
WMO	World Meteorological Organization
WRI	World Resources Institute
WSI	Water satisfaction index
WSN	Wireless sensor networks



Earthquake and tsunami, Palu, Sulawesi, Indonesia 2018



Introduction

Agriculture on the proving grounds

Disasters threaten all three pillars of sustainable development: social, environmental, economic. This is happening more rapidly and unpredictably than anticipated, across multiple sectors, dimensions and scales. Agriculture continues to bear the brunt of disaster impacts as new risks and correlations emerge. The COVID-19 pandemic, for example, is straining food supply chains across the world. With only a decade left to achieve the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) and the Sustainable Development Goals (SDG), urgent efforts are necessary to build disaster-, disease-, and climate-resilient agricultural systems that will be capable of improving the nutrition and food security of present and future generations, even in the face of mounting threats.

2010–2019 was the most turbulent decade for disasters, no truce in sight for the 2020s

The new decade opened with the COVID-19 pandemic, huge locust swarms worsening conditions for 42 million people already facing acute food insecurity, and a record-breaking 30 named storms in the Atlantic basin

The turn of the decade is proving to be a time of heightened global urgency. At no other point in modern history has humankind faced such an array of both familiar and unfamiliar risks and hazards, interacting in a hyper-connected and rapidly changing world. Within the first few months of 2020, huge swarms of desert locusts began to ravage multiple countries across the Greater Horn of Africa, the Arabian Peninsula and Southwest Asia, worsening conditions for more than 42 million people already facing acute food insecurity. By its end, the 2020 Atlantic hurricane season produced 30 named systems, far surpassing the 12-storm average.

Meanwhile, the COVID-19 pandemic has been devastating lives, livelihoods and economies the world over. For countries that are already dealing with fragility, chronic disasters or environmental degradation, the compounding effect of these new emergencies is like fighting a crisis within a crisis. Spreading at an alarming speed, the SARS-CoV-2 virus has infected millions of people around the world, at times bringing economic activity to a near-standstill as countries impose stringent restrictions to halt its spread. As the health and human toll continues to grow, the economic damage is evident and represents the largest economic shock the world has experienced in decades (World Bank, 2020). With the situation still unfolding, it is difficult to definitively assess the full impact of lockdowns and other containment measures, but current estimates predict that the number of undernourished people will increase by a minimum of 83 million and possibly as many as 132 million as a result of the economic recession triggered by COVID-19 (FAO, IFAD, UNICEF, WFP & WHO, 2020, *State of Food Security and Nutrition in the World, [SOFI 2020]*; ILO, FAO, IFAD & WHO, *Joint statement 13 October 2020*). The setback throws into further doubt achievement of Sustainable Development Goal 2, Zero Hunger (SDG 2).

Farmers are experiencing reduced access to inputs, labour and farmlands, resulting in production loss, lower household income and nutrition declines. Across the world, the severity of the damage caused depends on multiple factors such as timing of COVID-19's spread and respective containment measures *vis-à-vis* the calendar for agricultural activities, the disruption of input prices and demand, etc. This underlines the need to quantify the COVID-19 impact on the agricultural sector to determine the effort required to restore damages and meet capacity needs.

Coinciding with COVID-19 is the upsurge in desert locusts, which has been unravelling in the Horn of Africa, the Arabian Peninsula and Southwest Asia and which at one point even threatened Africa's Sahel region. The world's most dangerous migratory pest, the desert locust can ravage crops, trees, and pastureland, destroying food and vegetation and jeopardizing the livelihoods of rural communities along its path. Just a small one-square-kilometre locust swarm can consume the same amount of food in one day as approximately 35 000 people. In the current outbreak, unusually expansive swarms formed that were many orders of magnitude larger than that, making it the most serious such threat faced by East Africa in generations – and an unprecedented risk to food security and livelihoods in a region already reeling from recurrent and extended drought, flooding, and instability and strife, where millions of people were already experiencing crisis-level food insecurity before the pest arrived on the scene.

Clearly, the new decade is offering no reprieve from the volatile 2010s, which were punctuated by a succession of distressing, destructive and debilitating events. Six category 5 hurricanes tore through the Atlantic, decimating entire communities.



© FAO/Sven Torfinn



© WHO/Blink Media - Lisette Poole

TOP: Desert locust crisis, Kenya 2020 | BOTTOM: COVID-19 response, Mexico 2020

Unprecedented wildfires scorched hundreds of thousands of acres of forestland across the Amazon, Australia, California and Greece. Devastating earthquakes hit Haiti (2010), Japan (2011), New Zealand (2011), Nepal (2015), Ecuador (2016), and Indonesia (2018), leaving countries with the years-long challenges of reconstructing infrastructures and economies.

The 2010s also constitute the hottest decade on the books, claiming seven of the ten warmest years on record; 2019 itself was the second-warmest year since 1851 in terms of both land and ocean temperatures, thus intensifying floods, droughts, heat waves and water scarcity, with direct social and economic impacts. Climate-related disasters such as these are known contributors to civil tensions, forced migration and even conflict.

Disasters steadily on the rise

News of disasters and threats frequently dominate the news media and are reported to wreak havoc, jeopardize lives and sink billions of dollars in recovery and reconstruction. Yet, are disasters truly becoming more frequent and dangerous or are we succumbing to perception bias?

Disasters per year by decade: 90 (1970s); 100+ (1980s); 440 (2000s); 360 (2010s) but more intense, claiming seven of the ten hottest years on record, including 2019, the second-hottest year since 1851

Available data shows that increased disaster occurrence is indeed the new normal. While, a quick short-run comparison with the preceding decade shows that there were relatively fewer disaster peak years in the 2010s, the overall level of occurrence remains at an all-time high. With the new millennium, disasters took a drastic leap in frequency and have continued to occur at a consistently high rate over the past 20 years. In both recent decades, disasters averaged more than 360 distinct events per year (in the 2010s) and 440 per year (in the 2000s), compared to just over 100 in the 1980s and a moderate 90 per year in the 1970s. These included geophysical disasters, climate and weather-related disasters as well as outbreaks of animal and plant pests and diseases (Figure 1). Those figures, however, reflect mostly the occurrence of rapid-onset and large-scale disasters, with low inclusion rates for slow-onset hazards and sub-national, localized or small-scale disasters¹ which often affect agriculture. This means that the true disaster outlook therefore lies even above the currently reported occurrence rates.

Examining the evolution of particular hazard types over the decades reveals a more complex pattern. While the average rate of geophysical disasters, such as earthquakes, landslides and mass movements, remained fairly stable over time (around 25 events per year in the 1980s and 1970s, up to 30–35 events annually in the 2000s and 2010s), other disaster types have radically increased since the 1970s. In the climate- and weather-related group, disasters such as drought, storms (e.g. cyclones, hurricanes, typhoons) and extreme temperatures averaged roughly 40 events per year in the 1970s, but nearly quadrupled to over 150 annually in the 2010s. The pattern is similar for hydrological disasters. Floods, which averaged 30 events per year in the 1970s, doubled to over 60 in the 1980s, and skyrocketed to an average of 180 in the 2000s, with a peak of 246 flood events in 2006 (Figure 2).

While disaster occurrence remains at its new and consistently high level, disaster impacts on livelihoods and economies continue to expand significantly. On a global level, the economic loss associated with all disasters (climatological, hydrological, biological and geophysical combined) has averaged roughly USD 170 billion per year over the past decade, with peaks in 2011 and 2017,

¹ To be entered into EM-DAT CRED, a disaster event must meet at least one of these four criteria:

- ten or more human deaths,
- 100 or more people affected/injured/homeless,
- declaration by the country of a state of emergency,
- an appeal for international assistance.

Globally, disaster-related economic loss during the 2010s averaged USD 170 billion per year

when loss soared to over USD 300 billion (EM-DAT CRED). While the economic impact of geophysical disasters (earthquakes, tsunamis, volcanic eruptions and mass movements) and hydrological disasters (floods) has remained fairly stable over recent decades, annual economic loss from climate and weather-related events has risen significantly since the 2000s, in line with their amplified frequency (Figure 3).

Meanwhile, the economic impact of biological hazards, such as pest and disease outbreaks and pandemics, remains largely underreported at both the national and global levels; the paucity of relevant data explains the absence of this hazard group from Figure 3. As drought, floods, storms and temperature extremes emerge as the costliest disasters on record, current DRR systems need to take a strategic leap towards focusing on systemic risk, targeting slow-onset disasters alongside sudden-onset events such as floods and earthquakes. This requires stronger institutional partnerships and shared responsibilities with strong sectoral ownership.

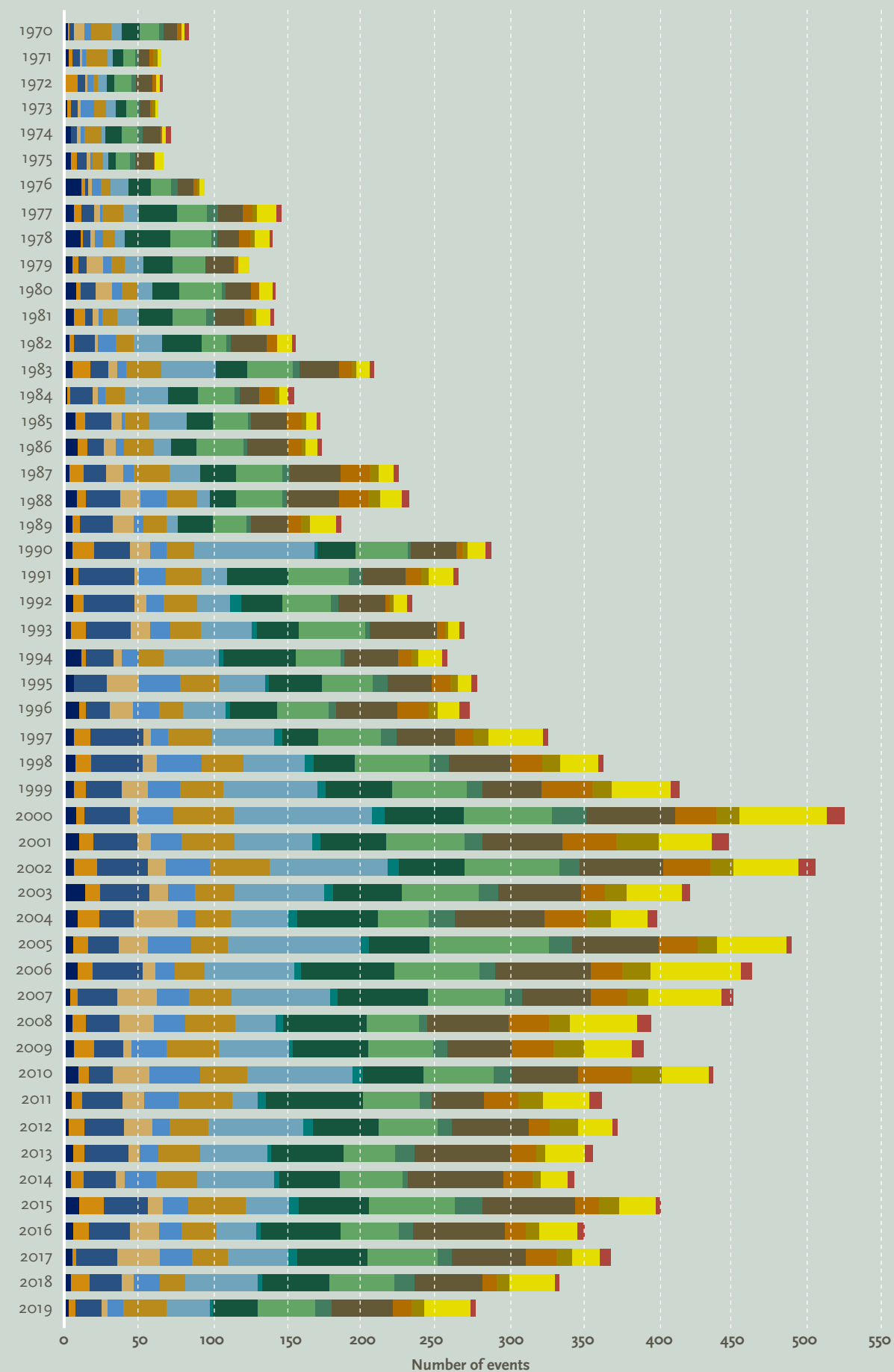
The brunt of disasters is borne by the urban and rural poor, including smallholder and subsistence farmers, pastoralists, fisherfolk and wage labourers

In addition, such global figures do not capture the disproportionate burden borne by the most vulnerable. Many of the countries that suffer most from economic loss are Small Island Developing States (SIDS). Due to devastation wrought by Cyclone Pam in 2015, for instance, Vanuatu's scheduled 2017 graduation from Least Developed Country (LDC) status was pushed back to December 2020. Vulnerability does not necessarily equal poverty, yet evidence shows that it is generally the urban and rural poor – including smallholder and subsistence farmers, pastoralists, fisherfolk and wage labourers – who bear the brunt of disasters. Yet, every hazard need not mature into a disaster occurrence. This is precisely why prevention and DRR measures in agriculture are especially useful in avoiding or reducing damage and loss in less severe, high- to medium-frequency events. Reinforcing the capacities of communities and their institutions to prevent or mitigate disaster impacts – as well as to adapt to or recover from them in a timely, efficient and sustainable manner – is at the core of FAO's work on DRR.



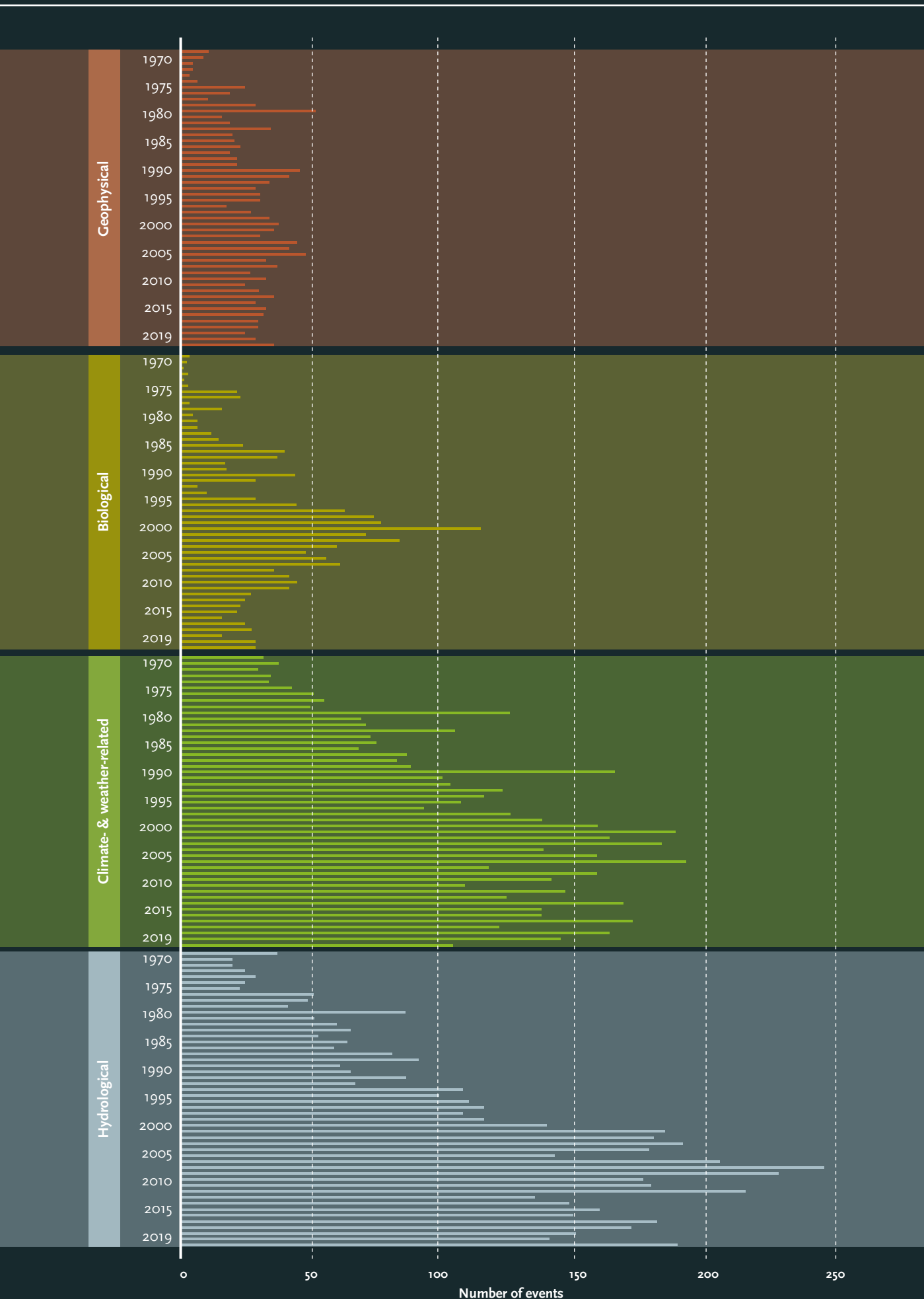
Desert storm, Iraq 2016

Figure 1. Global disaster occurrence, 1970–2019



Source: FAO, EM-DAT CRED

Figure 2. Global disaster occurrence by type, 1970–2019



Source: FAO, EM-DAT CRED

Figure 3. Global economic loss from disasters, 1970–2019

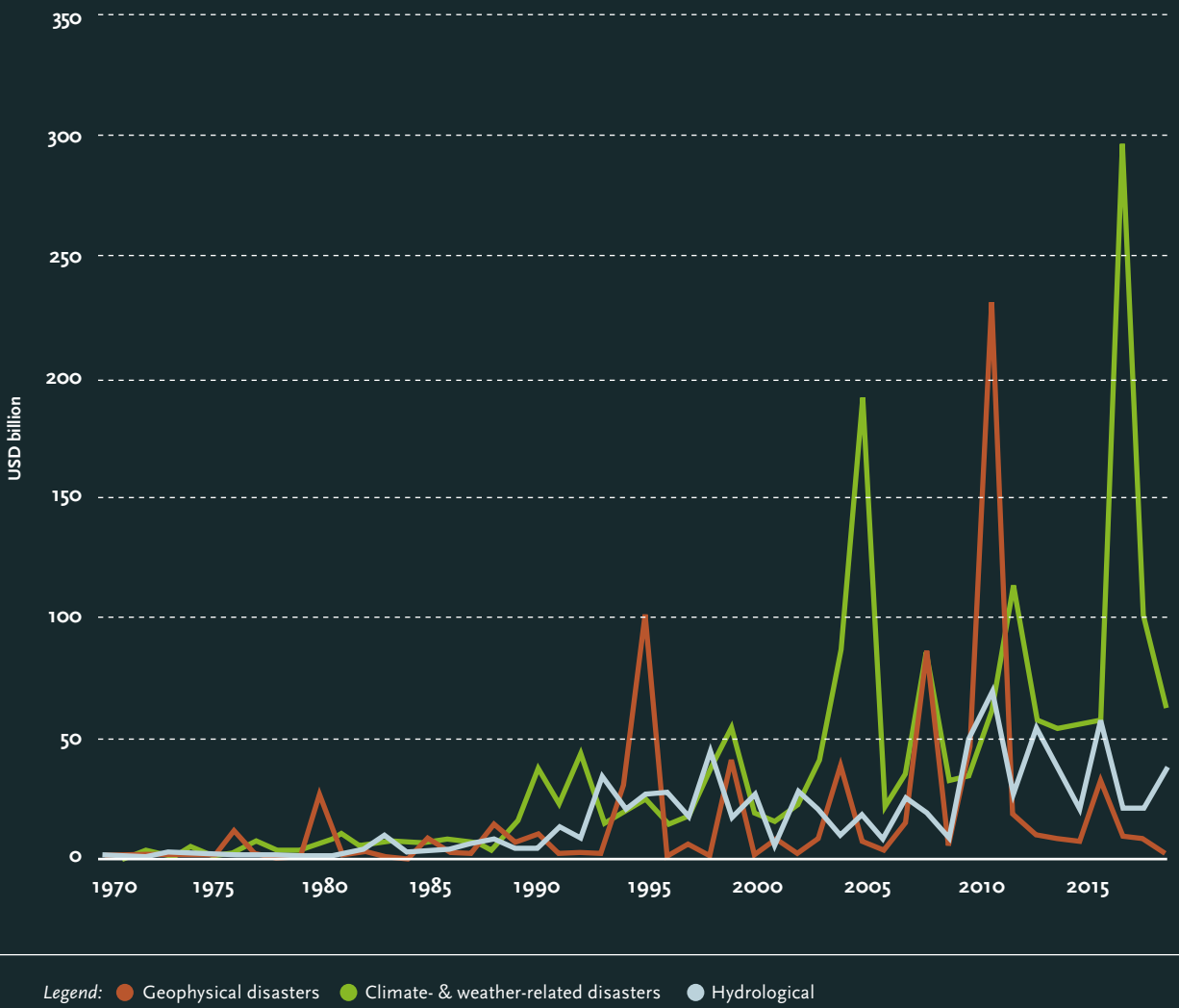


Figure 4a. Damage and loss in agriculture relative to combined industry, commerce, and tourism sectors, 2008–2018

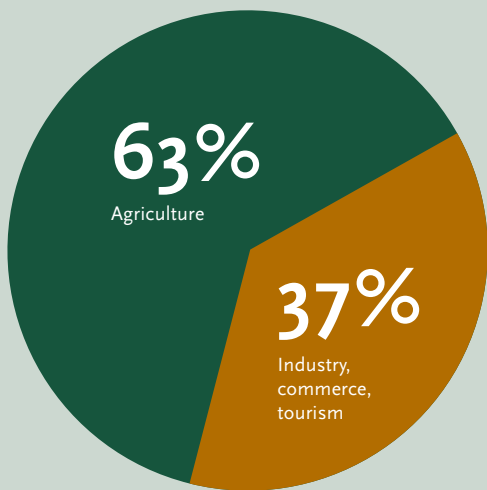
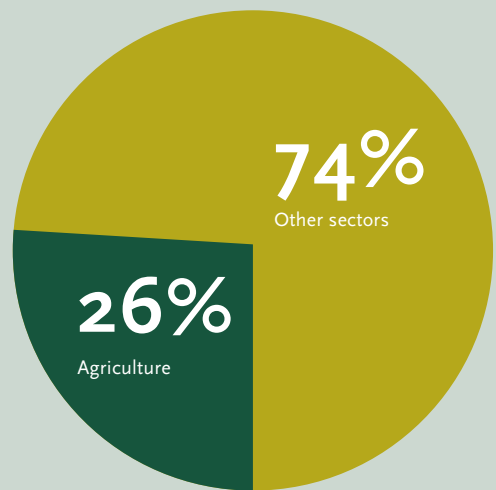


Figure 4b. Damage and loss in agriculture as share of total damage and loss in all sectors, 20008–2018



For agriculture, exceptions are the new rule

Given its reliance on weather and climate, agriculture is especially vulnerable to the increased frequency and intensity of extreme weather-related and climate-induced events

The agricultural sector is particularly vulnerable to natural hazards and disasters. While variability has always been the rule when it comes to weather and climate conditions and is already factored into expectations for agricultural output, sudden disasters – by definition – surpass normal expectations for variability. Therefore, the notable increase in the frequency and intensity of extreme weather-related and climate-induced events observed over the past decades poses a significant challenge to agricultural systems, given their heavy reliance on weather and climate. Disasters can be detrimental to crop growth, livestock health, fisheries and aquaculture production, and can seriously compromise forest and other ecosystems. Furthermore, an alarming increase in the number of outbreaks of transboundary animal and plant pests and diseases is putting large pressures on the human food chain.

Data from 71 Post-Disaster Needs Assessments (PDNA) conducted between 2008–2018 shows that agriculture continues to be a crucial sector when it comes to disaster impact. **Over that period, agriculture – including crops, livestock, forestry, fisheries and aquaculture – absorbed 26 percent of the overall impact caused by medium- to large-scale disasters in low- and lower-middle-income countries (Figure 4b). Relative to agriculture, industry, commerce and tourism taken as a whole, agriculture on its own bears the disproportionate share of 63 percent of damage and loss from disasters (Figure 4a).**

The significance of this share is underscored by agriculture’s importance for the economic development of many countries across the globe. Agriculture is among the main economic activities in low- and lower-middle-income countries (LICs and LMICs), contributing anywhere between 10–20 percent of national gross domestic product (GDP) in lower-middle-income countries and over 40 percent in low-income countries.

82 percent of all damage and loss caused by drought was absorbed by agriculture in low- and lower-middle-income countries between 2008–2018

As established in previous editions of this report, the impact of drought is borne almost exclusively by agriculture. In particular, drought affects the crops and livestock domain disproportionately relative to all other sectors of the economy. Eighty-two percent of all damage and loss caused by drought was absorbed by agriculture in low- and lower-middle-income countries between 2008–2018. Drought causes short- and medium-term water shortages and extreme heat stress on livestock and crops (including fodder), which can be detrimental to yields. In the case of prolonged or recurring droughts, longer-term impacts can transpire, such as land subsidence, seawater intrusion along river systems with reduced water flow and ecosystems damage. Furthermore, when combined with socio-economic factors or conflict, droughts have caused some of the most serious famines known to history.

Biological hazards: pest and disease outbreaks are pushing the boundaries

Biological hazards, such as pests and disease outbreaks pose a serious risk to human, animal and plant life and health. They often coincide with other disasters, threats and protracted crises, leading to cascading impacts, intensifying risks and entrenching vulnerabilities. Both animal and human disease outbreaks and pandemics are cyclical in nature and likely to intensify as the climate warms, population size grows and agriculture expands. Through its rapid onset and cannonballing spread, COVID-19 quickly dominated agriculture's transition into the new decade on both domestic and global levels. While the worldwide scope of the current pandemic presents a unique and unprecedented set of challenges, there are important lessons that can be drawn from this and previous outbreaks – such as Ebola Virus Disease (EVD), Middle East Respiratory Syndrome Coronavirus (MERS-CoV), and Severe Acute Respiratory Syndrome (SARS-CoV) – and their respective impacts on agriculture and food systems. Namely, the considerable food security implications of outbreaks and pandemics at national, regional and global levels. Since its onset, COVID-19 (caused by the newly discovered SARS-CoV-2 virus) has had a profound impact on food prices – up to 50 percent increase in the price of imported foods in Somalia – and national, regional and global food systems. Movement and trade restrictions have interrupted agricultural labour migrations, impacted international food prices and reduced overall production and food chain viability throughout the agricultural sector. The International Food Policy Research Institute predicts that LICs and LMICs could see a 25 percent reduction in their agriculture- and food-related commodity exports due to COVID-19. Mass food insecurity is not only already occurring in many developing countries, it is spiking too in vulnerable communities of developed ones. In many affected food chains, shortages and even production falloffs will persist as this pandemic unfolds and future ones occur.

LICs and LMICs could see a 25 percent reduction in their agriculture- and food-related commodity exports due to COVID-19

Plant and animal pests and diseases in general have historically been a destabilizing factor for agriculture and a major threat to food security. Locusts, armyworm, fruit flies, banana diseases, cassava diseases and wheat rusts are among the most destructive transboundary plant pests and diseases. On the other hand, high-impact animal diseases such as foot-and-mouth disease, peste des petits ruminants, classical or African swine fevers – while not directly affecting human health – do affect food and nutrition security as well as livestock production and trade. Though animal disease outbreaks peaked in the 2000s, their impact on the livestock sector and human food chain remains under-reported and poorly analysed. Changing agro-ecological conditions, intensifying food production systems, and expanding global trade are among the factors affecting the likelihood

Containing African swine fever in Asia

In 2018, African swine fever (ASF) became a matter of utmost urgency in Asia, causing devastation with far-reaching global implications. China's 2019 pork production decreased by 21 percent, while average pork prices rose by over 40 percent. As the outbreak continues to spread across China, Southeast Asia and even Mongolia, the livelihoods of the most vulnerable small-scale farmers are hit the hardest. Chapter 5 details the most recent ASF outbreak and its consequences for food security, market stability and trade.

of transboundary pest and animal disease outbreaks and their reach. Some countries and geographic areas are more vulnerable to their spread than others, depending on their level of economic development, political context, regulatory regime and ecological conditions.

Drought and floods, destructive in themselves, also catalyse disease-spreading conditions, foster vector-breeding and intensify disease transmission

The growing interconnectedness between intensified animal and plant pest and disease outbreaks and natural hazard-related disasters poses further conceptual challenges. Drought and floods are among the most common events that threaten – and often batter – agricultural production systems, and both have a complex relationship with pest and disease outbreaks. They can catalyse disease-spreading conditions, foster vector-breeding sites and intensify disease transmission. While these two types of threats – natural hazards and pests and diseases – interact in multiple ways, the effects of the latter on the former remain largely unexplored and are seldom taken into consideration during assessments and policy planning.

Biological disasters, such as the COVID-19 pandemic, demonstrate the systemic nature of risk and the exposure of our economies and societies to multi-hazard emergencies with cascading effects. In an increasingly populous, networked, and globalized society, the very nature and scale of risk have evolved to such a degree that they surpass the current capacities and approaches of many risk management institutions. This brings to prominence the need for coordinated and systemic multi-hazard disaster risk reduction and prevention mechanisms within and across all sectors. We need not start from scratch. Biological hazards are already prominently featured in the globally agreed Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), which was the first to integrate them. SFDRR's current mechanisms and strategies for disaster resilience can therefore build upon and enhance prevention, preparedness and responses to epidemics or global pandemics such as COVID-19 as part of a broader, systemic approach to risk. On that basis, there is a unique opportunity to foster risk-informed policy and decision-making; promote multi-hazard and cross-sectoral approaches to assessing risk; and encourage a deeper understanding of socio-economic and environmental vulnerability within and across different sectors. In assessing COVID-19-related disruptions to agricultural production, FAO's work on damage and loss assessment offers a good starting point for impact analysis.

SFDRR's systematic approach to risks – the first to include biological hazards – can enhance prevention, preparedness and response to epidemics and pandemics

The occurrence of biological threats is a highlight of this report. Chapter 5 explores the extent and impact of animal disease outbreaks on the livestock sector, while underlining the repercussions for food security and human food systems. Chapter 6 takes on the subject of locusts, the world's most devastating pest.

Desert locust crisis in East Africa

The desert locust is the most destructive migratory pest in the world. Since early 2020, vast locust swarms have been sweeping across East Africa and beyond, damaging crops and forage along their path. This outbreak is the worst to strike Ethiopia and Somalia in 25 years and the worst that Kenya and Uganda have experienced in 70 years. Pastures and croplands have suffered considerable damage, implying severe consequences for the region where nearly 42 million people were already coping with acute food insecurity. Chapter 6 provides a closer look at the situation.

The heat is on

Earth has been running a tenacious fever: global average surface temperature has been rising progressively in the past 50 years compared to 1961–1980

Increased disaster occurrence has been accompanied by a continued upward trend in the earth's global average surface temperature. While 2019 capped a decade of exceptionally high global temperatures, retreating ice and a record rise in sea level, anthropogenically driven by untenably large amounts of greenhouse gases (GHG) in the atmosphere, the earth has been running a tenacious fever for quite some time. Global average surface temperature has been rising progressively over the past five decades compared to a baseline period of 1961–1980 (Figure 5).

While attribution science is still nascent, we are starting to see evidence of how climate change is causing an increase in the frequency, intensity – or both – of extreme weather events. Small shifts in climate can produce initial ripples, which can be amplified by non-linear effects and hazards, manifesting in an array of extreme events. When it comes to agriculture, a sector crucially dependent on climate for its production, the effects are often grave and far-reaching.

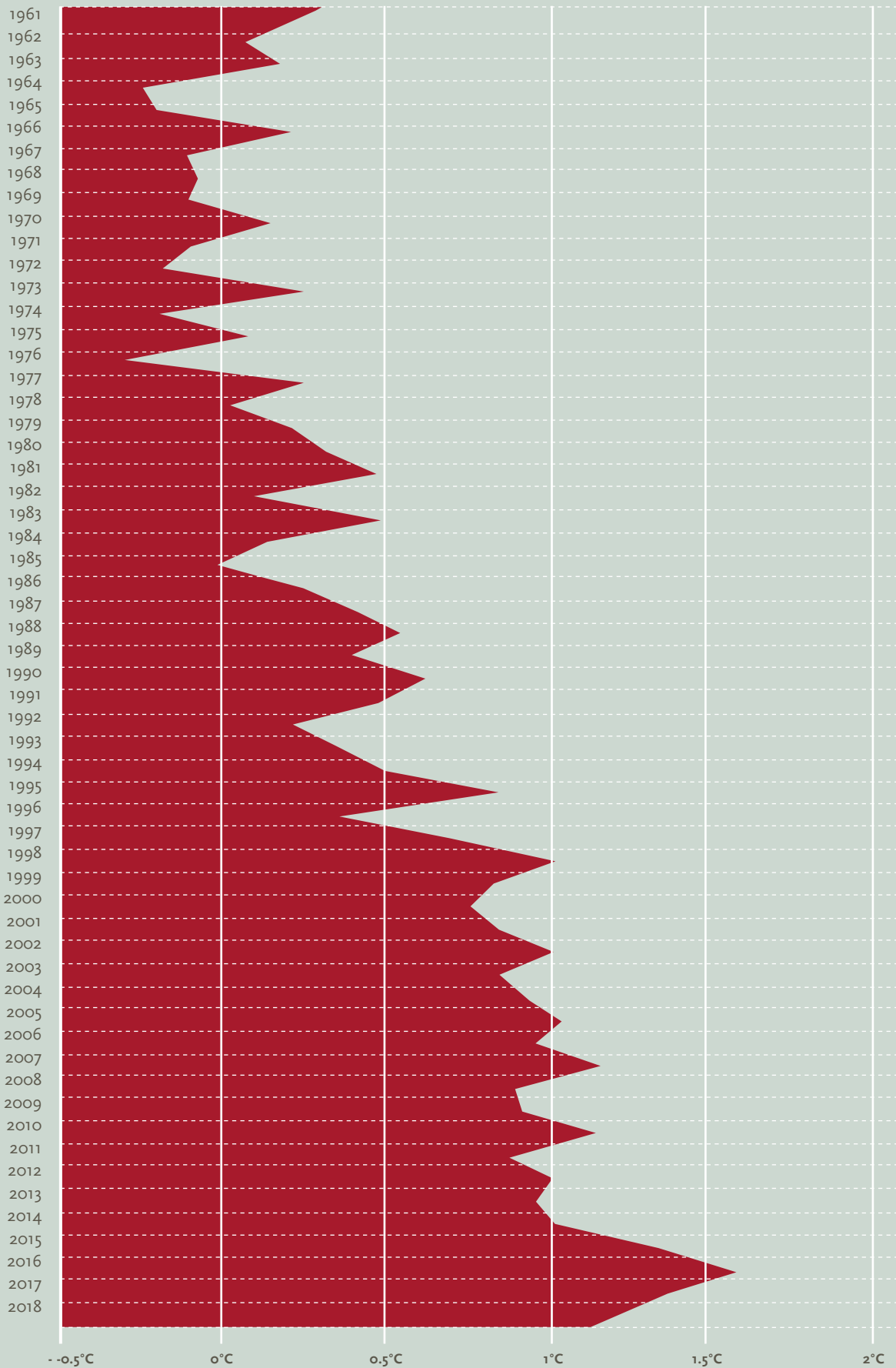
On the other hand, traditional human activity such as agriculture is not merely a recipient of climate change consequences but a contributing factor. Agriculture has not only altered landscapes, economies and lifestyles over time, it has also transformed nature, bringing more exposure, and increasing the propensity for reverberations across multiple systems with unpredictable effects. Yet, while agriculture is responsible for roughly a quarter of all GHG emissions, it also offers solutions for emissions efficiency gains, absolute reductions and carbon sinks. The sector has a key role to play in both resilience-building and socio-economic development. Agriculture must, therefore, convert from being part of the problem to being part of the solution.

FAO's DL methodology is well-placed to inform implementation of the Paris Agreement

The 2030 Agenda for Sustainable Development and the Paris Agreement (PA) call for a profound transformation of our food systems as well as our modalities of operation: we can no longer consider food, livelihoods, and natural resources management separately. Allowing predominantly agro-intensive countries to pursue a development trajectory that is manageable, renewable and sustainable, in line with the aspirations of the 2030 Agenda, calls for better-informed policy frameworks. Understanding how and to what extent disasters – including those that are climate-related – impact the sector is a prerequisite. To that end, and in accord with the Warsaw International Mechanism for Loss and Damage Associated with Climate Change Impacts (WIM), FAO's damage and loss (DL) methodology, introduced in the 2017 edition of this report, is well-placed to inform implementation of the PA.

Chapter 7 offers a further discussion on the nexus between agriculture, disasters and climate change adaptation.

Figure 5. Global mean temperature change by year, 1961–2018

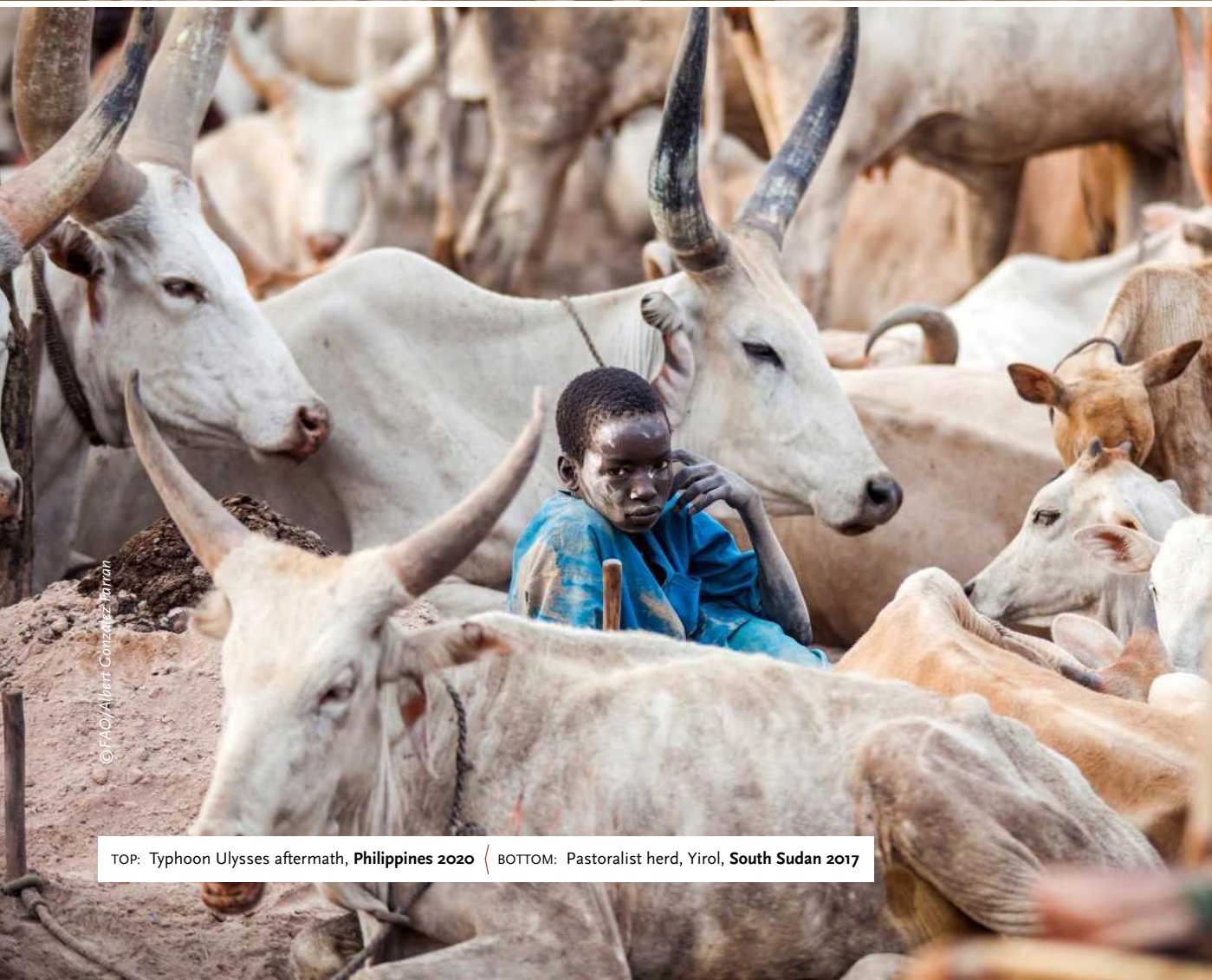


Source: Data based on the Global Surface Temperature Analysis (GISTEMP) of the National Aeronautics and Space Administration Goddard Institute for Space Studies (NASA-GISS); compiled and calculated by FAO

Legend: ● World temperature change



© Basilio H. Sepe / Greenpeace



© FAO / Albert Gonzalez Barran

TOP: Typhoon Ulysses aftermath, Philippines 2020 | BOTTOM: Pastoralist herd, Yirol, South Sudan 2017

Global 2030 Agenda – one decade left

As the 2020s begin, the clock is ticking louder for achievement of the SDGs and SFDRR. Despite great progress since its launch in 2015, the 2030 Agenda has not advanced at the pace or scale required. Deep and transformative change aimed at alleviating hunger, eradicating poverty and inequality, building peace and protecting the environment requires more ambitious action to meet the 17 SDGs within the deadline. Dubbed the ‘Decade of Action,’ the next ten years usher in a quest for accelerated solutions to the world’s most critical challenges, including the COVID-19 pandemic, which will certainly be considered one of the major risks of the 21st century.

Disasters and their immediate impacts, however, threaten to reverse development gains and slow poverty reduction and hunger alleviation. The menace of their increased frequency poses a fundamental threat to achieving international commitments, including the 2030 Agenda.

At the same time, it is important to understand that while disasters are threatening development gains, development is also an essential factor in the creation of disaster risk. Disasters are often considered external shocks, but they result from the complex interplay between development processes that generate conditions of exposure, vulnerability and hazard. **The damage and loss that characterize disasters result not only from the severity of the hazard event itself, but also from the exposure and vulnerability that preceded it.**

Building resilience and reducing disaster risk in all its dimensions (hazard, exposure, vulnerability) is, therefore, not only an end in itself but also a critical means of achieving the goals of eradicating extreme poverty, ending hunger and ensuring food security and nutrition. Disaster risk reduction and increasing resilience comprise a crucial path to success.

The various global landmark agreements form the basis for achieving a transformative recovery from the COVID-19 pandemic

The COVID-19 pandemic has quickly created a profound socio-economic crisis impacting all 17 SDGs. Yet even as it significantly endangers progress towards the SDGs, it also makes their achievement all the more urgent and necessary. Now more than ever, it is crucial that accrued development gains are protected and efforts to fully achieve the SDGs are set in motion. Moreover, the key to building back better in the post-COVID-19 recovery can already be found in the principles on which the 2030 Agenda was established. It provides the basis on which to pursue a transformative COVID-19 recovery that will address the crisis, reduce future risks and relaunch the implementation efforts to deliver the 2030 Agenda and SDGs within the Decade of Action. The continued pursuit of these universal commitments can maintain national focus on economic growth and stability, while also prioritizing inclusion, equity, livelihoods, food security and sustainability.

Agriculture – which underpins the livelihoods of over 2.5 billion people worldwide and up to 60 percent of those in LDCs (World Bank Open Data, 2020) – is integral to the achievement of both the SDGs and the Sendai Framework. Furthermore, by making the logical connection between reducing disaster impact, building resilience and providing sustainable solutions, the sector strengthens the connective tissue between the 2030 Agenda, the PA, and the WIM. Agriculture is fundamental, given the sector’s innate interactions with the environment, its direct reliance on natural resources for production, and its significance for national socio-economic development. So, in this emerging Decade for Action, both agriculture’s vulnerability to risks, disasters and climate change as well as its great potential for sustainable solutions must be considered – and a new role for the sector carved out.

FAO's DL methodology is already being used in Latin America & the Caribbean, Central Asia, South-eastern Asia, Eastern Europe, Northern Africa & the Near East, and in Eastern Africa

FAO's DL methodology to assess direct loss from disasters – developed in partnership with the United Nations Office for Disaster Risk Reduction (UNDRR) – is now being used to track progress towards achieving the Sendai Framework Indicator C-2 (Target C) and SDG Indicator 1.5.2. FAO's tailored tool standardizes disaster impact assessment in agriculture to ensure that agricultural loss is consistently and representatively reported at global level. Regions already trained and adopting the FAO DL methodology are: Latin America and the Caribbean, with Chile, Uruguay and Colombia already at the implementation stage; Central Asia, with pilots under way in Kyrgyzstan and Tajikistan; South-eastern Asia; Eastern Europe; Northern Africa and the Near East; and Eastern Africa. However, for the Sendai Framework to 'work' for agriculture, this methodology must be further institutionalized, especially in countries highly exposed to risk.

The quest continues for disaggregated sectoral data on damage and loss

Implementing strategies for risk-informed, resilient and sustainable agricultural development requires functioning risk information systems that can provide reliable data and statistics that are timely, accurate, disaggregated, gender-sensitive and widely available. This will best enable countries to craft policy and direct investments that correspond to specific needs and contexts. FAO has been working to improve the availability and quality of disaster impact statistics for agriculture and its subsectors (crops, livestock, forestry, fisheries and aquaculture) at the national, regional, and global levels. Notwithstanding ongoing efforts, data gaps prevail either because data have not been reported in a systematic way or have not been collected at all, which – as already noted – is especially true in the case of biological hazards. Furthermore, available statistics on damage and loss from disasters do not offer a sufficient level of disaggregation, i.e. by crop or animal type, etc., to allow for an in-depth understanding of the mechanisms at play.

Meanwhile, the 2030 Agenda and Sendai Framework have created new requirements for data collection and reporting at national level. With the use of common indicators and metrics through the online Sendai Framework Monitor (SFM), monitoring and reporting on the Sendai Framework and disaster-related SDGs is already advancing. National statistical offices are building the framework to integrate disaster-related data within the domain of official statistics, including disaster-related agricultural statistics. Despite these advances, however, the rate of reporting on the agricultural loss Indicator C-2 by Member States is falling behind and requires special attention to address the disaggregated, subsector-specific data requirements.

Now that SFDRR Target C reporting is obligatory, more effort is urgently needed to improve national information systems for collecting and reporting data on disaster-related loss

Reporting annual agricultural production loss from disasters in a manner consistent with the FAO methodology for Indicator C-2 represents a distinct challenge. While data availability and quality are steadily improving, more effort should be devoted to establishing national information systems for collecting and reporting on agricultural loss from disasters. To this end, FAO has been providing support and developing capacities of national institutions for the adoption, operationalization and implementation of the methodology. A growing number of countries across Latin America, the Caribbean, Eastern Africa, South-eastern Asia and Central Asia are already employing this new approach as they ready themselves to track and report their Sendai Framework and SDG commitments, especially since Target C reporting became obligatory in 2020.

The realm of statistical capacity development offers great potential for collaborative synergies across increasingly complex data systems with the aim of producing more complete, reliable and timely data on disaster impact in agriculture.



© FAO/Karel Prinsloo



© UNICEF/UN0216986/LeMoyné

TOP: Emaciated livestock due to drought, **Somalia 2017** | BOTTOM: Flooding, Cox's Bazar, **Bangladesh 2017**

Developing statistical capacity fosters collaborative synergies across different disciplines and global frameworks, but requires increased international attention and funding

Coordinated, integrated global and national efforts to strengthen data generation, taxonomy, interoperability, statistical capacity and reporting for agricultural disaster impact must increase to build collaborative synergies with related efforts and processes that are ongoing across different global frameworks. This includes supporting and drawing from the data revolution for sustainable development that was recommended by the United Nations Secretary-General's Independent Expert Advisory Group (IEAG), FAO's Agricultural Integrated Survey Programme (AGRISurvey), as well as the recently launched multi-agency 50x2030 Initiative to Close the Agricultural Data Gap, the most ambitious global effort yet to collect and survey agricultural disaster loss data. Increased international attention and targeted funding across different goals is slowly starting to yield results. It is critical that momentum is not lost.

In addition, smart data should be put to better use. Developments in open data and analysis, shared and interoperable software, computing power, remote sensing, geographic information systems (GIS) and other technologies enable better data science and should be leveraged to improve agricultural disaster statistics. Chapter 8 discusses the new frontiers for disaster impact assessment through remote sensing and GIS technologies.

From governance of evidence to governance of action

The prevailing, interconnected and multidimensional threats that overhang agri-food systems worldwide require systemic programmatic approaches built on an understanding of the nature of disaster-related impact on agriculture across all its subsectors and, subsequently, on livelihoods. This will nurture a governance structure adapted to the context. These can be formal intergovernmental mechanisms or innovative multi-stakeholder partnerships, using governance frameworks of laws, policies, institutions and financing already in place at national and regional levels.

Establishing and enhancing governance frameworks for agricultural disaster risk reduction and management (DRR and DRM) as well as resilience building represents a core step for national governments to achieve the Sendai Framework and 2030 Agenda targets and move towards more disaster-resilient agriculture systems. This step necessitates better data, including on the magnitudes of risk and impacts, and the integration of information across different subsectors, cooperation between different levels of government, as well as engagement with civil society and the private sector. It also entails analysis of both current and historical data to understand the disaster risk profile of the sector. In this context, national DRR policies and planning frameworks that – informed by the Sendai Framework monitoring system – incorporate agriculture, livelihoods, food security and nutrition, are well-suited to create the evidence needed for risk sensitive decision-making. They further provide overall guidance for prioritization of sector-based technical solutions to sustainable and resilient development. Integrating the knowledge DRR provides about disaster impacts and patterns into national policies

Resilience at FAO

FAO's resilience agenda covers three groups of shocks: natural hazards, including extreme climate change events; food chain crises and transboundary threats, including pests, diseases, and food safety; and protracted crises, including violent conflicts. Through this holistic approach, FAO works to address the compound nature of disasters and the interconnectedness of threats.

and plans for crops, livestock, forestry, fisheries, aquaculture, and natural resources is a crucial step for enhancing the resilience of smallholders from a sector perspective.

Stronger governance at national level also translates into stronger global governance. Actors like the Committee on World Food Security (CFS) are already coordinating efforts at national and regional levels to establish a global approach to food security. CFS promotes policy convergence, accountability and knowledge sharing. By using disaster impact information as an evidence base, national agricultural disaster risk governance structures have an essential role to play in strengthening the global strategic framework on food security and nutrition.

In tandem with enhanced governance is the opportunity to unlock the potential of public-private partnerships. Not only can these address the urgent need for substantial investment in reducing agriculture's susceptibility to disasters and climate change, they can serve as platforms or vehicles to leverage the expertise of a broad array of multilateral agencies and national governments alike. Blended finance solutions could be used to de-risk projects, making them bankable while closing vulnerability gaps. To this end, estimating and quantifying the impact of natural hazard-induced disasters, climate-related events, food chain hazards and protracted crises on the agricultural sector is essential if these investments are to help build sustainable resilience.

Efficiency gains can be further harvested through an inclusive and gender-sensitive approach towards DRR and resilience building in agriculture. Climate change and disasters are not gender-neutral and may affect women and men differently. Women as a group are not innately more vulnerable. However, given differentiated gender roles and conditions of inequality, disasters may indeed exert a stronger socio-economic impact on women than on men. This is particularly true for agriculture, where women already face more structural challenges, such as reduced access to land, resources and credit. For example, the COVID-19 pandemic is disproportionately affecting the productive and income-generating capacities of rural women because it is reducing their economic opportunities while at the same time increasing their workloads and escalating gender-based violence. Accordingly, targeted policy responses to the pandemic and to other disasters should consider gender roles in agri-food systems and ensure that women's multiple needs – as custodians of household food security, food producers, farm managers, traders, wage workers and entrepreneurs – are adequately addressed. It is important that national, regional, and global policy be built on the basis of solid gender-sensitive analysis of disaster impact on agriculture.

Disasters may have stronger socio-economic impacts on women – the custodians of household security – than on men, especially in agriculture, where women already face greater challenges

Indeed, our understanding of how disasters affect agricultural livelihoods from a gender perspective is already lagging behind. To compile an initial baseline, a fundamental first step is ensuring the availability of disaggregated data on agricultural damage and loss from disasters. While goals related to gender-sensitive development are recognized in the Sendai Framework, and in greater detail in the 2030 Agenda, they are mainly to be realized through increasing women's participation at all levels.

Committee on World Food Security

The Committee on World Food Security (CFS) is the world's leading international and intergovernmental platform where stakeholders work together to ensure universal food security and nutrition. Reporting to the UN General Assembly through the Economic and Social Council (ECOSOC), and to the FAO Conference, CFS helps countries implement negotiated cross-cutting policy products. CFS develops and endorses policy recommendations and guidance documents on a wide range of pressing food security and nutrition topics.



© FAO/Lieke Visser



© FAO/Farooq Naeem

TOP: Fishing, South Sudan 2016 | BOTTOM: Rehabilitating water channels ruined by floods, Pakistan 2011

Time to act

Given intensifying disaster risk, it is urgent that FAO's DL methodology be institutionalized at country level, as part of a holistic Sendai Framework and disaster loss information governance system

In this Decade of Action, there is a powerful case for investing in resilience and disaster risk reduction, especially with regard to data and information generation. Consolidating efforts to measure and analyse the disaster impact on agriculture, including institutionalizing FAO's own framework for damage and loss assessment as part of the SFM, is essential to producing a targeted evidence base for national resilience, DRR and climate change adaptation policy and planning.

The urgency of doing so cannot be ignored. Disasters are nothing new – not to farmers, nor to the rest of us who rely on them for our collective food security. But the imperative of changing how we manage disasters, at this moment in human history, is existentially pressing. To be effective, national strategies on DRR, emergency response, resilience and climate change adaptation must be firmly grounded in a comprehensive understanding of the particular impact disasters have on agriculture, including:

- Identifying damage and loss patterns.
- Providing subsectoral breakdowns of impacts on crops, livestock, forestry, fisheries and aquaculture.
- Building profiles of all disaster types: from rapid-onset large-scale catastrophes such as hurricanes, to events that develop slowly over time such as drought, as well as small-scale localized or 'silent' disasters, which are often unreported but can be detrimental to livelihoods of small-scale farmers.
- Expanding beyond the impacts of natural hazard-related disasters to consider broader threats, such as pandemics, food chain crises, conflicts and protracted crises.
- Navigating the nexus of disaster assessment, risk reduction and climate change adaptation.

This report lays out the latest thinking and cutting-edge analysis addressing these issues.



Buffalos escape a fire, New Delhi, India 2015



PART I

More disasters, more impact on agriculture

Chapter I
Proving the case:
measurement and
evidence 2008–2018

Chapter II
Disasters and forests:
unpacking a complex
relationship

Chapter III
Impact of disasters
on fisheries and
aquaculture



© REUTERS/Nicky Loh

Earthquake-hit area of Shifang, Sichuan Province, China 2008



Chapter I

Proving the case: measurement and evidence 2008–2018

Disasters, extreme events and climate variability have far-reaching repercussions on agricultural and food production systems. The most direct impact is reduced production, which cascades along the entire value chain, affecting agricultural growth and rural livelihoods, and placing all dimensions of food security and nutrition at risk. This chapter examines the cumulative effect of large- and medium-scale disasters across all countries and regions over the previous decade. It also examines the impact of disasters on agriculture through a nutrition lens, quantifying the nutrients behind the loss.

Expanding the scope

Looking back over a decade of severe weather anomalies, superstorms, pest infestations and earthquakes with impacts on a scale previously unimaginable, there is a pressing need to understand the toll that has been taken. In 2019 alone, disaster-related economic loss – from droughts in East Africa to typhoons in Mozambique to the Amazonian wildfires – amounted to USD 122 billion globally (EM-DAT CRED, 2020). Because climate change makes weather patterns more extreme, the outlook for the decade to come is a daunting one. As the need to prevent, mitigate and compensate loss grows, critical questions remain about the scale of agricultural loss and the brunt the sector bears.

Disasters pose long-lasting consequences for agriculture, such as deterioration of animal health, contamination of aquatic resources, loss of harvests, disease outbreaks, and infrastructure destruction

Heavily reliant on weather, climate and water for its ability to prosper, agriculture is particularly vulnerable to disasters, weather extremes and climate change. Staple food production in many agriculture-based countries remains largely rain-fed and uninsured against the large fluctuations caused by weather and climatic variability. The sector often faces multipronged and long-lasting consequences of disasters, such as the deterioration of animal health, contamination of aquaculture facilities, loss of harvests, outbreaks of disease or destruction of irrigation systems and other infrastructure. Such impacts can be particularly detrimental in LDCs, where agriculture tends to be the economic backbone, often contributing up to 20–30 percent of national GDP and employment.

The 2017 edition of FAO's report on *The Impact of disasters and crises on agriculture and food security* presented an improved approach to analysing disaster loss data for agricultural production. Findings revealed that between 2005 and 2015, LDC and lower-middle-income countries (LMIC) across Africa, Latin America and the Caribbean (LAC), and Asia and the Pacific suffered a total of USD 96 billion in crop and livestock production loss due to 332 large- and medium-scale disasters; over half of this was attributed to floods and droughts.

The current edition looks at how the most recent trends in agricultural production loss were attributed to disasters, and takes stock of the evolving tendencies.

The volume and value of reduced agricultural production due to disasters is examined for the 2008–2018 period. In line with the 2017 edition, the scope and level of analysis extends beyond the large-scale disaster focus to include both medium- and smaller-scale disasters affecting more than 100 000 people, or 10 percent of the national population. This allows for smaller and less populous countries, including SIDS, to be equally considered. The sector's economic loss from disasters is estimated by analysing trends in crop and livestock production flows and associated deviations in the years in which disasters are recorded.

This report's global analysis covers 457 disasters in 109 countries across all regions and income categories

The analysis covers 457 disasters in 109 countries across all regions and income categories, including for the first time upper-middle- and high-income countries (UMICs and HICs), thereby providing a wider perspective and comparison of loss. Of the 109 countries to register disaster-related agriculture loss, 94 are in the LDC and LMIC categories, where 389 disasters hampered agricultural production. The analysis can be considered global in the sense that it includes every country that registered a disaster-related change in production (Box 2). The crop and livestock sectors are considered as a whole, looking at every reported commodity produced in each country (or an average of 125 commodities per country).

As a further innovation, this chapter includes a focus on the nutrition dimension of agricultural loss. The crop and livestock production volumes estimated as disaster-related losses have been converted to calorie and essential nutrient equivalents using adjusted food composition data from the United States Department of Agriculture (USDA). While this analysis does not quantify actual dietary deficiencies experienced after the disasters in question, it highlights the potential extent of disaster loss for human nutrition and food security. See Boxes 1, 3, and Figures 10–14.



© UNICEF/UN 0119956/Врунн



© FAO/Granitica Contolini

TOP: Flooding, Cox's Bazar, Bangladesh 2017 | BOTTOM: Hurricane Matthew aftermath, Haiti 2016

Overview of production loss

Between 2008–2018, disaster-related loss recorded in crop and livestock production was USD 280 billion

One of the most direct ways in which disasters affect agriculture is through lower-than-expected production. This results in direct economic loss to farmers, which can cascade along the entire value chain, affecting the overall growth of the sector or national economies at large. Reduced production, therefore, remains not only the most direct measure of disaster impact, but also a strong indication of the scope and scale of that impact. Between 2008 and 2018, approximately USD 108.5 billion was lost as a result of declines in crop and livestock production in LDCs and LMICs following disasters. Across all income groups, including UMICs and HICs, loss amounts to USD 280 billion.

Loss over the period amounts to USD 30 billion for Africa (both sub-Saharan and North Africa), and slightly lower for Latin America and the Caribbean at USD 29 billion. Loss across the Caribbean SIDS amounts to USD 8.7 billion alone. For the same period, Asia experienced crop and livestock production loss valued at a notable USD 49 billion, with Southeast Asia and Southern Asia surpassing all other sub-regions at USD 20.7 and USD 25 billion respectively. The total estimated loss for the Pacific SIDS across Oceania is much lower in absolute terms at USD 108 million for the 2008–2018 time period.

Lost potential

As previously demonstrated in this report series, the extent and gravity of agricultural production loss becomes more evident and easily comparable across regions when presented in terms of share of potential production (Figure 3). In order to do this, the expected production under normal conditions is estimated for each commodity. The resulting difference between the expected and actual production in a disaster year represents the share of foregone potential production due to disasters.

For 2008–2018, loss from disasters accounts for 4 percent of potential crop and livestock production at the global level. **This is a significant amount, capable of causing perceivable production disruptions with severe impacts on international markets and global food supply. Furthermore, disasters often occur within a limited geographical area, where they may cause the complete destruction of local production or infrastructure. While not always felt at the national level, such impacts may fundamentally disrupt local livelihoods and food security in affected areas.**

Across North, Central, and Southern Africa, production loss reached a hefty 5–8 percent of overall potential production in each region

Apparent through this analysis is the tendency of some regions to experience overall larger share reductions of production despite having relatively lower aggregate loss in absolute terms, and *vice versa*. This is particularly the case across North, Central and Southern Africa, where production loss for the 2008–2018 period is USD 4 billion, 3 billion, and 1 billion respectively. However, this represents a hefty share of overall potential production, between 5–8 percent in each region, considerably higher than the global level. SIDS in both the Caribbean and the Pacific are a particular case at hand: low levels of loss in absolute terms translate to a large burden on the local agricultural sector, destroying up to 14 percent of potential production in the case of the Caribbean. On the opposite end of the spectrum lies Asia, where the extremely high volume of production loss represents a relatively small share of potential production, thereby suggesting that shocks caused by disasters can be more easily absorbed by the region's food production systems (Figure 3).

Figure 1. Total crop and livestock production loss in LDCs and LMICs, 2008–2018, USD billion

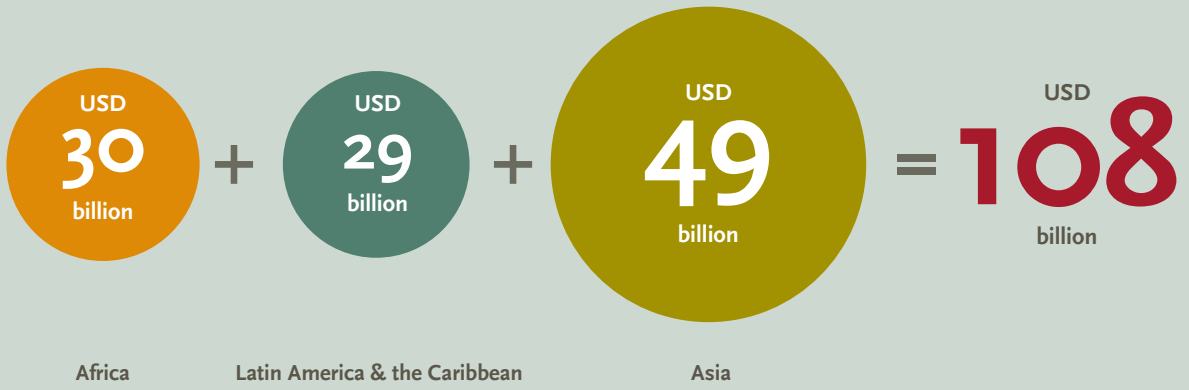


Figure 2. Regional distribution of crop and livestock production loss, 2008–2018

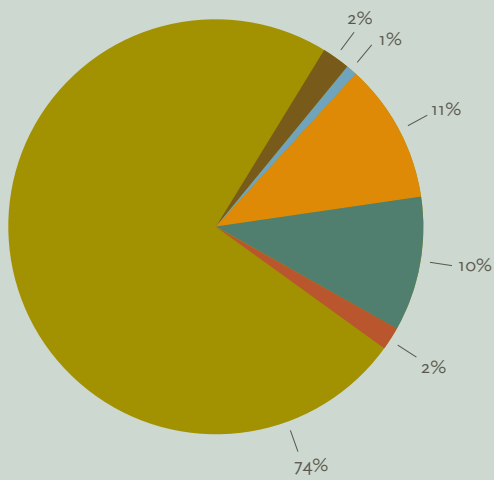
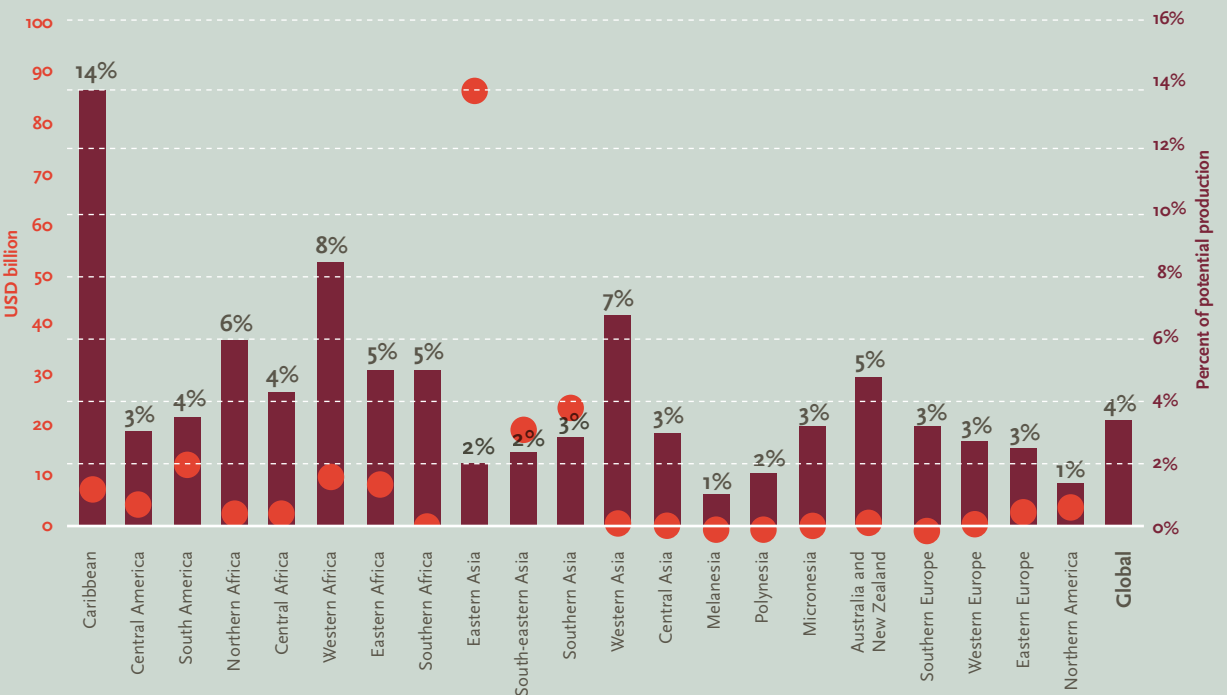


Figure 2 shows the scale of agricultural loss per region for all regions. The total loss is USD 280 billion, with a large share – 39 percent (USD 108.5 billion) – concentrated in the LDC and LMIC groups. On the other hand, Asia alone accounts for around 74 percent of all crop and livestock production loss (USD 207 billion).

A particular case in point is China, where disasters have cost over USD 153 billion over the 2008–2018 period, constituting 55 percent of global agricultural loss.

Legend: Africa, Latin America & the Caribbean, Northern America, Asia, Europe, Oceania

Figure 3. Crop and livestock production loss by region as percentage of potential production and in USD billion, 2008–2018



Legend: % Potential production, loss in USD billion

Zooming in on China

China suffered USD 153 billion in disaster-related agricultural loss 2008–2018

China sustained a cumulative agricultural loss of USD 153 billion over the 2008–2018 period, a staggering record as far as any single country is concerned. China accounts for 55 percent of overall loss at the global level, and an overwhelming 90 percent share of loss within the group of 15 UMIC and HIC countries considered in this analysis.

The magnitude of such loss is a consequence of the country's extremely high exposure to hazards and the vast scale of its agricultural operations – livestock production in particular.

China is among those countries that suffer disproportionately from disasters and climate related extreme events. Not only does its risk profile encompass almost every disaster on the books, but the frequency of their occurrence is also particularly accelerated (Global Facility for Disaster Reduction and Recovery, GFDRR, online utilities, 2019; Meiyuan *et al.*, 2015). Higher ocean temperatures – exacerbated by climate change – are leading to more severe typhoons, while colder winter temperatures are producing more blizzards; recent trends in increased drought episodes intensify land desertification.

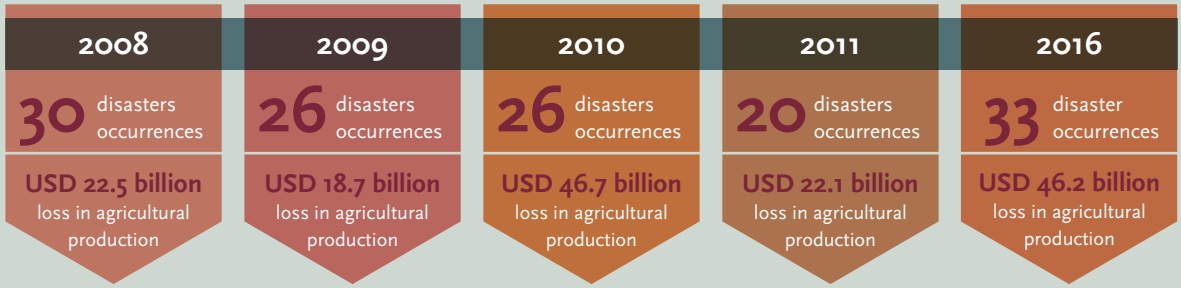
Within the scope of this report's analysis, China features a record high of 27 large- and medium-scale disaster events on average every year, nearly six-fold the average annual occurrences in countries of the UMIC and HIC group. The most destructive disasters, as far as agricultural loss is concerned, have been drought (causing around USD 28 billion in crop and livestock production loss), earthquakes and storms (each causing around USD 27 billion in agricultural loss respectively). Animal and plant pests and diseases have also been a costly occurrence, causing USD 18 billion in loss, mostly in livestock production.

China's overall economic loss from disasters amounts to an average of USD 111 billion every year (EM-DAT CRED). Of this, annual agricultural loss – at USD 15.3 billion on average – is bound to be significant considering the overall scale of the sector and its growth in recent decades. China's agriculture sector has undergone a rapid development over the past 70 years, with grain output expanding five-fold, reaching 658 million metric tonnes in 2018. Currently, agriculture production in China is capable of feeding around 20 percent of the world's population using less than 9 percent of the world's arable land (National Bureau of Statistics of China, 2019). Furthermore, the country has diversified domestic food supply by expanding its animal breeding industry. Against this background, China's high absolute value of agricultural loss translates to only 1.8 percent of its potential production. This is well below the average loss of 4 percent at the global level. Despite the large production volume forfeited to disasters every year, the relative size and scale of China's agriculture sector means that it can likely absorb and cushion any subsequent impacts on food availability, food security and nutrition.

Given China's extremely high exposure to disasters, the country has developed a comprehensive DRR agenda to reduce economic loss and strengthen resilience

The case of China, therefore, illustrates the dynamic nature of disaster impact, which is a function of exposure, vulnerability and coping capacity. While China's exposure levels are among the highest in the world, substantial investment in reducing vulnerabilities and developing coping strategies have helped buffer the negative impacts of frequent disasters in the agricultural sector. In addition, the country is already prioritizing a comprehensive DRR policy agenda to strengthen resilience and reduce loss. Moreover, China's active commitment to the international disaster risk reduction agenda – through the Sendai Framework and Agenda 2030 – offers a key opportunity for new partnerships around innovative DRR solutions.

Figure 4. Focus on China: highlights from China's agricultural loss profile




China's most damaging disasters, 2008–2018

2008 
Sichuan earthquake

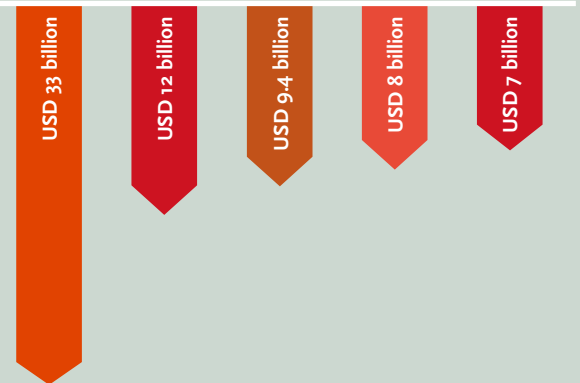
2009 
Typhoon Morakot
Xiapu, Fujian province

2010 and 2011 
Flooding in Yangtze River's
downstream provinces

2016 
Typhoons and
flooding across
southern and
central China

Most affected commodities – loss in USD billion, 2008–2018

 Pig meat  Vegetables  Sweet potatoes  Rice  Cow milk



Typhoon Morakot aftermath, Zhejiang province, China 2009

© REUTERS/Lang Lang

Disasters, across space and time

Worldwide, effective DRR policy and decision-making requires a grounded and multi-dimensional understanding of the economic impact of disasters on the agriculture sector. This involves knowing which disasters strike with the greatest impact and where. Over the 2008–2018 period, the following calamities have taken their toll on agricultural production systems of LDCs and LMICs across the world:

Globally, 82 percent of all drought impact is concentrated in the agriculture sector

→ **Drought** has previously been established within this report series as the single greatest culprit of agricultural production loss (FAO, *The Impact of disasters and crises on agriculture and food security*, 2017). It still is. Over 34 percent of crop and livestock production loss in LDCs and LMICs is traced to the occurrence of drought, costing the sector USD 37 billion overall. Moreover, as highlighted in the Introduction of this edition, drought impacts agriculture almost exclusively; it sustains 82 percent of all drought impact, compared to 18 percent in all other sectors. Agricultural drought risk assessment, therefore, lies at the core of overall drought risk management and is the prerequisite for the development of sustainable drought mitigation measures.

→ **Floods** are still the second gravest disaster for the agriculture sector, responsible for a total of USD 21 billion of the crop and livestock production loss 2008–2018 in LDCs and LMICs; this amounts to 19 percent of total loss.

→ **Storms** have nearly caught up with floods in this reporting period. This is particularly due to the 2017 Atlantic hurricane season, which was the costliest and one of the most hyperactive tropical cyclone seasons on record. It featured 17 named storms, 10 hurricanes, and six major hurricanes including Harvey, Irma, Maria and Nate. The latter was the worst disaster in Costa Rican history. Between 2008–2018, extreme storms such as tropical hurricanes have caused more than USD 19 billion in crop and livestock production loss, accounting for over 18 percent of overall loss.

The 2020–2021 desert locust crisis in East Africa and the huge production loss it caused calls for greater attention to food chain crises in the overall DRR context, and enhanced locust prevention and preparedness capacities

→ **Crop and livestock pests, diseases and infestations** are also an important stressor for the sector. Over the 2008–2018 period, such biological disasters caused 9 percent of all crop and livestock production loss. The 2020–2021 desert locust crisis in East Africa will likely exacerbate the role of biological disasters in production disruption, as the region braces itself for significantly reduced crop harvests and major pasture loss in arid and semi-arid regions.

→ **Wildfires** appear to be less impactful to agricultural production systems, responsible for just over USD 1 billion or 1 percent of loss. This, however, accounts for only the damage caused to crop and livestock production; it does not incorporate loss incurred in the forestry sector, in terms of timber and other systems. The impact of ravaging wildfires scorching through millions of acres across California (2017), Greece (2018), the Amazon (2019), and Australia (2019–2020), to name a few, is likely to be enormous. Chapter 2 sheds more light on methodological solutions for assessing damage and loss from disasters in that sector.

Drought is the most destructive force for agriculture, causing USD 37 billion in crop and livestock production loss 2008–2018

In line with global tendencies, at the regional level drought continued to be the main disaster stressor for crop and livestock production in Africa (Figure 6), accounting for over USD 14 billion in production loss over the 2008–2018 period. The second most costly disasters on the continent were pests and diseases, which resulted in cumulative loss of USD 6.5 billion over the period. Drought was also the most destructive disaster to hit agriculture in Latin American and the Caribbean, causing a total of USD 13 billion in crop and production loss. Second in line are storms, which also have a significant occurrence for the region, inflicting loss of USD 6 billion between 2008–2018. Meanwhile in Asia, geophysical disasters emerge as an important threat, causing USD 11.4 billion of crop and livestock loss in the region. Floods and storms have also taken a large toll in Asia, causing around USD 11 billion and USD 10 billion in loss respectively during the 2008–2018 period.

Figure 5. Total crop and livestock production loss per disaster type, LDCs and LMICs, 2008–2018

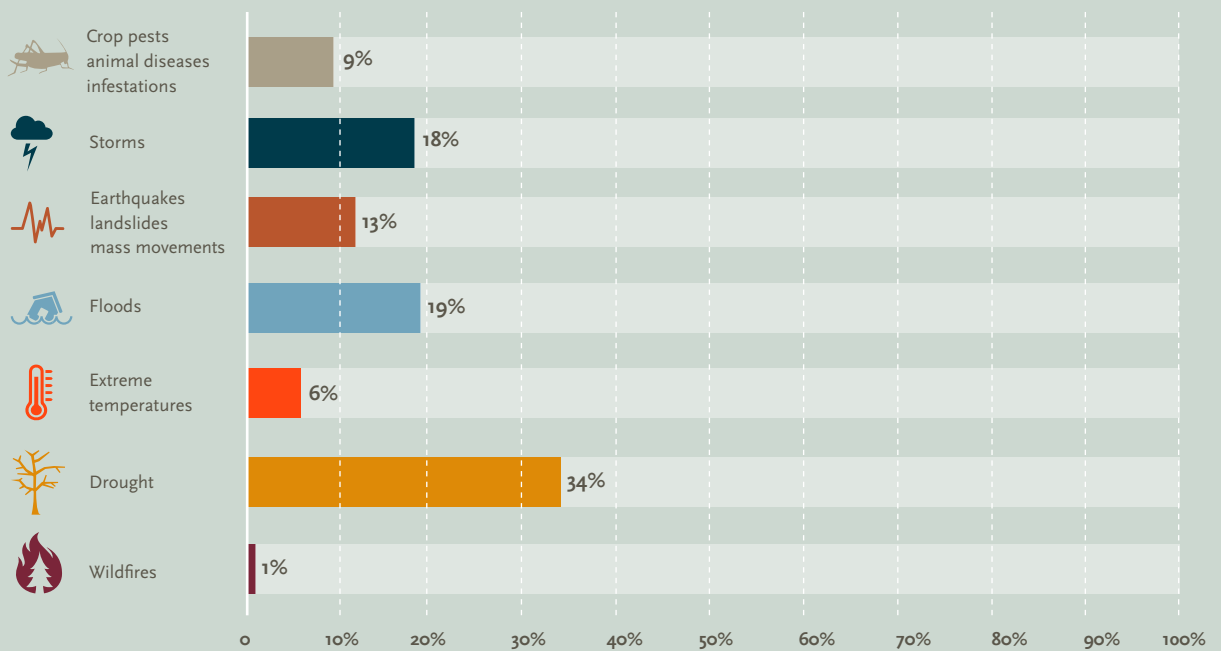
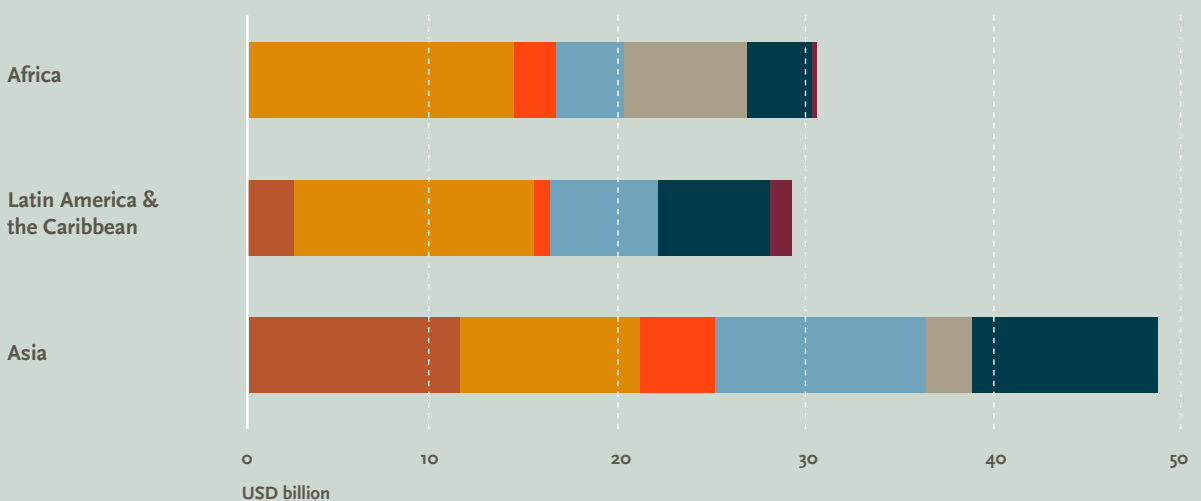


Figure 6. Total crop and livestock production loss by region and per disaster, LDCs and LMICs, 2008–2018



Legend: Earthquakes/landslides/mass movements, Drought, Extreme temperature, Floods, Crop pests/animal diseases/ infestations, Storms, Wildfires

On a year-by-year basis, disastrous events have inflicted a consistently high loss on crop and livestock production in LDCs and LMICs. The impact peaked at over USD 20 billion in 2012 – reflecting the compound effect of the particularly destructive Atlantic hurricane seasons and the prolonged Sahel drought – and again in 2015, following a series of devastating events across Asia. While loss in 2018 appears to have slowed down versus 2016, the overall trend is one of volatility and irregularity (Figure 7). This calls for a dynamic and flexible approach to DRR – especially in LDCs and LMICs – which can ensure preparedness in an uncertain and rapidly changing disaster context.

Figure 7. Total loss in crop and livestock production, developing countries in all three regions, 2008–2018, USD billion

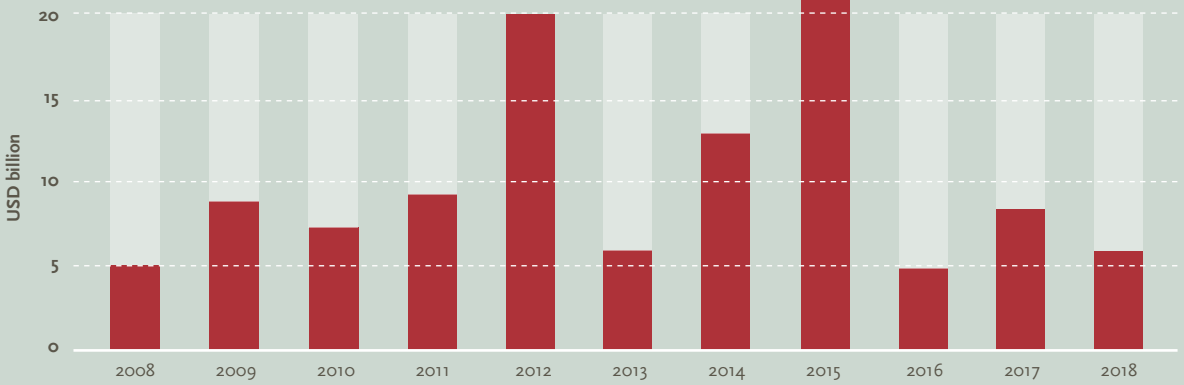
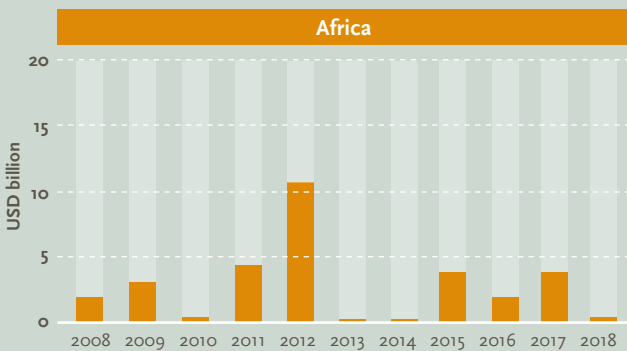
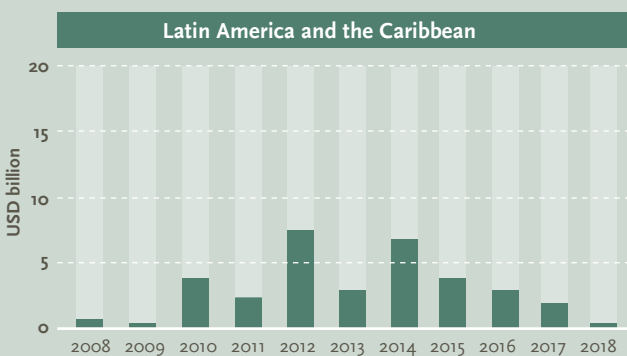


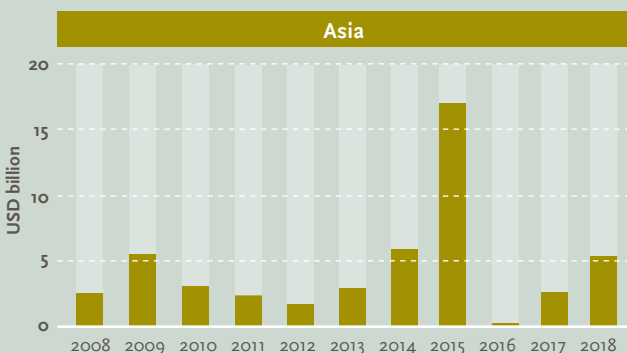
Figure 8. Total loss in crop and livestock production by year, 2008–2018



In Africa – both sub-Saharan and the North – crop and livestock loss tends to fluctuate widely, with peaks spread across the period in 2011, 2012, 2015 and 2017. These spikes in loss are mostly driven by recurring drought episodes in the Sahel and Horn regions, while both drought and floods in Southern Africa are behind the 2015 figures.

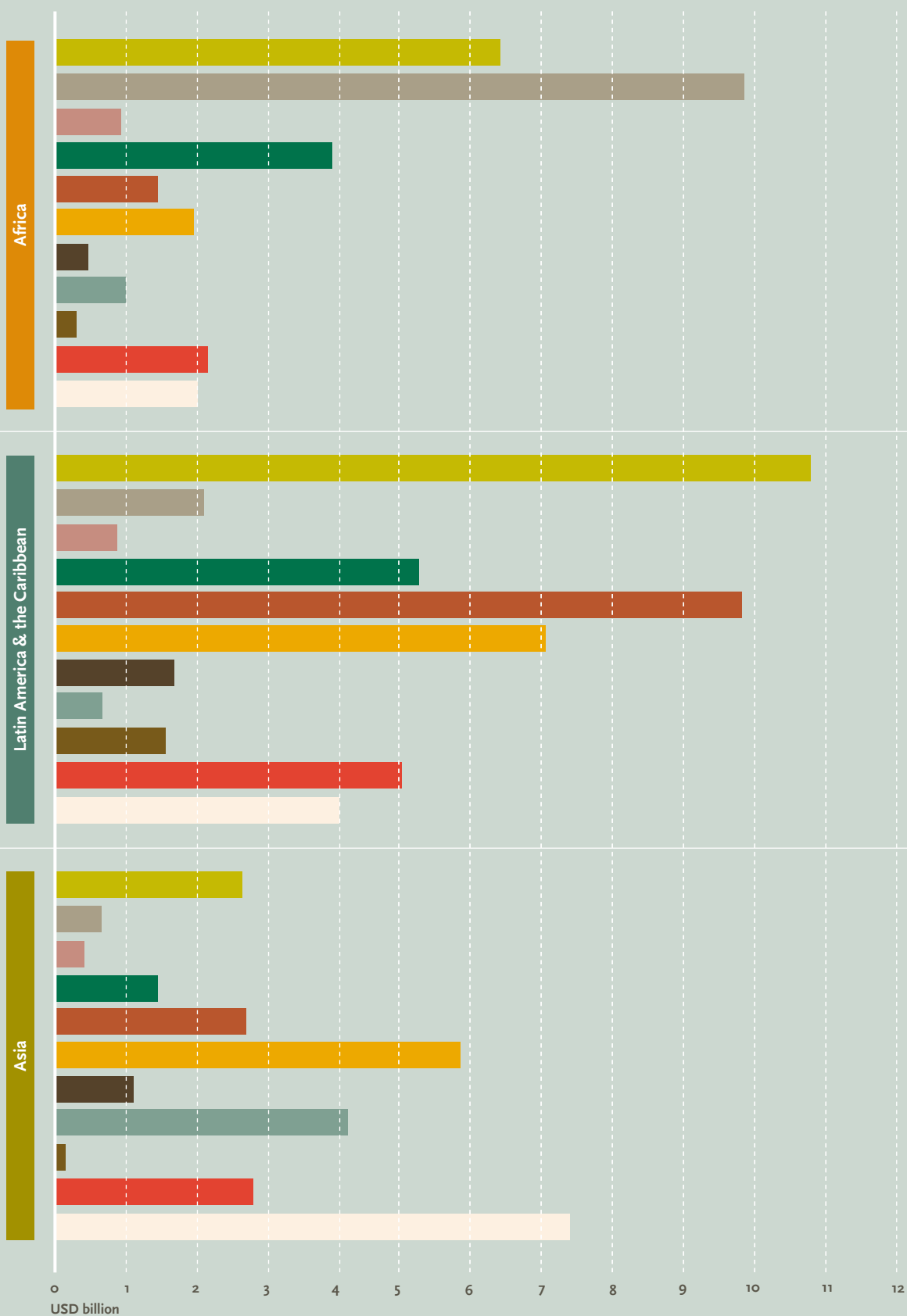


In Latin America and the Caribbean, significant loss was incurred mid-decade with pronounced peaks in 2012 and 2014. These reflect severe La Niña-related drought episodes, which ravaged crop harvests in Argentina and Brazil in 2012 and much of Central America in 2014. Since 2015 however, the region is on a positive path of decreasing agricultural loss.



In Asia, the overall loss in agricultural production is comparatively higher. A distinct peak in 2015 reflects a series of massive disasters across the region, i.e. the Nepal earthquake, monsoon flooding in Myanmar, Bangladesh and India, and widespread flooding in Chennai, India.

Figure 9. Production loss by commodity group, LDCs and LMICs, 2008–2018, USD billion



Disasters have a varying impact on different commodities across regions (Figure 9). The distribution of loss across commodity groups largely reflects its relative importance in the production mix of each country, as well as the vulnerability of their production systems. Over the 2008–2018 period, the production of roots and tubers – such as potatoes, sweet potatoes, cassava and yams – sustained the highest loss in Africa, amounting to just over USD 10 billion. Cereal production loss followed at USD 5 billion, while the production of coffee, tea and spice crops was relatively unscathed by disasters. In Asia, cereal production stands out with a cumulative loss of about USD 11 billion over the decade. Rice and wheat were among the commodities most affected. Furthermore, disasters in Asia had a serious impact on production of fruit (loss of USD 10 billion), oilseeds (loss of USD 7 billion) and vegetables (loss of about USD 5 billion). On the other hand, disasters striking across Latin America and the Caribbean mostly affected the livestock sector, causing a loss of just under USD 7 billion in milk, eggs and honey production.

Trade flows can change after disasters as countries compensate for declines in crop and livestock production

The impact of disasters on agriculture extends beyond production loss alone. Declines in crop and livestock production after disasters can trigger sudden changes in agricultural trade flows. As countries try to compensate for domestic loss, they increase import expenditures and reduce export revenues. For some cases in Africa, the compensatory increase in imports has been as high as half the loss (FAO, 2018). Furthermore, the general deterioration of production and trade balances following large and medium-scale disasters can exert tangible impacts across the food value chain with overall adverse consequences on sector growth, agro-industries and ultimately national economies.

In a similar vein, reduced production and productivity may also have far-reaching repercussions on food systems. Disasters have the potential to affect all dimensions of food security and nutrition – food availability, access, utilization and stability. The association between extreme events and food security and nutrition indicators corroborates this.



© Paul Langrock Greenpeace



© REUTERS/Mike Hutchings

TOP: Drought-stricken Westerwald, Germany 2020 | BOTTOM: Drought, South Africa 2019

Disaster impacts on food security and nutrition

Annual occurrence of disasters is now more than three times that of the 1970s and 1980s

As previously established, disasters are occurring at a persistently high frequency, with more than triple the number of annual occurrences, compared to the 1970s and 1980s. Their economic impact is relentlessly increasing. Most notably, climate- and weather-related disasters and floods have been rising disproportionately in both incidence and gravity. This is a testimony to the climate variability and weather extremes experienced on a daily basis, and of the underlying climate change tendencies that may be causing these shifts. The large volume and economic value of agricultural production loss associated with disasters can pose tremendous problems for national food systems. Depending on trade balances and other factors, food availability can be reduced while access to available food may also be restricted during the physical aftermath of disasters. This disaster-triggered diversion may result in interruptions in the normal food supply and, coupled with inefficiencies in food systems, ultimately cause conditions of food insecurity at the national or local levels.

In LDCs and LMICs, 2008–2018, crop and livestock production loss equates to the annual calorie intake of 7 million adults

Agricultural production loss expressed in dietary energy equivalent

An indication of the potential repercussions on food security and nutrition from disaster-induced reduced production can be derived by converting the volume of loss into calories and essential minerals. The crop and livestock production loss in LDCs and LMICs between 2008 and 2018 converts to a total of 6.9 trillion kilocalories per year.¹ This equates to the annual calorie intake of 7 million adult persons.²

In Africa, that period's accumulated post-disaster production loss amounts to an annual dietary energy supply of 204 000 calories, or 82 days of calorie intake, per capita per year.

In Latin America and the Caribbean, crop and livestock production loss converts to an alarming average annual loss per capita of 355 000 calories, or 142 days of calorie intake. Despite manifesting the lowest monetary loss of the three regions (USD 29 billion), LAC appears to be more vulnerable to the potential dietary implications that flow from it. This is corroborated by the region's commodity loss profile, which shows the majority of loss was concentrated in higher-calorie commodities, such as milk and dairy, honey, oilseeds and sugar corps (Figure 9).

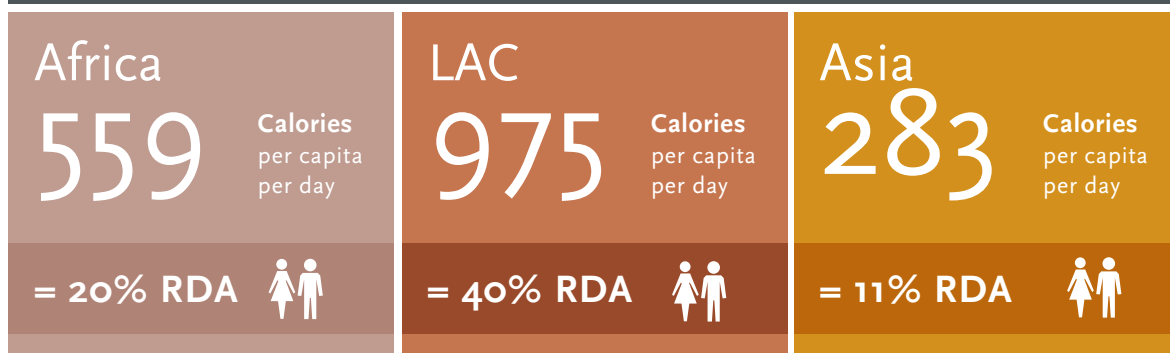
Box 1. Calculating nutrient loss

The estimates of calorie and essential nutrient loss are based on deriving the nutritional values of the volume of crop and livestock production loss. The loss quantities were converted into calorie equivalents and their respective iron, zinc, calcium and vitamin A contents were identified. The USDA National Nutrient Database for Standard Reference was used to obtain the nutrient composition data for each commodity in the analysis.

The resulting estimates account for the calories, iron, zinc, calcium and vitamin A in raw edible food, postharvest, which would have been available for human consumption if not for disaster impact. These figures were not adjusted for cooking and processing loss, loss during inadequate storage, food waste and other farm-to-fork causes of calorie and nutrient loss.

¹ FAO analysis using data from FAOSTAT, EM-DAT CRED and USDA.
² Based on a recommended dietary allowance (RDA) of 2 500 calories.

Figure 10. Disaster-induced production loss equivalent, expressed in average daily dietary energy supply per capita, 2008–2018



On the other hand, Asia – despite having the highest level of monetary loss overall (USD 49 billion) – displays a relatively lower equivalent in average annual calorie loss per capita: 103 000 calories, or 41 days of dietary energy supply. This corresponds to a loss of about 283 calories per capita every day, or 11 percent of the Recommended Daily Allowance (RDA).³ This reflects the relatively low share of losses in the region, compared to overall and potential production: for most parts of Asia, the share of production loss is around 2 percent, or half of the global 4 percent level (Figure 3). Furthermore, the most affected commodities in the region are relatively less calorie-dense cereals, fruit and vegetables, while meat and dairy losses have been relatively low.

Agricultural production loss expressed in essential nutrient equivalents

This speculative assessment reveals – for the first time – how disaster-related production losses can yield significant negative nutritional outcomes

Calories alone do not constitute a comprehensive measure of dietary sufficiency. Among the plentiful research and information available on food security and nutrition in relation to agricultural production, the quantification of nutrient loss remains largely unexplored. Meanwhile dietary deficiencies and inadequate supplies of essential nutrients – sometimes referred to as ‘hidden hunger’ – are among the perpetuating factors behind malnutrition and food insecurity. Vitamin A deficiency remains prevalent across LDCs and LMICs and is suspected of being responsible for the deaths of millions of children every year. Because they comprise enzymes and control key chemical reactions, minerals such as iron (Fe), zinc (Zn) and calcium (Ca) are essential to the body’s normal functioning. Zinc deficiencies may result in stunting and poor mental development in children.

Quantifying the nutritional value of agricultural production loss by converting it to the full nutrient profile of the affected crop and livestock commodities provides insight into the potential impact of disasters on human nutrition further down the food chain. This is a speculative and indicative assessment and, as such, does not provide evidence on the actual trends in diets. Whether lost production would have otherwise materialized into nutritious food depends on multiple factors, such as food safety considerations, storage, transportation costs, etc. Therefore, these results are not intended to, and do not, estimate the actual nutrition and calorie deficits created by crop and production loss following disasters. They do, however, reveal for the first time how disaster-related production losses can translate into significant – and negative – nutritional outcomes. Conversely, this analysis highlights the positive nutritional contributions that can be achieved through DRR and greater resilience in agriculture.

³ RDA is the average daily level of intake sufficient to meet the nutrient requirements of most (97–98 percent) healthy people.

Iron⁴

Crop and livestock production loss in LDCs and LMICs 2008–2018 converts to 994 trillion milligrams (mg) of iron, an average of 256 billion mg per year. This corresponds to the annual recommended iron intake of 78 million adult men or 47 million adult women.⁵

In Africa and LAC, agricultural production loss converts to an annual average of 8 500 mg and 10 000 mg of iron per capita respectively. This is more than three times the recommended annual iron intake for an adult male and just under two times that for an adult female. In Asia, loss converts to the much lower annual average of 4 000 mg per capita, or about 120 percent of the recommended annual iron intake for an adult male and 73 percent of that for an adult female. Daily breakdowns are provided in Figure 11.

Zinc⁶

Agriculture production loss in LDCs and LMICs 2008–2018 converts to 21 trillion mg of zinc, or an average of 177 billion mg per year. This corresponds to the annual recommended zinc intake of 50 million adult women or 36 million adult men.⁷ On a per capita basis, the amount of potential zinc loss for Africa and LAC is at least double that of Asia. Daily breakdowns by region are provided in Figure 12.

Calcium⁸

Crop and livestock production loss caused by disasters in LDCs and LMICs 2008–2018 converts to a total of 494 trillion mg of calcium. This is equivalent to the annual recommended calcium intake of 9 million people.⁹

This is the equivalent of 100 000 mg of calcium per year per capita, roughly a third of the annual recommended calcium intake for an adult male or female. Regionally, this translates to an average annual per capita calcium loss of 107 000 mg in Africa and 155 000 mg in LAC. In Asia, the repercussion of production loss is again relatively lower: 51 000 mg of calcium on average per year per capita. Daily breakdowns are provided in Figure 13.

Vitamin A¹⁰

Agricultural production loss in LDCs and LMICs 2008–2018 converts to a total of 994 trillion micrograms (mcg) of vitamin A, or an average of 7 trillion mcg every year. This corresponds to the annual recommended vitamin A intake of 21 million adult men or 27 million adult women.¹¹

On a per capita basis, production loss from crop and livestock commodities in LDCs and LMICs for the period corresponds to an annual average vitamin A intake of just over 200 000 mcg, or 288 days for an adult woman and 220 days for an adult man. Daily breakdowns by region are provided in Figure 14.

4 FAO analysis using data from FAOSTAT, EM-DAT CRED and USDA.

5 Based on an RDA of 9 mg of iron per day for adult men and 15 mg for adult women.

6 FAO analysis using data from FAOSTAT, EM-DAT CRED and USDA.

7 Based on an RDA of 11 mg of zinc per day for adult men and 8 mg for adult women.

Figure 11. Disaster-induced production loss equivalent, expressed in average daily iron supply per capita, 2008–2018

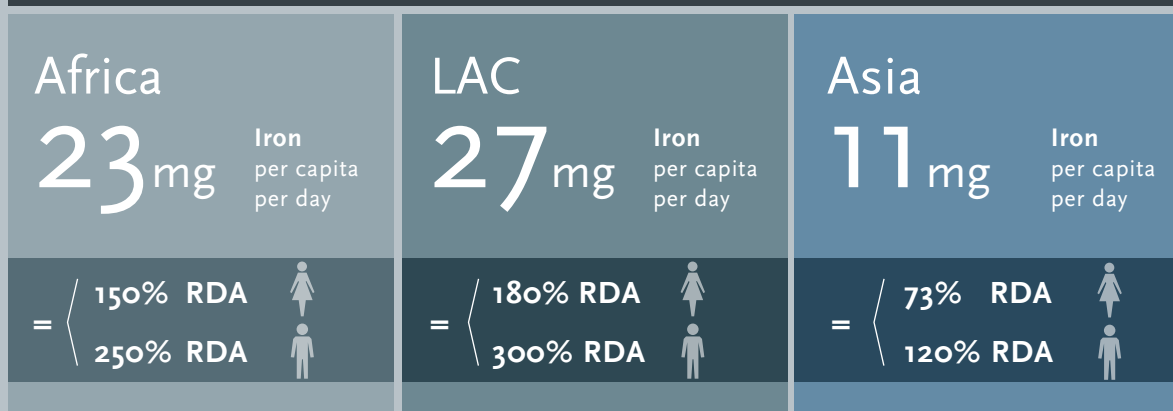


Figure 12 Disaster-induced production loss equivalent, expressed in average daily zinc supply per capita, 2008–2018

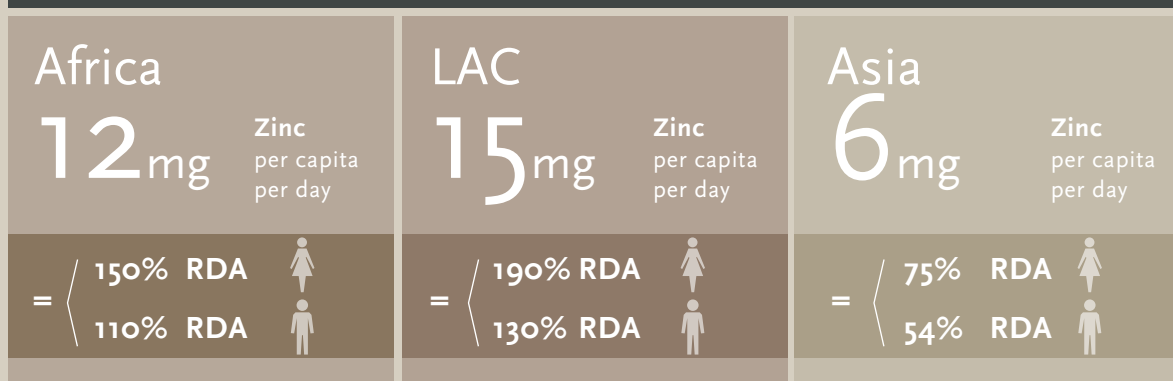


Figure 13 Disaster-induced production loss equivalent, expressed in average daily calcium supply per capita, 2008–2018

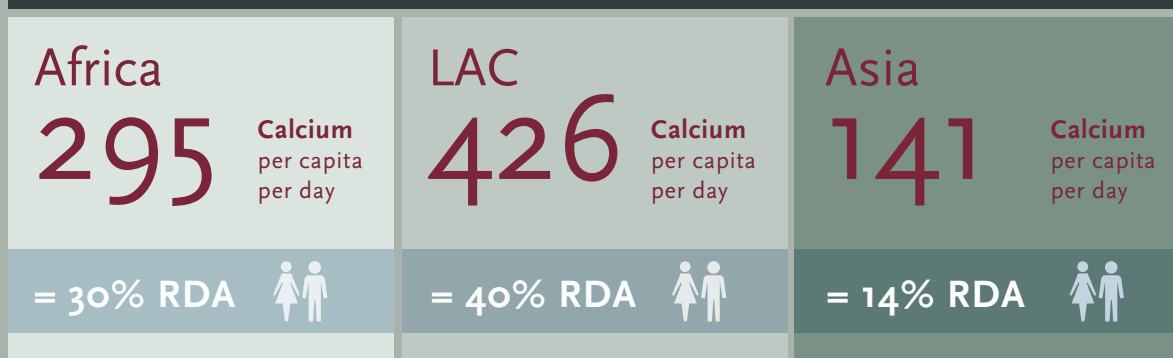
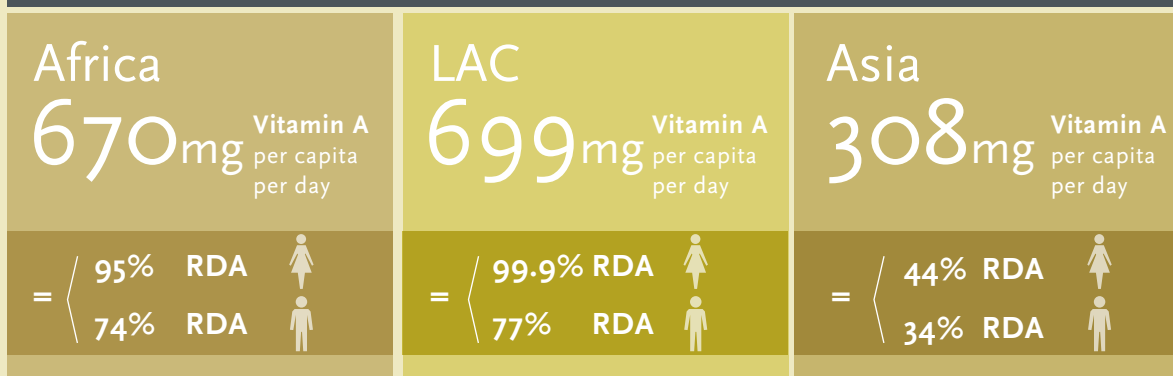


Figure 14 Disaster-induced production loss equivalent, expressed in average daily vitamin A supply per capita, 2008–2018



8 FAO analysis using data from FAOSTAT, EM-DAT CRED and USDA.

9 Based on an RDA of 1 000 mg of calcium per day for both adult men and women.

10 FAO analysis using data from FAOSTAT, EM-DAT CRED and USDA.

11 Based on an RDA of 900 micrograms of vitamin A per day for adult men and 700 micrograms of vitamin A for adult women.

Food security and nutrition after disasters: shaping the narrative

The analysis of the direct relationship between disasters and nutrition provides a valuable lens for understanding the fallout from disasters and extreme events as being more extensive and complex than the impacts on productivity alone. It sheds light on the fact that production loss does not mean merely lost farmer income, but also implies foregone calories and nutrients. On average, 22 percent of daily calorie intake is lost from disasters in LDCs and LMICs. The loss-equivalents in main essential nutrients are staggering (Figures 10 through 14). In a world where more than 690 million people do not have enough to eat (FAO, 2020), forfeits in nutrition potential of this magnitude can have far-reaching detrimental consequences, such as long-term development setbacks, loss of income potential, erosion of social capital and instability.

To effectively address the challenges disasters, extreme events and climate variability pose to food security and nutrition, it is important to consider the magnitude and interplay of their diverse direct and indirect impacts. These can flow through various channels, further exacerbating basic triggers of food insecurity and malnutrition. Drought illustrates this dynamic. Drought can directly undermine crop yields and livestock health, resulting in lower food production and availability. Through indirect channels, drought-related crop failures can further hinder access to food, e.g. if food prices rise significantly. The cumulative effect of these direct and indirect impacts leads to a downward spiral of increased food insecurity and nutrition.

Production loss does not mean merely lost farmer income, there is a direct relationship between disasters and foregone calories and nutrients

Moreover, production loss of the magnitude shown in this chapter inevitably translates into income loss for farmers whose livelihoods depend primarily on agriculture. Coupled with the customary high food price volatility following disasters, this is likely to significantly impact farmers' ability to access food. Women and children are particularly vulnerable to the wide-ranging impact of disasters on production, food security and nutrition. Disasters and climate extremes can compromise maternal health and childcare practices as production loss creates food shortages and nutritional insufficiencies. While anecdotal case-based evidence exists, further analysis is needed to shed light on the gender perspective of the nutritional aspects of disaster impacts in agriculture and food security.

As LDCs and LMICs become increasingly exposed to extreme weather events and climate change, the vulnerability of their agricultural systems may lead to compromised food availability and poor nutrition outcomes. The calorie and nutrient loss figures presented in this chapter are a first illustration of the extent of the full spectrum of impacts, in static conditions. The vulnerability of agricultural production systems, food supply chains and natural resource-based livelihoods to disasters merits a high profile on the global policy-making agenda.

Disasters and climate extremes compromise maternal health and childcare practices as production loss creates food shortages and nutritional insufficiencies

The far-reaching repercussions of disasters for food security and nutrition requires scaled-up cross-sectoral actions along the entire food chain in order to strengthen the resilience of food systems against hazards and weather extremes. The above analysis suggests that scale, diversification, cohesion and responsiveness are key features that support resilience of agricultural production and agri-food value chains. Such actions should be based on integrated disaster risk reduction and management, climate change adaptation and sustainable production policies, programmes and practices with a short-, medium- and long-term vision. Moreover, the vulnerability of food production systems highlights the fact that traditional DRR, DRM and adaptation are not without limits or challenges. This necessitates the transformation of systems themselves in a manner that leads to increased resilience and improved food security.

Targeted nutrition objectives should be included in national resilience and DRM policy frameworks

Furthermore, it is important to strengthen the legislative, policy and governance environment in order to maximize the nutritional impact of measures designed to improve resilience. Targeted nutrition objectives should be embedded in national resilience and DRM policy frameworks, including development policies related to specific hazards and risks such as climate change. This will ensure that the needs of the most vulnerable are addressed, and that resilience-building and DRM programmes cater to people's nutritional status. Universal synergies should be sought between resilience/DRM strategies and multisectoral food and nutrition security policies and planning processes.

Towards transformative frameworks, policies and programmes for resilient agriculture

As the data presented above render apparent, the time is ripe to accelerate collective action to strengthen resilience and adaptive capacity to the impacts of disasters and climate change-induced extreme events. There is a substantiated need to improve agricultural resilience on a comprehensive scale, covering agricultural livelihoods, production, food systems and nutrition. But innovative and integrated disaster resilience strategies, programmes and investments ought to tackle not only the direct impacts but also the underlying vulnerabilities, which are established through other development priorities, and often aggravated by climate change.

Regardless of the context, governments are faced with the mounting challenges of establishing coherent measures to prevent and reduce disaster risk, while addressing increased impacts of climate change. They are guided by the comprehensive architecture of the current global policy platforms – i.e. the Sendai Framework for Disaster Risk Reduction 2015–2030, the 2015 Paris Agreement, the 2015 Addis Ababa Action Agenda, the 2016 World Humanitarian Summit, the UN Decade of Action on Nutrition (2016–2025), as well as the overarching 2030 Agenda for Sustainable Development. During the push to operationalize their directives and guidelines, greater integration between these global frameworks must remain a priority. This will ensure that coordinated actions across countries, regions and sectors achieve correlating, transformative objectives and outcomes. For agriculture, this ultimately holds the promise of achieving significant reductions in disaster impacts in the foreseeable future.

The comprehensiveness of the food system needs to be understood, including how it can be transformed to address disaster and climate risk through sustainable, environmentally-, nutrition- and health-sensitive action

Policy makers must be mindful of the key determinants for the success or failure of resilience programmes and interventions. Systematic and multi-hazard risk assessments are fundamental for understanding risk and its impacts across agriculture, food security and nutrition. Data is critical for identifying key needs and vulnerabilities and designing the appropriate solutions. Participatory, inclusive and equitable gender-based approaches must guide the entire resilience policy, programme or investment cycle, while placing vulnerable groups at the centre of responses. The comprehensiveness of the food system needs to be understood, including how it can be transformed to address disaster and climate risk through sustainable, environmentally-, nutrition- and health-sensitive action.

The international community is facing a complex risk landscape, characterized by cumulative or cascading disasters, climate change, environmental degradation, pandemics, conflict, protracted crises, and forced displacement and migration. This begs for a re-evaluation of the goals, objectives and modalities of resilience building and DRR/DRM programming in fragile countries. An important example of food security and nutrition policy making, the CFS Framework for Action for Food Security and Nutrition in Protracted Crises (CFS-FFA) provides a set of concrete guidelines to tackle key underlying vulnerability factors in a crisis context.

CFS-FFA represents the first global consensus on mitigating threats to food security and nutrition during protracted crises

It further identifies protracted crises as situations requiring special attention, whereby appropriate responses differ from those required in short-term crises or in non-crisis contexts. The CFS-FFA represents the first global consensus on how to mitigate the threat to food security and nutrition during protracted crises.

Box 3 highlights malnutrition in the context of food crises.

Overall, reducing disaster-related loss in agricultural production and making real progress in strengthening overall livelihoods, resilience policies, programmes and investments requires cross-sectoral evidence-based grounds as well as the willingness and ability to address systemic risk in an integrated and comprehensive way. The approach should remain inclusive and participatory, while better combining humanitarian and development strategies to address the needs of vulnerable groups.

Box 2. Calculating production – approach and analysis

Agriculture loss from disasters between 2008–2018 is estimated by analysing trends in crop and livestock production flows and associated deviations following disasters that occurred over the period.

The analysis covers 457 disasters in 109 countries: 389 disasters in 94 LDCs and LMICs across Africa, Latin America and the Caribbean, Asia and the Pacific; and 68 disasters in 15 UMICs and HICs across all regions. It is global in the sense that it includes every country that registered a disaster-related change in production. Furthermore, the analysis considers the crop and livestock sector as a whole, looking at every reported commodity produced in each country (an average of 125 commodities per country). Finally, both large- and medium- (to small-) scale disasters are considered. Hazardous events considered are those that have affected 100 000 people or more, or at least 10 percent of the national population.

It is important to underline that using deviations from trends in production as estimates of production loss implies a number of strict assumptions and several limitations. Agricultural production is subject to significant year-to-year variability for reasons that are unrelated to the occurrence of disasters. By and large, annual production of each commodity can vary due to market trends and expected demand, normal climate variability, disease outbreaks or other immediate reasons at regional, national or local level. The use of ‘expected’ production as a starting point to measure the impact of disasters on production implies that none of these non-disaster-related factors would have significantly affected production in the absence of a disaster. Moreover, deviations from production trends can be both positive and negative. Only negative trends are considered in this analysis, as the aim is to document the overall decreases in production occurring as a consequence of disasters.

Finally, the procedure employed assumes a disaster’s impact on production is entirely exhausted in the same year in which the disaster occurs, and disregards cumulative impacts that may occur over more than one year. While this assumption is consistent with the emphasis on loss as opposed to damage, it can still be problematic for certain products, such as perennial crops. Despite such limitations, this approach represents a good and viable option to run large-scale comparative assessments in the absence of more accurate data.



Food and nutrition security, Aklan, Philippines 2016

Box 3. Nutrition in food crises

The 2020 Global Report on Food Crises analysed data from 55 countries and territories experiencing food crises in 2019. These countries hosted 135 million people in crisis or worse, i.e. Integrated Food Security Phase Classification/Cadre Harmonisé (IPC/CH) Phase 3 or above. It is estimated that, in these countries, 17 million children under five years of age suffer from acute malnutrition (wasting) while 75 million children suffer from chronic malnutrition (stunting).

During crises, food production, storage, processing, distribution and markets may be disrupted, making it more difficult to meet individual dietary needs. Fewer than 20 percent of children 6 to 23 months old received the minimum dietary diversity in the ten countries experiencing 2019's worst food crises, namely Yemen, the Democratic Republic of Congo, Afghanistan, the Bolivarian Republic of Venezuela, Ethiopia, South Sudan, the Syrian Arabic Republic, Sudan, Nigeria and Haiti.

Using Demographic and Health Surveys (DHS) and other data, the report shows that limited dietary diversity can also increase the risk of micronutrient deficiencies. Among them, iron deficiency is the most common cause of anaemia. In Ethiopia, for instance, over half (57 percent) of children under the age of 5 and nearly one in four (24 percent) women ages 15 to 49 are anaemic (DHS 2016). In Nigeria, anaemia is one of the major malnutrition concerns, as more than two-thirds of children ages 6 to 59 months (68 percent) and more than half of women of reproductive age (58 percent) are anaemic (DHS 2018). This problem reaches even higher levels in Yemen, where 83 percent of children ages 6 to 59 months and 70 percent of reproductive-age women suffer from anaemia.

Likewise, in food-crisis countries, lack of safe water and sanitation increases the likelihood of disease outbreaks, another direct determinant of nutritional status. People usually also have limited economic access to health services or health systems have collapsed, resulting in a lack of infrastructure, medicines, equipment or trained staff. High rates of illness compromise the nutritional status of the population, particularly children and pregnant and lactating women.



Forest fires, Krasnoyarsk region, Siberia, Russian Federation 2020



Chapter II

Disasters and forests: unpacking a complex relationship

Forests have a central role to play as the world confronts the challenges of climate change, disaster risk, food security, and improving livelihoods for a growing population. Disasters caused by extreme weather events, fires, outbreaks of animal and plant pests, conflicts, civil unrest and displacement often result in forest degradation and deforestation. Yet the impact on forests is often unclear and unreported. This chapter highlights an improved methodology for assessing disaster-related forest damage and loss. It also demonstrates the role of forests in disaster prevention, mitigation and post-disaster reconstruction and recovery.

Forests: a tale of strengths and vulnerabilities

Forests worldwide are facing unprecedented pressure from the growing occurrence of natural hazard-induced disasters, even as they buttress surrounding communities and ecosystems from the harmful effects of climate change

2019 was a year when the world burned. In the Amazon, California and Australia, forest fires burned millions of hectares (ha). These are not uncommon occurrences historically, but evidence suggests climate change is making fires more frequent and intense. Wildfires – together with pests, disease, invasive species, storms, hurricanes, drought, floods, and landslides – have a major impact on forests and forestry activities. Inevitably, such disasters disrupt the supply of forest products and environmental services, threatening the subsistence and livelihoods of local communities and forest industries. They can trigger unprecedented pressure on forests, with survivors and displaced people resorting to the over-exploitation of forest resources for food, timber, woodfuel, fodder and even clearing forest areas for agriculture.

Forests have a complex relationship with both disasters and climate change. Deforestation accounts for nearly 20 percent of global carbon emissions through clearing, overuse or degradation of trees. On the other hand, healthy forests act as carbon sinks, absorbing and storing about one-tenth of projected annual global carbon emissions into their biomass, soils and products. The combined absorption capacity of the world's forests is estimated at 2.6 billion tonnes of carbon dioxide per year, which is equivalent to a third of the carbon dioxide released from burning fossil fuels.

While forests endure substantial damage from growing disaster occurrence worldwide, they also hold a strong potential for mitigation and recovery. Forested land in hazard-prone areas plays a crucial role in reducing the severity of disasters such as tsunamis and tidal waves, and promotes the speedy rehabilitation of affected populations. Furthermore, forest ecosystems play an important role in reducing the overall vulnerability of communities to disasters, both in terms of limiting their physical exposure to natural hazards and providing them with the livelihood resources to withstand and recover from crises. The degradation of forest ecosystems and their exposure to destructive forces, such as wildfires and invasive species, are exacerbating vulnerabilities around the world.

Two destructive forces: conflagrations and infiltrations

Wildfires in a hotter, drier world

In 2019, forest fires were responsible for more than 1.8 gigatonnes of carbon emissions, nearly the emission rate of international transportation

Fires roar across the Amazon every year during its 'fire season' (June–November). In August 2019, the number of blazes reached a nine-year high, sparking an international crisis. The tropics lost 11.9 million hectares of tree cover in 2019 with a third of that loss occurring in the humid tropical primary forest, which is particularly important for biodiversity and carbon storage. An estimated 1.8 gigatonnes of carbon emissions are attributable to the 2019 primary forest loss, nearly equivalent to the annual emission rate of international transportation. Despite global and localized mitigative and preventive measures, primary forest loss due to fires was 2.8 percent higher in 2019 compared to 2018, continuing the consistent rise witnessed throughout the two prior decades (Weisse & Goldman, 2020, *Global Forest Watch*).

Over the past decade, the most damaging fires have been associated with heat waves and drought

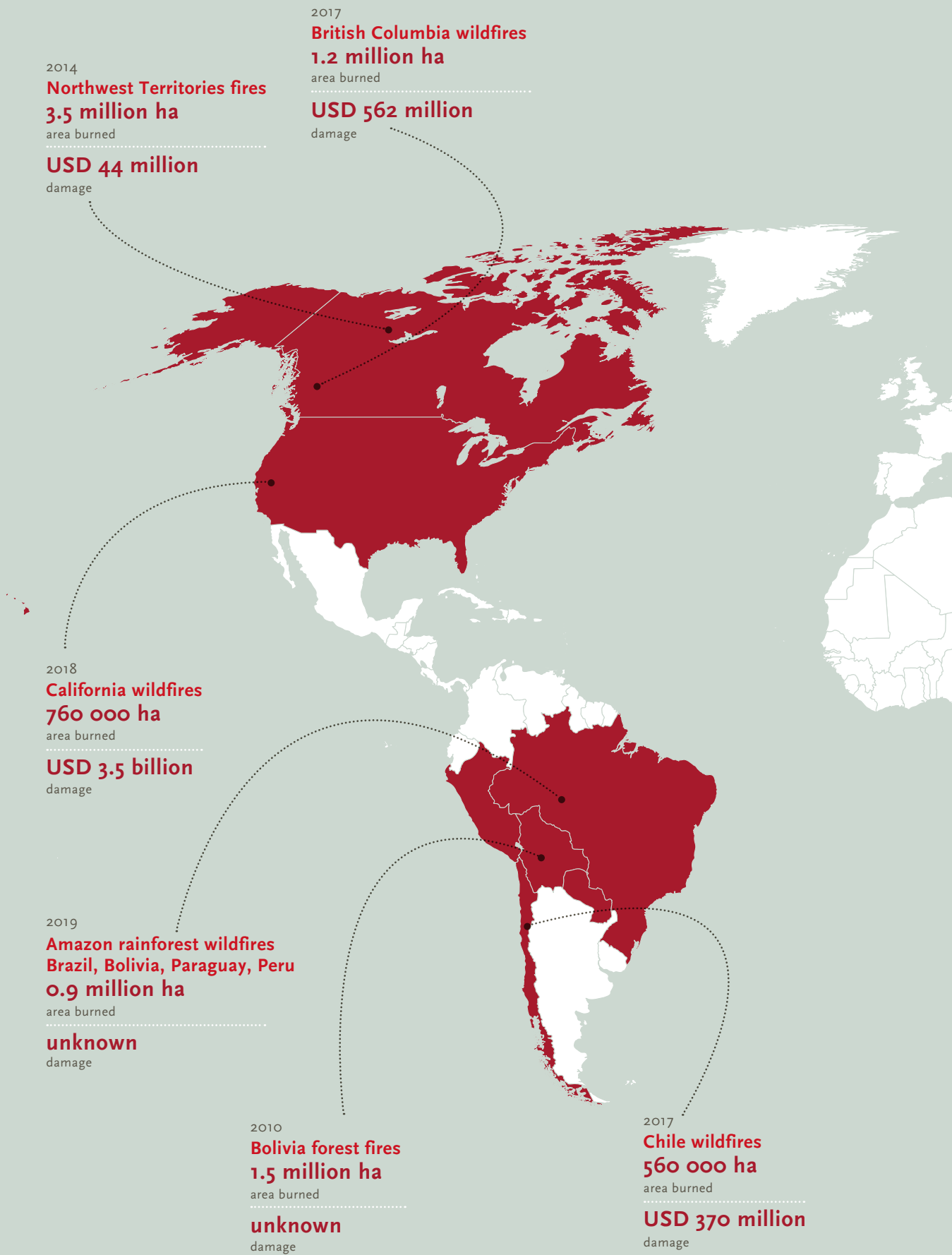
Hot and dry are the two watchwords for large wildfires – hot and dry atmospheric conditions determine the likelihood of fire outbreak, its intensity and the speed at which it spreads. As the world warms, so does its potential to burn. Heat waves and drought are associated with the majority of the past decades' most damaging fires (Bowman *et al.*, 2017) (Figure 1). While approximately 67 million ha of forest burned around the globe every year between 2003 and 2012 (van Lierop *et al.*, 2015), that number skyrocketed in 2015, when fire claimed roughly 98 million of the world's forest hectares. This occurred mainly in the tropical domain, where fire consumed about 4 percent of the total forest area that year. More than two-thirds of the affected forests were in Africa and South America.

Extreme wildfires cause considerable damage to landscapes, put pressure on environmental services and carry a heavy economic toll. They inflict damage to infrastructure and services, including power and communication lines, water systems, roads and railways. There are also the immediate and exorbitant costs of firefighting. Furthermore, wildfire events have severe effects on human health and can strain national health services. Human activity, combined with adverse weather conditions, constitute the most common cause of wildfires. Climate change is making extreme wildfires more frequent and damaging, and expanding the locations where they occur.

In the future, climate change is expected to bring longer fire seasons and more-severe fires over much of the globe, including some areas where fire has not previously been a common problem. Forest fires cannot be avoided but their occurrence and impacts can be significantly reduced by applying integrated fire management and fire-smart forest management, and by taking socio-cultural realities and ecological imperatives into account in the landscapes where fire occurs. There is potential for countries to meet greenhouse gas (GHG) reduction commitments and benefit from climate change funding flows through improved fire management.

While some part of the world is on fire at any given time, the southern hemisphere experiences particularly distinct and damaging wildfire seasons, driven by dry periods and human activity, such as agricultural burning.

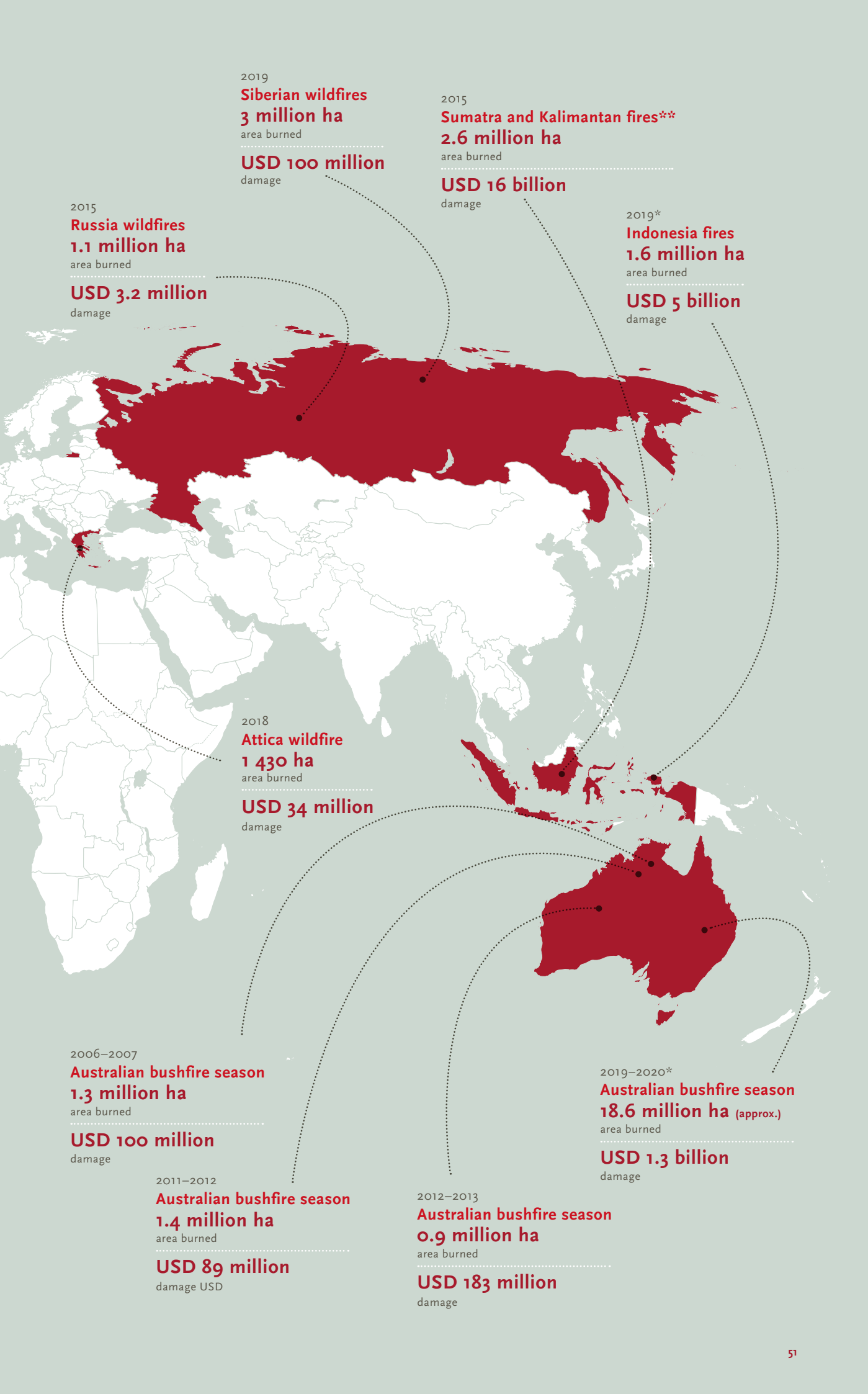
Figure 1. Largest wildfires 2010–2019, hectares burned, damage in USD



* While most destruction occurred in 2019, fires were not fully doused until heavy rains in January and early February 2020; hectare and damage estimates provided here include 2020.

** These fires sparked the 2015 Southeast Asian Haze, an air pollution crisis affecting Brunei Darussalam, Cambodia, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Viet Nam.

Source: FAO, 2020. Map conforms to United Nations World map, February 2020.



2019
Siberian wildfires
3 million ha
 area burned

USD 100 million
 damage

2015
Sumatra and Kalimantan fires**
2.6 million ha
 area burned

USD 16 billion
 damage

2015
Russia wildfires
1.1 million ha
 area burned

USD 3.2 million
 damage

2019*
Indonesia fires
1.6 million ha
 area burned

USD 5 billion
 damage

2018
Attica wildfire
1 430 ha
 area burned

USD 34 million
 damage

2006–2007
Australian bushfire season
1.3 million ha
 area burned

USD 100 million
 damage

2019–2020*
Australian bushfire season
18.6 million ha (approx.)
 area burned

USD 1.3 billion
 damage

2011–2012
Australian bushfire season
1.4 million ha
 area burned

USD 89 million
 damage USD

2012–2013
Australian bushfire season
0.9 million ha
 area burned

USD 183 million
 damage

Invasive species concerns

Invasive species of plants, animals, insects, and microbes pose a growing threat to the health, sustainability and productivity of natural and planted forests around the world. This is exacerbated by the ever-increasing movement of goods and people across the globe and the impacts of climate change. In many countries, forests and forest ecosystems have been subject to severe outbreaks of invasive species causing billions of dollars' worth of damage to the economy, environment and socio-cultural practices. Insects, disease and severe weather events damaged about 40 million ha of forests in 2015, mainly in the temperate and boreal domains.

Yet, calculating the full impact of invasive species on forests is complex because of the many components to be considered, e.g. impacts on: biodiversity, ecosystem functions, human health, social and cultural values as well as indirect costs such as those related to control measures. For this reason and despite the urgent need for reliable data, the issue has never been studied at the global level.

In just six countries, invasive species of plants, animals, insects, and microbes inflicted a combined total of USD 314 billion in damage and loss annually

The closest we come is a now two-decades-old review of country level data from six countries: Australia, Brazil, India, South Africa, United Kingdom of Great Britain and Northern Ireland, United States of America. Though dated, this study demonstrates that invasive species cause considerable damage to both agriculture and forestry in particular: USD 314 billion in damage and loss per year (Pimentel *et al.*, 2001).

Examining the issue from the perspective of specific threats, it is clear that some invasive forest species inflict severe environmental and economic impacts, including the near extinction of certain tree species. For example: the invasion of chestnut blight (caused by *Cryphonectria parasitica*, a fungal pathogen native to southeast Asia), has killed more than 4 billion trees in the United States of America; ash dieback (caused by a newly identified fungal pathogen, *Hymenoscyphus fraxineus*), first detected in the United Kingdom of Great Britain and Northern Ireland; while *Miconia calvescens*, a tree native to South America, has significantly altered the forests of French Polynesia and other Pacific islands (Denslow, 2002).

Pine wilt is among the most devastating illnesses worldwide, resulting in trade embargoes and requiring that shipping materials made of pine be specially treated to prevent its spread

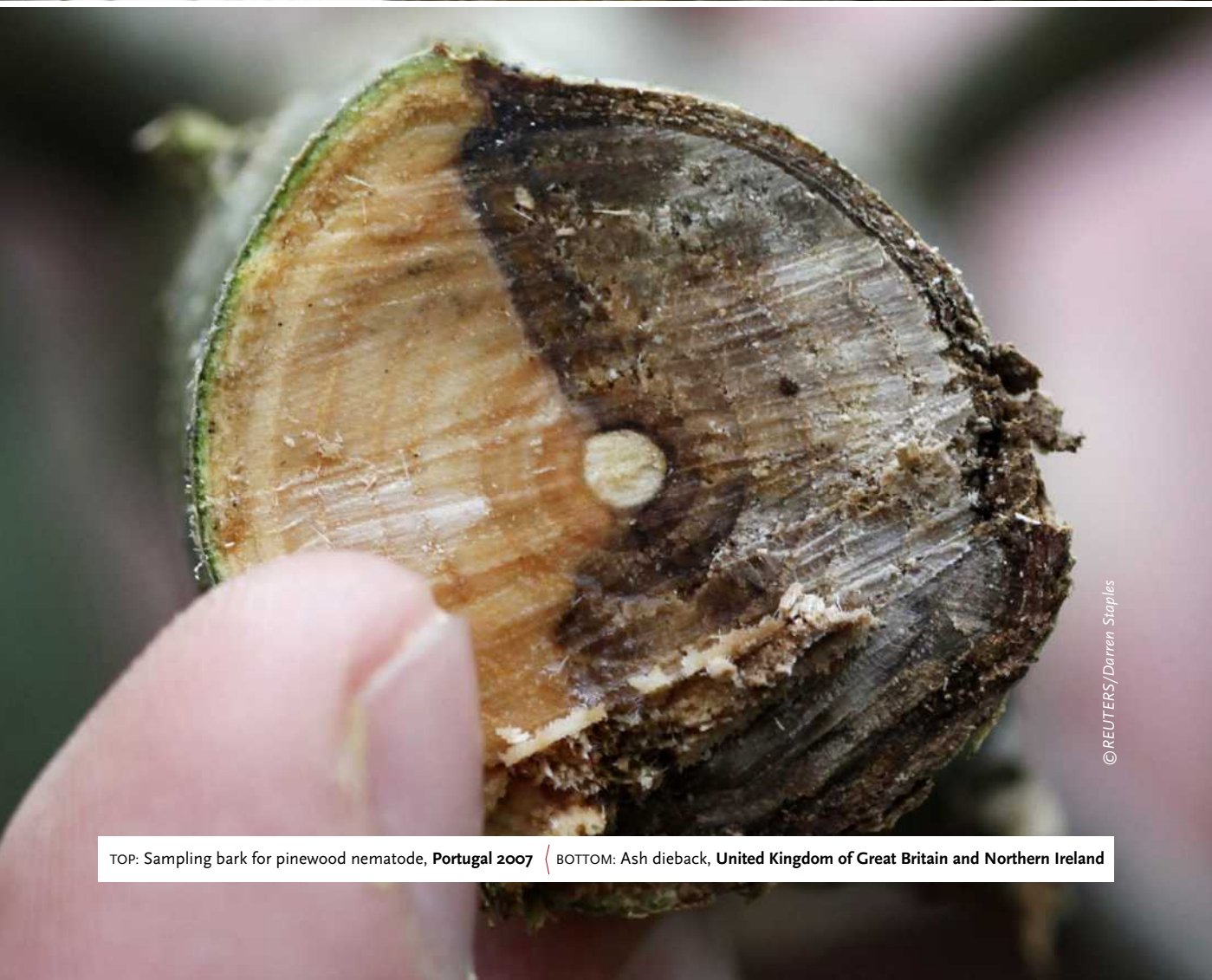
Another invasive disease, pine wilt, is one of the most significant and devastating illnesses affecting pine trees worldwide (Mota & Vieira, 2008). It is caused by the pinewood nematode (*Bursaphelenchus xylophilus*), which is spread by vector beetles. It can kill affected trees within a few weeks, and its expansion into new countries has resulted in extensive management costs and loss of timber. For example, Japan lost more than 100 million cubic meters (m³) of wood annually between 1978 and 1988, and more than 50 million m³ annually between 1989 and 2014, resulting in a combined wood loss of roughly USD 3.7 billion (Hirata *et al.*, 2017). In China, pine wilt killed more than 1 million trees annually 1995–2006 (Zhao, 2008), soaring to 2.3 million trees in 2008 (Robinet *et al.*, 2009).

In South Korea, from 2008 to 2018, pine wilt disease inflicted a total of USD 7.5 million in direct loss of forest products. If wider environmental impacts, such as loss of forest carbon sequestration and biodiversity are considered, the impact is estimated at USD 890 million (An *et al.*, 2019). Managing response to the country's pinewood nematode invasion cost South Korea an additional USD 67 million each year. As for the European Union, pinewood nematode is expected to cause an estimated EUR 22 billion loss in forestry stock for the 22-year period spanning 2008–2030 (Soliman *et al.*, 2012).

Trade restrictions have been imposed to curb the spread of pinewood nematode, impacting the import and export markets of forestry products (Dwinell & Nickle, 1989).



© REUTERS/José Manuel Ribeiro



© REUTERS/Darren Staples

TOP: Sampling bark for pinewood nematode, Portugal 2007 | BOTTOM: Ash dieback, United Kingdom of Great Britain and Northern Ireland

For example, Europe’s import restrictions could cause annual losses of USD 150 million in the United States of America, and USD 700 million in Canada (Carnegie *et al.*, 2018). To protect forests from pinewood nematode and other insect pests and pathogens, FAO’s International Plant Protection Convention (IPPC) requires that all wood materials used for shipping products between countries (pallets, crates, etc.) be debarked, treated and stamped with a mark of compliance.

Towards a tailor-made assessment

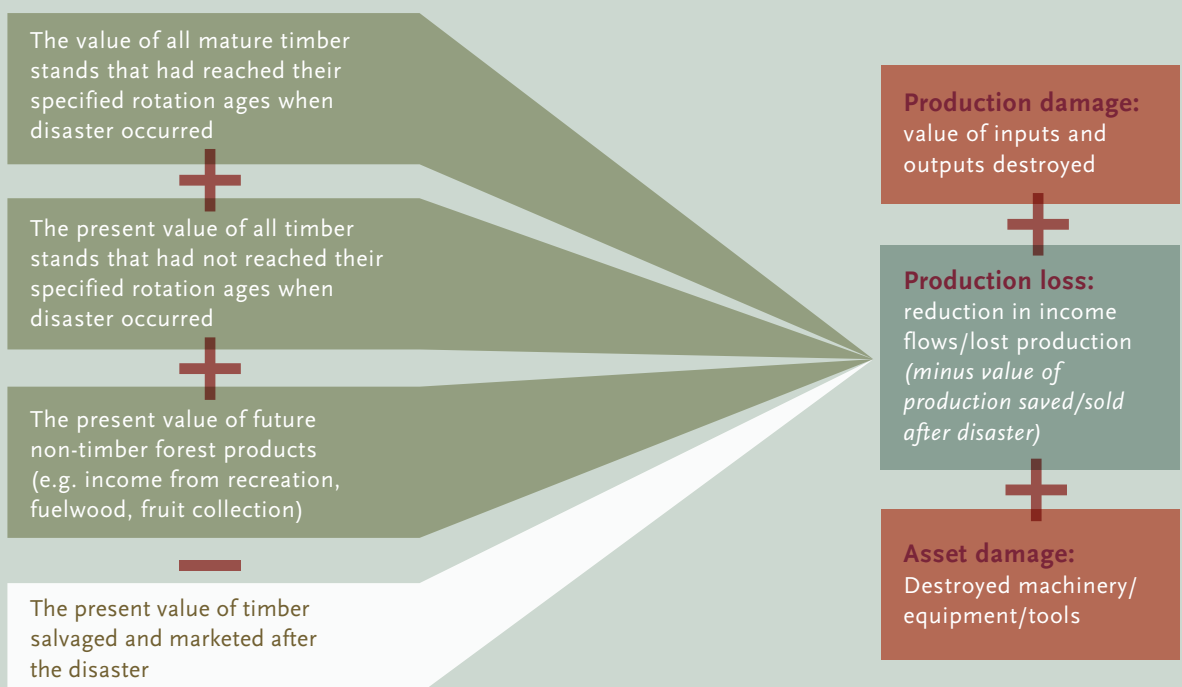
Hazardous events such as wildfires, storms, tsunamis, invasive species, etc. result in economic loss within forest systems, and pose large-scale threats to life and safety, especially for people in LDCs and LMICs. While forest systems worldwide suffer substantial disaster-related damage and loss each year, incomplete reporting, data collection and assessment hamper a more thorough understanding of what is at stake.

Improved data and monitoring are prerequisite to a better understanding of the substantial disaster-related damage and loss inflicted on forestry each year

Improved data and monitoring constitute a prerequisite for building forestry’s resilience to shocks and disasters such as devastating wildfires and invasive species. The case is made in the 2017 edition of this report, which introduces FAO’s damage and loss assessment methodology. This tool comprises a set of procedural and methodological steps for each agricultural subsector that can be used at subnational, national, global levels to calculate and analyse damage and loss. This ensures coherence across all subsectors regarding assessment categories, as well as consistency across disasters and countries.

Since then, through a FAO-UNDRR collaborative process, this methodology has been officially adopted as part of international resilience agendas, including the SDGs and Sendai Framework, and is being increasingly adopted and institutionalized by countries as part of their customized national frameworks for data collection and reporting. It is expected that this globally standardized approach will become the backbone for evidence-based disaster-resilient strategies and practices.

Figure 2. FAO’s methodology for assessing damage and loss in forestry



A key innovation of the Sendai Framework's agricultural indicator, the forestry DL methodology has recently been revised and strengthened by FAO and UNDRR, allowing for more complete disaster loss monitoring in forestry

Actual use of the methodology informs its enhancement. As a result, FAO is now able to address a structural gap in the forestry sector formula, strengthening the equation for calculating forestry production loss. Furthermore, the forestry-specific element of FAO's methodology now incorporates specific features tailored to a universal assessment of the sector, such as disaggregation by forest stand as a basic spatial entity, accounting for standing timber loss, salvaged timber and non-wood forest products. Such emphasis on detail will further ensure that the forestry sector is adequately represented in global reporting for the Sendai Framework and SDGs.

Before presenting the enhanced forestry formula (see the Technical annex), it is helpful to re-cap FAO's overall methodological approach. The damage and loss assessment methodology distinguishes between **damage**, i.e. total or partial destruction of physical assets, and **loss**, i.e. changes in economic flows arising from a disaster. Each of these is also divided into two main components: **production** and **assets**. The production component measures disaster impact on inputs and outputs.

Production damage includes the value of stored inputs (e.g. seeds) and outputs (e.g. crops) that were fully or partially destroyed by the disaster. On the other hand, **production loss** refers to declines in the value of agricultural production resulting from the disaster. The **asset damage** component measures disaster impact on facilities, machinery, tools, and key infrastructure related to agricultural production.

Production loss in forestry

A forest typically consists of two productive asset classes: the forest and the land upon which the forest grows. The former is a capital asset which can be increased by investment, silviculturally and via biological timber growth over time; and reduced by timber harvesting or natural disturbances. Land, on the other hand, is fixed in supply and can only be repurposed in terms of use and management intensity. The damage from fires, insect or disease outbreaks is usually inflicted on the forest itself and less so on the land (although fires can have varying effects on soil fertility). This section focuses on damage to the forest (timber) only, not the land.

A forest often consists of many timber stands (compartments or sub-compartments), each having different characteristics (Pearse, 1990; Helms, 1998). A timber stand is a contiguous group of trees sufficiently uniform in age-class distribution, composition, and structure, growing on a site of sufficiently uniform quality, so as to be a distinguishable unit. Merchantable timber stands consist of trees that are salable (Helms, 1998). Pre-merchantable timber stands are stands of trees that are not able to be profitably harvested and sold (Zhang & Pearse, 2011).

The assessed production loss of forest resources covered here are monetary values that are measured as standing forests, (as opposed to commodities in a processed form, i.e. logs, plywood, pulp, etc.) that would have been traded in a market at the time the damage and loss occurred. It does not cover environmental values (such as climate mitigation and water conservation) or livelihoods, because these are not traded in markets.¹ The production loss value of a forest is the summation of all stand values. The value of forest loss due to disasters is outlined in Figure 2; see the Technical annex for the complete forestry sector formula.

¹ In other words, the monetary value assessed here is the market value of forest damage and loss, not the full value of damaged and lost ecosystem services — the benefits that people obtain from ecosystems. Ecosystem services include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling, which maintains conditions (FAO, 2018c).

Production and asset damage in forestry

Risk-informed forest management helps mitigate impacts of climate change, disasters, and extreme weather events on forests and forest-dependent communities

Consistent with other subsectors, forestry's production damage category comprises the value of destroyed stored inputs for forestry production as well as any stored timber or other forest products damaged by the disaster. Also in line with other subsectors, asset damage in forestry considers the value of any forestry machinery and equipment damaged or destroyed by disasters, including skidders, feller bunchers, forwarders and harvesters.

Overall, a streamlined damage and loss assessment methodology provides an assessment framework and, ultimately, the necessary evidence base for timely, informed and targeted policy and action towards the disaster preparedness, prevention, mitigation, response and recovery of the forestry sector. Moreover, risk-informed sustainable forest management can help ensure that forests play their proper role in mitigating the effects of climate change, disasters and climate extreme events. Forest management decisions made now will affect forests and forest-dependent people many decades into the future.

A two-way street: the role of forests in disaster prevention and mitigation

Social dynamics of forest systems

Forests constitute an integral part of the resilience of communities and their livelihoods to disasters, threats and crises and can help tackle underlying causes of food insecurity and poverty. An estimated 1 to 1.7 billion people rely on forest resources for their livelihoods. To date, wood remains a primary source of energy for cooking and water sterilization. Some 2.4 billion people worldwide currently rely on wood as a main source of energy for cooking. In addition, about 80 percent of an unprecedented 79.5 million displaced people around the world rely on traditional biomass fuels, mainly firewood and charcoal, for cooking and heating (FAO, 2019b). In addition to providing wild food, fodder, and material for shelter, forests conserve water resources and perform multiple ecosystem services.

Worldwide, more than 1 billion people depend on forest foods for themselves or their livestock, many more during times of crises that affect agriculture and food production

For centuries, forests have provided a natural safety net for communities during famines, shocks or other events that impact agricultural and food production. Because they can help feed people and livestock, forest resources such as fruits, gum, honey, leaves, mushrooms, nuts, roots, seeds, tubers, edible insects, bushmeat, and fish are commonly used for seasonal gap-filling or when crops fail. Worldwide, around 1 billion people depend on forests for food to some extent. This can significantly increase in times of crisis, conflict and displacement, when people turn to forests not only for food but also for shelter and safety. It is not only low- and middle-income countries that benefit from the nutritional value of forest foods; more than 100 million people in the European Union regularly consume wild food. Currently, forests provide over 86 million green jobs worldwide and support the livelihoods of many more people (FAO & UNEP, 2020).

At the same time, a large share of the world's forests is under increasing threat due to human activity and climate change. Although the pace of deforestation has slowed in some regions, some 420 million ha of forest have been lost since 1990 and the trend continues at a rate of about 14.5 million ha per year (FAO & UNEP, 2020). In parts of the Amazon rainforest, rising temperatures and changing rainfall patterns are connected with the increased risk of catastrophic dieback with dangerous local, regional and global consequences. In the Congo Basin, the intense pressure of mineral exploitation, growing energy needs, and intensified transportation emissions are challenging the integrity of this vast rainforest area. Furthermore, an increasing number of studies link the emergence of infectious diseases to changes in land cover and land use, with deforestation and forest

fragmentation being major contributors. The two most prominent diseases originating from forests are HIV and dengue fever, which began within primate transmission cycles in African forests and eventually spread globally. Other forest-associated diseases include malaria, Chagas disease (also known as American trypanosomiasis), African trypanosomiasis (sleeping sickness), leishmaniasis, Lyme disease and Ebola. Most new infectious diseases are zoonotic and their emergence may be linked to increased human exposure to wildlife due to changes in forestation and the expansion of human populations into forest areas.

Inclusive green growth strategies helps decelerate the deforestation that often accompanies development, thereby contributing to climate change mitigation

Large-scale forest restoration is needed to meet the SDGs and to prevent, halt and reverse the loss of biodiversity. If countries are able to pursue inclusive green growth strategies that overcome some of the more severe trade-offs between growth and forest protection, the deforestation that has historically accompanied development in many countries could be decelerated, making an important contribution to climate change mitigation. While 61 countries have pledged to restore a combined 170 million ha of degraded forest lands under the Bonn Challenge, progress to date is slow. The United Nations Decade on Ecosystem Restoration 2021–2030, announced in March 2019, aims to accelerate ecosystem restoration action worldwide.

Coastal forests

Coastal forests, including mangroves and coastal shelterbelts, can reduce the force, depth and velocity of storm surges and tsunamis, lessening damage to property and reducing loss of life. Assessments after Japan's 11 March 2011 earthquake and tsunami demonstrate that coastal forests reduced the tsunami's power and speed and captured drifting objects, mitigating the tsunami's impact on property and human lives (Ohta, 2012; Sakamoto, 2012).



Fisherman catches crabs in a mangrove forest, Brazil 2019

Some studies show lesser damage to trees further away from a coastal forest's leading edge, implying that the forest itself blunts the waves' force, protecting trees in the rear. Though coastal forests are only partially effective against flooding, they can limit the extent of its damage by slowing and weakening the waves and making them more shallow.

While it is not feasible to establish a coastal forest 'bioshield' – unbroken and of sufficient width and density – along the entire length of every coastline prone to storm surge or tsunami, forests play a major role in mitigating the impacts of coastal hazards. Given their low establishment and maintenance costs relative to other protective structures such as seawalls and levees, as well as their potential for generating environmental benefits, these 'green' structures should become more widely utilized. Coastal forests can also enhance the flow of a whole range of associated benefits and ecosystem services that contribute to the overall social, economic and ecological resilience of coastal systems (Spurrier *et al.*, 2019).

Other protective functions of forests

It is estimated that by 2015, 230 major watersheds had dropped from 68 percent to 29 percent, increasing risk of soil erosion, forest fire, and baseline water stress

Forests and trees play an important role in regulating water flows and reducing soil erosion, often referred to as forests' protective functions. Forests regulate water through several processes, including intercepting precipitation, promoting soil water infiltration and storage, and through evapotranspiration; while trees and ground cover reduce water surface flows and facilitate soil infiltration and groundwater recharge, which mitigates soil erosion and sedimentation. Loss of tree cover, land-use conversion and unsustainable land practices can reduce the ability of forests and their soils to provide these protective services.

It is estimated that the world's major 230 watersheds had an average of 68 percent tree cover prior to 2000. By 2015, that had plummeted to an average 29 percent, with nearly half these watersheds losing more than half of their tree cover (FAO, 2018c). Of those major watersheds that lost more than 50 percent of their tree cover, 88 percent show medium to very high risk of erosion, 68 percent are at medium to very high risk of forest fire, and 48 percent have a medium to very high risk of baseline water stress (Springgay *et al.*, 2019; FAO, 2018c). These hazards pose significant threats to communities, food security and livelihoods.

By the end of 2019, East Africa was host to 4 million refugees and asylum seekers, resulting in severe overexploitation of forest resources

According to FAO's *Global Forest Resource Assessment 2020*, an estimated 399 million forest hectares are designated primarily for the protection of soil and water, an increase of 119 million ha since 1990. While the rate of increase in hectares allocated for this purpose has grown over the entire period, this is especially so in the last ten years. Meanwhile, an estimated 25 percent of the world's forests are managed to conserve water and soil resources, with less than 10 percent managed primarily for this purpose. While the global trend for the management of forests for soil and water is increasing, there is a downward trend in subtropical and tropical forests, correlated with deforestation in those forest types.

Forests in the humanitarian – development nexus

There are millions of refugees in the world, mostly due to protracted crises. The average length of stay in refugee camps such as Cox's Bazar is more than two decades (Betts and Collier, 2017). Of particular concern is the situation in East Africa, which – by the end of 2019 – was host to more than 4 million refugees and asylum seekers, the majority of them in Uganda (1.3 million), Sudan (1.1 million), and Ethiopia (700 000). In addition, the number of internal displaced persons (IDPs) was more than 9 million, largely in Ethiopia (3.2 million), Somalia (more than 2.7 million), Sudan (1.9 million), and South Sudan (close to 1.8 million).



© UNICEF/UNI1302773/Akacha



© UNICEF/UN6325326/Brown

TOP: Building refugee shelters, Syrian Arab Republic 2020 | BOTTOM: Reinforcing flooded path, Cox's Bazar, Bangladesh 2019

When sustainably managed, forests and woodlands provide vital safety nets and life-supporting assets in displacement settlements, while also acting as buffers that help refugee communities withstand extreme weather and other shocks. However, the recent rapid increase in the number of forcibly displaced people both within countries and across borders, combined with an overall rapid population growth in the hosting areas, has caused overexploitation of forest resources due to increasing demand for woodfuel, construction material and agricultural expansion.

In six Ugandan refugee settlements assessed by FAO and the World Bank, households rely almost entirely on woodfuel to meet their energy needs

The 2017 issue of this report discussed a four-step method to assess woodfuel supply and demand upon the construction of a displacement camp, in view of developing sustainable forest management plans. Based on this method, between 2018 and 2019, FAO and the World Bank assessed forest resources degradation in refugee-hosting areas of Uganda to identify well-planned forestry interventions – including afforestation, reforestation, and restoration – that could ensure a sustainable supply of woodfuel, timber and other forest products for those communities, facilitating sustainable development and minimizing environmental impacts.

The area targeted was a wide ‘buffer zone’ up to 5 km from the boundaries of six settlements: Kyaka II, Kyangwali, Rwamwanja, Kiryandongo, Nakivale and Oruchinga. A wider area of up to 15 km from the settlement boundaries was also assessed to understand dynamics within host communities. Both host and refugee households rely almost entirely – up to 92.5 percent – on woodfuel to meet their energy needs. Total estimated woodfuel consumption is 475 000 metric tons per year for the combined population of refugees and host communities within the 5 km buffer zone. The estimated above-ground biomass stock within the same area is 2.5 million tonnes, with an annual increment of 194 000 tonnes. Assuming that woodfuel demand is met only with biomass from within the 5 km buffer zone, there is an annual deficit of 11 percent of above-ground biomass stock.

Forest degradation and deforestation in the settlement buffer areas is further driven by the territorial expansion of commercial and subsistence farming; the intensified harvesting of forest products such as charcoal, firewood, and timber; and the persistent expansion of settlements. These drivers often occur concurrently and are mutually reinforcing (World Bank & FAO, 2020).

Because forests and woodlands are an essential safety net in the displacement context, a range of interventions are in order to mitigate forest degradation and enhance energy access for both refugee and host communities, while also improving the livelihood and income sources of both communities. Due to the current high dependency of both refugees and hosts on charcoal and firewood, and given the likelihood that this dependency is expected to continue for the foreseeable future, responsible planning for sustainable management of wood resources offers opportunities to sustainably supply woodfuel, create employment and income through forest product value chains, and contribute to a wide range of ecosystem services.²

2 The interventions proposed by the World Bank/FAO assessment include: (a) development of agroforestry systems; (b) establishment of private woodlots for energy and other purposes; (c) restoration and conservation of natural forests in protected areas; (d) rehabilitation and conservation of natural forests on private and communal land; and (e) upgrading cooking systems and energy value chains.

Way forward on damage and loss assessment in forestry

Given the complex disaster risk profile of the forestry sector – in terms of its exposure and vulnerability to specific types of disasters as well as the ability of forest systems to partake in disaster prevention, mitigation and recovery – it is important to adopt a universal methodological basis for detailed analysis. FAO's updated methodology puts together a tailored approach to estimating sector-specific damage and loss in forestry. Practical aspects such as the present-value asset valuation of timber and the salvaging of merchantable timber make this a pragmatic approach to forestry assessments. Furthermore, it implies a certain degree of flexibility in allowing disasters to have an overall positive impact through increased timber production and revenue growth.

Ability to evaluate the nature, size and magnitude of disaster impact rests on the availability of data on the forest's pre-disaster size, composition, and age

While the methodological tools are in place, the challenges ahead lie in developing detailed databases and information systems at national and regional level. Data on size, composition, forest age, as well as damaged and salvaged timber volumes in affected forest areas is crucial to evaluate the nature, size and magnitude of the disaster impact, be it from a wildfire, a tsunami or a pest. It is therefore necessary to build stronger capacities for data collection and information management and to enhance technical understanding of relevant assessment methodologies among key sector stakeholders at national and regional level. Such an understanding is necessary to inform adequate policy decisions and allow for an effective and holistic monitoring of agreed international resilience targets under the Sendai Framework (Indicator C-2) and the SDGs (Indicator 1.5.2). Consistent and comprehensive reporting of national disaster loss in forestry is therefore key for securing the sector's place on the map of global resilience-building.



Rwamwanja refugee camp, Uganda 2019



Cyclone Idai aftermath, Mozambique 2019



Chapter III

Impact of disasters on fisheries and aquaculture

Those dependent on fisheries and aquaculture for their livelihoods must navigate the increasing disaster risks that flow from climate change and human-induced hazards. Effective resilience and emergency response strategies require in-depth understanding of fisheries and aquaculture as well as damage and loss monitoring and assessment systems and practices. This chapter discusses the availability and analysis of data for DRR and resilience planning in the context of disasters, complex emergencies and protracted crises. Proof-of-concept trials using FAO's damage and loss assessment methodology in five diverse countries in South America and the Caribbean and East Africa make the case for using this tool to better incorporate disaster risk reduction into fisheries and aquaculture management.

Casting a wider net over disaster impact on fisheries

Fisheries and aquaculture provide food security, nutrition and livelihoods for vulnerable and disadvantaged communities worldwide. Fish constitute a source of high-quality protein, omega-3 fatty acids, as well as essential micronutrients such as calcium, phosphorous and zinc, which promote health and nutrition. As of 2018, 59.51 million people worldwide are engaged in capture fisheries (39 million people) and aquaculture (20.5 million people). Of that global total, 85 percent are in Asia, and 14 percent are women (FAO, 2020f).

Fishing communities are highly vulnerable due to their close proximity to water bodies that receive the brunt of cyclones, tsunamis, floods, and toxic spills

The growing occurrence of disasters and extreme weather events, as well as the consequences of a changing climate have a multifaceted impact on aquatic ecosystems and the livelihoods of those who depend on them. In addition, complex emergencies, conflict and protracted crises can increase pressure on fisheries and aquaculture because shifting populations and rising food prices prompt more fishing. In the context of conflicts and crises, fisheries can provide alternative employment and livelihood opportunities for displaced communities. For example, when fishing communities in northern Sierra Leone fled civil war in the 1990s, they settled in neighboring Guinea, amplifying demand on Guinean fisheries. Transformative action to build resilience and adaptive capacity in the fisheries and aquaculture sector is a priority and should continue well into the future, given alarming disaster trends and future climate scenarios.

Fishers are usually on the low rung of the socio-economic ladder and their communities are in close proximity to coasts, lakes and other water bodies where they receive the brunt of many disasters such as tropical cyclones, tsunamis, floods, as well as spills from oil, toxic chemicals and nuclear substances. Fishing boats, fishing gear, and fisheries' infrastructure including markets, ports, ice-making and seafood processing facilities are often partially damaged or completely destroyed in these events. In aquaculture, impacts often include loss of production, brood stock, equipment and infrastructure such as hatcheries, feed mills, ponds and cages. In addition, disasters threaten entire aquatic ecosystems (e.g. fish habitats) and their biodiversity.

On the other hand, the rapid restoration of capture fisheries activities after a disaster can quickly provide nutritious food and employment, and fast-track a communities' return to normal economic activity. In the event of conflicts and complex emergencies, when the movement of internally displaced people (IDPs) and refugees intensifies, fisheries can play an important role in providing food security and livelihoods for them as well as the local population (Lee *et al.*, 2020).

This begs the question: Should all boats, gear and equipment lost or damaged in a disaster be replaced, or only enough to ensure fishing remains within sustainable levels? The building back better principle dictates that rehabilitation efforts should be proportional to available aquatic resources. The short-term benefits of getting affected populations back on their feet as quickly as possible by immediately replacing all inputs can actually harm the mid- and long-term sustainability of livelihoods of the very populations for whom the short-term assistance is intended. In such cases, it may be better to provide other types of humanitarian assistance such as agricultural inputs or promote other types of economic activities.



Anonymous photographer



© REUTERS/Willy Kurniawan

TOP: Oil spill off the coast of Mahébourg, Mauritius 2020 | BOTTOM: Drought forces East Sumba farmers to learn how to fish, Indonesia 2020

Decisions about post-disaster replacement efforts require up-to-date data on the pre-disaster fishing effort and health of aquatic resources

A good emergency response requires an understanding of the status and management of the aquatic resources. It is important to grasp the fishing effort in terms of gears, boats and the number of fishers in the impacted area before and after the disaster. The capacity to monitor and manage the sector is equally important. In some cases, limited management capacity may have already resulted in the fishery being fished to its maximum sustainable yield leading to overfishing and overexploitation of the aquatic resource. In aquaculture, it is essential to know the pre-disaster density and level of production as well as the number of farmers involved in this activity to determine the level of replacement inputs necessary in the disaster's aftermath.

Among the greatest disaster-related challenges for the fisheries and aquaculture sector is understanding the nature, extent and economic cost of the impact. Estimating the damage and loss from disasters and climate extreme events, in the context of a holistic information system, helps bridge existing data gaps and provides a strategic evidence base for DRR policy and programmes in the fisheries and aquaculture sector. Timely, accurate and reliable statistics are paramount in making decisions on the quantities and quality of gear, boats and infrastructure that can be distributed in a manner which does not risk over-fishing and/or stock collapse by oversupplying the fishing effort.¹

Recent and up-to-date data and information on the fishing effort, health of the affected aquatic resources, and the number of persons actively participating in the fisheries and/or aquaculture activity are all equally important when it comes to deciding the extent to which the sector should be rehabilitated after a disaster.

Importance of integrating disaster risk reduction into fisheries and aquaculture management

Almost all countries with fisheries and/or aquaculture resources have corresponding management frameworks, which integrate policy, legislation, research and development, strategic and programme planning, food safety, national and export markets and fisheries resources management plans. Climate change and gender are also increasingly incorporated into national fisheries and aquaculture management planning. Data and information are at the heart of these frameworks, providing the basis for fisheries management plans, policy formulation, regulations and overall strategic planning.

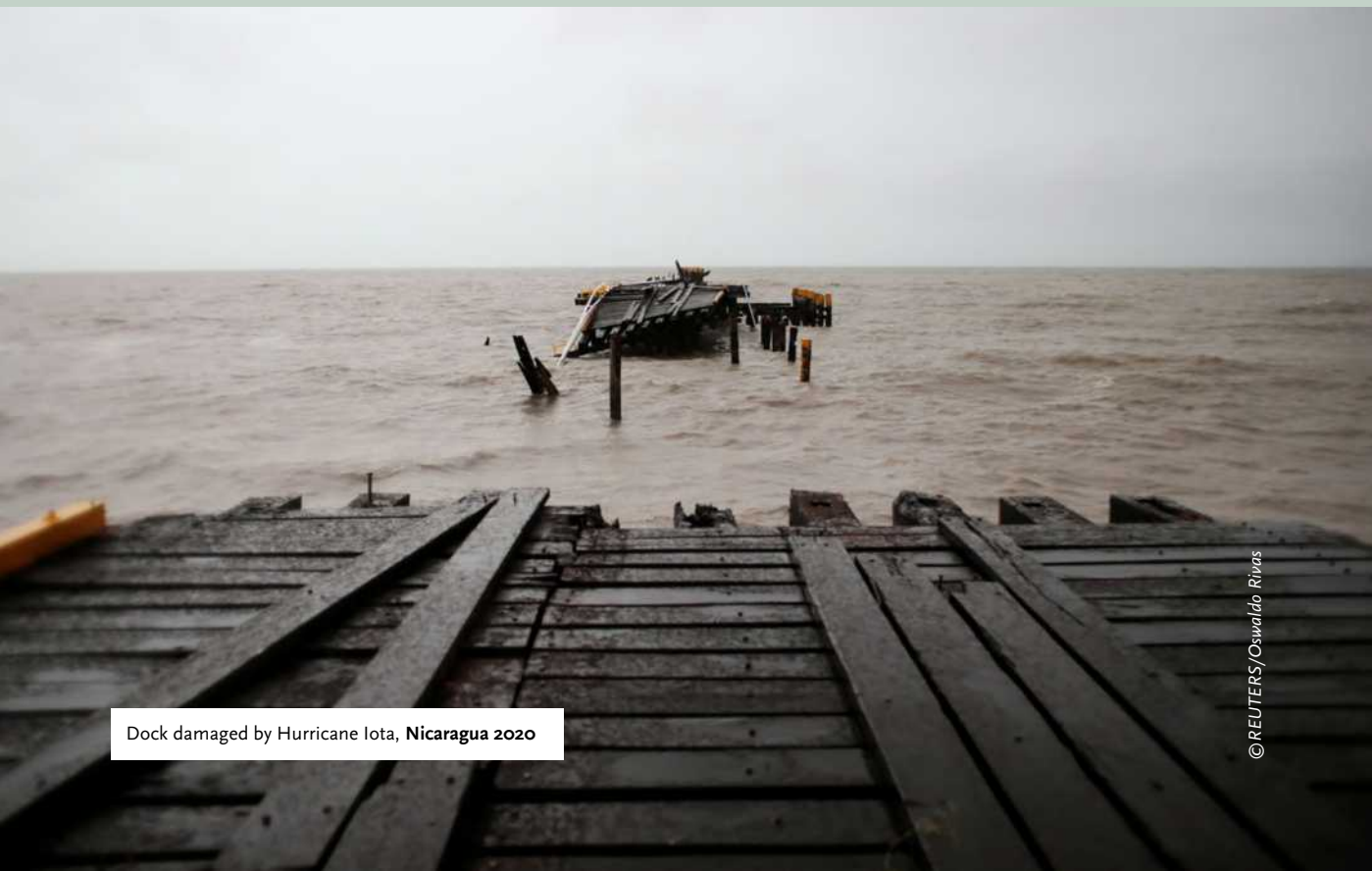
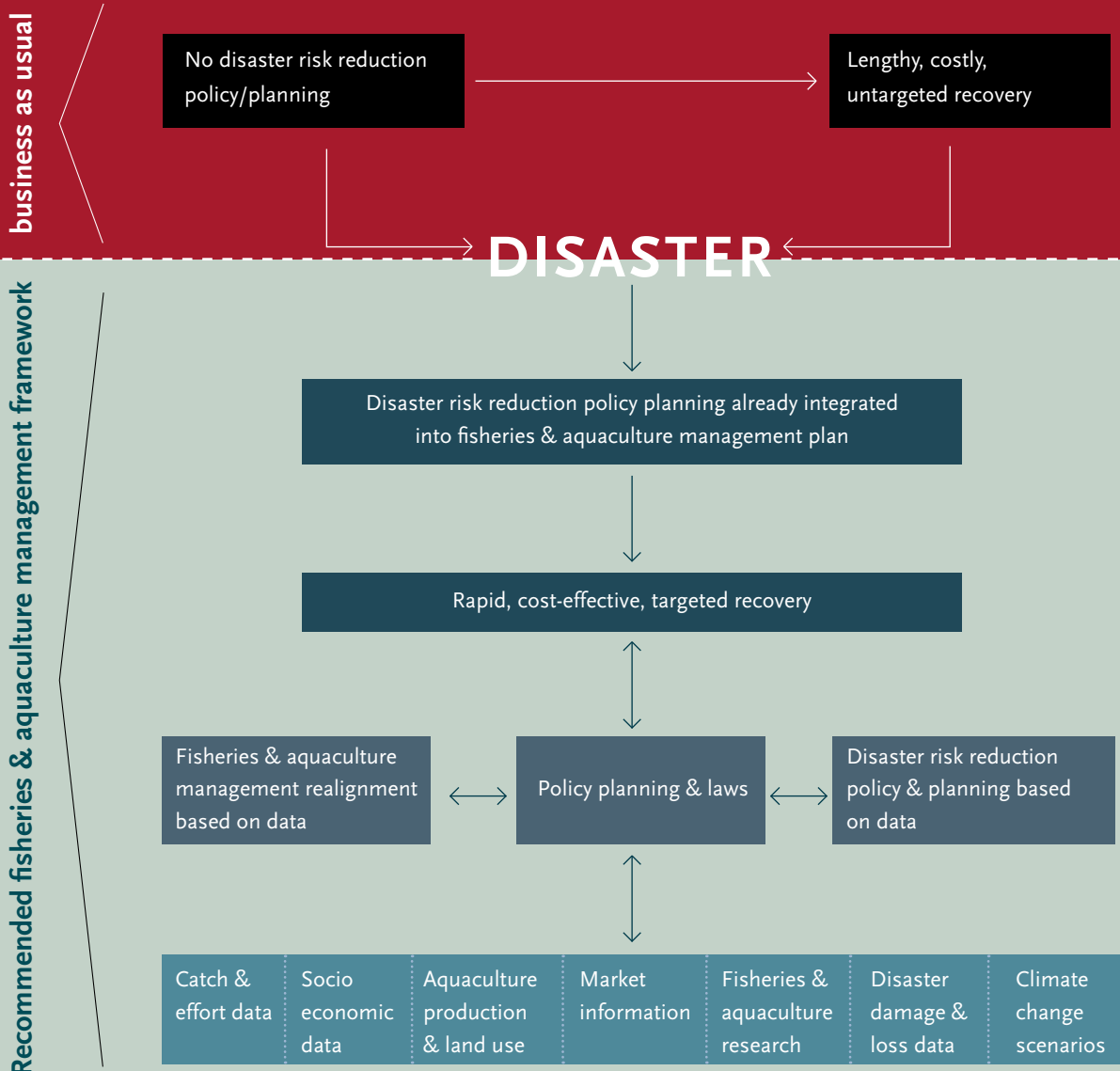
Rehabilitation can be chaotic when fisheries management plans are not in place

Nevertheless, most developing countries struggle to adequately implement their fisheries management plans, due largely to lack of financial resources and/or human capacities. As a result, when disaster strikes, rehabilitation can be chaotic.

Figure 1 demonstrates the importance of integrating disaster risk reduction into fisheries and/or aquaculture management planning and policy making. While all data and information required for DRR and damage and loss calculations can usually be found in fisheries/aquaculture frameworks, difficulties arise when that data and information is of poor quality and management is weak.

¹ Fishing effort is a measure of the amount of fishing. It is estimated as the amount of fishing gear of a specific type used on a fishing ground over a specific amount of time. Examples are: hours trawled per day, number of hooks set per day or number of hauls of a beach seine per day. Frequently, a proxy is used relating to a given combination of inputs into the fishing activity, such as the number of hours or days spent fishing, number of hooks used (in long-line fishing), kilometres of nets used, etc.

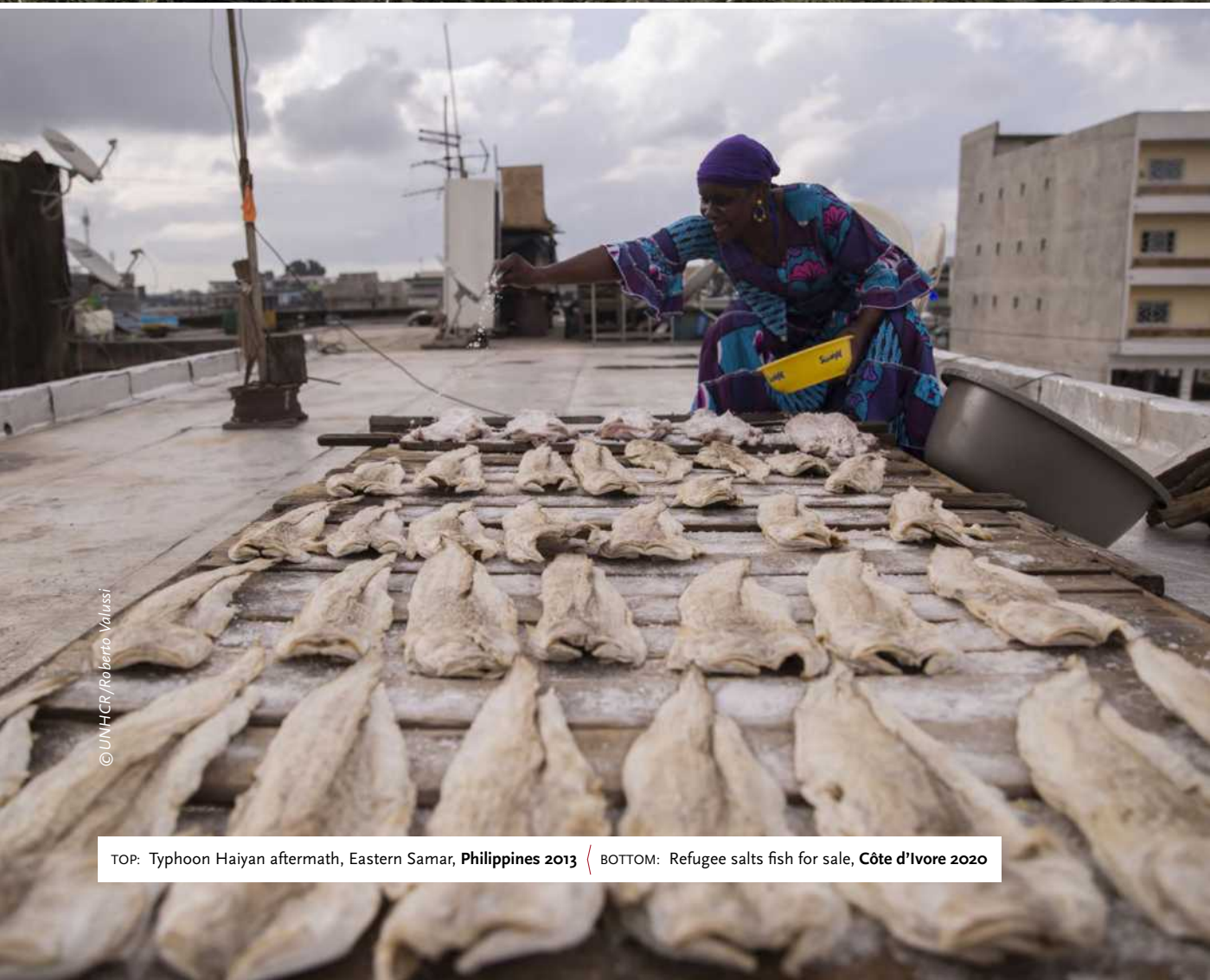
Figure 1. Integration of disaster risk reduction in fisheries management frameworks



Dock damaged by Hurricane Iota, Nicaragua 2020



© / @Reejscan / Matt Bjerrgaard Walsh



© UNHCR / Roberto Valussi

TOP: Typhoon Haiyan aftermath, Eastern Samar, Philippines 2013 | BOTTOM: Refugee salts fish for sale, Côte d'Ivoire 2020

Types, sources and availability of disaster-related data for fisheries and aquaculture

In the event of large-scale disasters and crises, high-level – and often multi-sectoral – assessments are conducted using tools and processes such as the Post Disaster Needs Assessment (PDNA), the Damage and Loss and Needs Assessment (DaLA), and/or the Multi-Cluster/Sector Initial Rapid Assessment (MIRA). Each provides crucial information for developing rehabilitation and recovery plans. However, they often face major hurdles in obtaining data for fisheries and aquaculture, and fail to apply assessment methodologies tailored to the sector. This means important decisions about rehabilitation are based on no, little, or even incorrect information. To help address this, FAO has developed the Fisheries Emergency Rapid Assessment Tool (FERAT) for use specifically in the context of inland fisheries (FAO, 2020c).

Reliable baseline data is essential for post-disaster assessment, but often absent or of poor quality for fisheries and aquaculture

To understand and calculate damage and loss in fisheries and aquaculture, it is important to have a baseline record of what existed before the disaster occurred.

Yet frequently, in precisely those areas where disasters strike most often, there is little or no systematic data collection. Where data is available, it is often not easily accessed. In such cases, the PDNA, DaLA, and MIRA must rely on other sources and methods to assess the actual loss.

It is imperative to reverse this situation. Collecting, monitoring and analysing damage and loss information for fisheries and aquaculture on a regular basis is of prime importance. A reliable disaster impact information system at country level can provide both the baseline and post-disaster data necessary for both emergency response planning and development of long-term recovery and resilience policy.

Table 1 shows the kinds of data required, their sources – such as FAO's *SOFIA*, FishStat, and Fisheries Global Information (FIGIS) – as well as alternative methods and sources that may be used if data is unavailable, incomplete or unreliable.

Cross-referencing various data sources will strengthen strategic recovery planning.

This table is useful also when applying FAO's own damage and loss methodology, discussed further on.

Table 1. Types of data and their sources required for damage and loss assessments

Data type	Traditional sources	Alternative/secondary sources
<p>Human population</p>	<ul style="list-style-type: none"> → National census → Administrative records → Population registers → Demographic sample surveys 	<ul style="list-style-type: none"> → Estimates from remote sensing (RS) tools (drones and satellite imagery) to count pre-disaster homes, markets and their post-disaster remnants → International organisations
<p>Refugee and IDP population</p>	<ul style="list-style-type: none"> → Registration data from UNHCR, IOM, UNOCHA, IFRC, ILO, UNDP, NGOs → Cluster 4W reports (who is doing what, where, when, and to whom) 	<ul style="list-style-type: none"> → Estimates drawn from RS surveillance (number of shelters and their occupants)
<p>Number of:</p> <ul style="list-style-type: none"> → fishers → boats (fleet size) → boat builders → aquaculture farmers → fish processors → fish marketers 	<ul style="list-style-type: none"> → Baseline surveys → Agricultural census → Agricultural sample surveys → Reports on fishing trends → Annual national fisheries reports → Regional fishery reports → Scientific reports and studies from scholars and universities → Reports from NGOs working in the area → Past emergency project reports → SOFIA and FIGIS → Cluster 4W reports 	<ul style="list-style-type: none"> → Field surveys → Interviews with: <ul style="list-style-type: none"> - fisheries officers - community leaders - fishers (focus groups) → Pre- and post-disaster boat count estimates from RS surveillance → Past fishery project reports
<p>Fisheries production:</p> <ul style="list-style-type: none"> → capture volume by type (marine, inland, etc.) 	<ul style="list-style-type: none"> → Agricultural sample surveys → Fishery production surveys → Baseline surveys → Annual national fisheries reports → Regional fisheries reports → Scientific reports and studies from scholars and universities → NGO reports (e.g. WWF) → SOFIA and FIGIS → Geographic Information System (GIS) mapping 	<ul style="list-style-type: none"> → Field surveys → Interviews about fisheries production trends with: <ul style="list-style-type: none"> - fisheries officers - community leaders - fishers (focus groups) - fish processors → Past fishery project reports
<p>Aquaculture production:</p> <ul style="list-style-type: none"> → volume by species → production area km² → value of production → value of hatchery investment → volume and value of hatchery production by species → fish feed volume and value 	<ul style="list-style-type: none"> → Agricultural sample surveys → Reports by national fisheries departments → Annual reports by private producers → Scientific reports and studies from scholars and universities → Customs export and import data → SOFIA and FIGIS → GIS mapping → Reports from land planning departments 	<ul style="list-style-type: none"> → Interviews about aquaculture production trends with: <ul style="list-style-type: none"> - aquaculture officers - aquaculture farmers - hatchery operators - fish processors → RS of fish farms

Data type	Traditional sources	Alternative/secondary sources
<p>Assets:</p> <ul style="list-style-type: none"> → number of boats by type, size and propulsion → quantities of fishing gear by type 	<ul style="list-style-type: none"> → Agricultural census → Specialized surveys → Fish production estimates → Baseline surveys → Past fishery project reports → Annual national fisheries reports → Regional fisheries reports → Scientific reports and studies from scholars and universities → NGO reports (e.g. WWF) → Cluster 4W reports 	<ul style="list-style-type: none"> → Field reconnaissance surveys → Administrative records → Estimates drawn from RS surveillance → Interviews with: <ul style="list-style-type: none"> - fishers (focus groups) - community leaders - boat suppliers - fishing gear suppliers
<p>Trade and markets:</p> <ul style="list-style-type: none"> → number of fish markets and marketers → trade volume → export volume → import volume 	<ul style="list-style-type: none"> → Market surveys → Customs import and export data → Fish prices and trends → Annual national fisheries reports → Regional fisheries reports 	<ul style="list-style-type: none"> → Interviews with: <ul style="list-style-type: none"> - fish marketers and traders - fisheries officers → Scientific reports and studies from scholars and universities → Reports from NGOs working in the area
<p>Environmental impacts on fishing</p>	<ul style="list-style-type: none"> → Meteorological office reports on seasonality of fishing → Ministry of environment reports on pollution → Scientific reports and studies from scholars and universities → Scientific studies on climate change impacts from UNDP <i>et al.</i> → NGO reports → European Union veterinary office reports on aquaculture (laboratory tests on pesticide and heavy metal residues) 	<ul style="list-style-type: none"> → Interviews and focus group discussions (on use of pesticides and other agro-chemicals around lakes and reservoirs) with: <ul style="list-style-type: none"> - agricultural officers - community leaders - fishers - aquaculture farmers → Observation of plastic and non-bio-degradable garbage
<p>Accountability to affected populations</p>	<ul style="list-style-type: none"> → Past fishery/aquaculture project reports → Cluster 4W reports → UNOCHA → Reports from grievance mechanisms in place 	<ul style="list-style-type: none"> → Interviews with and/or surveys of beneficiary groups

FAO's damage and loss methodology and its application in the fisheries and aquaculture sector

Standardization allows data to be aggregated and disaggregated across different activities (capture fisheries or aquaculture), geographically, and according to various disaster types

A global standard for damage and loss evaluation is fundamental for producing risk analysis that is specific to different kinds of threats, production systems, and infrastructure. Proactive management of climate- and non-climate-related risks require sound pre- and post-disaster data. However, more often than not, such data are either lacking or incomplete in the fisheries and aquaculture sector.

This deficiency is accentuated by the sector's great diversity, as marine and inland fisheries and aquaculture activities each present their own set of challenges to reducing risk, building resilience, and quantifying post-disaster damage and loss.

Standardizing evaluation methods requires uniformity in data collection to ensure that all activities are covered (marine, inland aquaculture), and to provide consistency across disaster types and countries. Only in this way can data be collated to develop aggregated and disaggregated disaster-related damage and loss assessments in capture fisheries and aquaculture on the national, regional and global levels.

FAO's damage and loss methodology, introduced in 2017 and presented again in the Technical annex of this current edition, was developed with those issues in mind.

It allows national disaster management officers to collate information on:

1) production loss in tonnes (including destroyed stored capture) and market value; 2) damage to assets including cost of repair and reparation. For the latter, consideration is given for the sector's range of production systems and commodities (including mariculture production).

FAO's methodology uses a standardized computation method to assess the direct damage and loss, and aims to measure the direct effects of a broad range of disasters of different types, duration and severity. It is designed to be applied to a range of disasters – from large-scale shocks to small- and medium-scale events with a cumulative impact.

Proof-of-concept trials in five countries validate FAO's DL methodology for fisheries and aquaculture

Proof-of-concept trials were conducted in the fisheries and aquaculture sector of five countries in South America and the Caribbean and East Africa: Burundi, Colombia, Dominica, Saint Lucia and the United Republic of Tanzania.

In each country, the methodology was tested in every context: marine, inland, and aquaculture. It was found that the methodology encourages countries to expand their data collection systems, incorporate existing fisheries baseline surveys or censuses, and consider fisheries and aquaculture sector value chain studies and analyses. The latter constitute an integral part of damage and loss assessment, because they show the economic value of fish and other fisheries products, and identify key value chain stakeholders.

These trials confirmed that while all five countries had existing systems for cataloguing fishers and aquaculture farmers, they lacked adequate tools to collect, monitor and assess disaster impacts on production. FAO's DL methodology helped to fill that gap, but underscored the need for these countries to build the supporting information infrastructure required for post-disaster analysis. The pilots also showed that disasters exert different impacts on each fishery type (marine or inland) and on aquaculture. Such typological specifics must be considered when tailoring damage and loss assessment systems at country level.

Marine fisheries in Dominica and Saint Lucia

Marine capture fisheries are particularly susceptible to storms and hurricanes, as well as heatwaves and algal blooms. Island nations often suffer the most from events related to climate change. In the Caribbean, for example, storms and hurricanes increase impacts on its often artisanal and small-scale fisheries sector. Hurricane Maria (2017) cost the sector millions of dollars in damage and loss. In Dominica, the hurricane destroyed the entire aquaculture activity, which produces mainly tilapia and *Macrobrachium*, but the lack of data collection prevents an accurate representation of the farmers' losses.

Sargassum impedes fisheries operations and managing its increased influx is costly

In recent years, some Caribbean islands such as Barbados and Saint Lucia have been heavily affected by an increase in sargassum, a seaweed that washes up on shore in very large quantities, impeding fisheries operations. Sargassum gets entangled in fishing gear, making it difficult to launch and manoeuvre fishing boats. As reported by some fishers, it also changes catch composition (i.e. observed decrease of flying fish in Barbados, prompting a large reduction in fishing effort starting from the 2011 event). Managing sargassum is costly. It requires specific equipment and infrastructure to collect, transport and store the seaweed. Although the economic impact of the region's sargassum influx has not yet been properly quantified, its effects are real. An in-depth regional assessment is fundamental to better comprehend the socio-economic impacts and challenges related to sargassum influx, and define sustainable response and prevention measures (UNEP-SPAW, s.d., Sargassum factsheet; Ramlogan *et al.*, 2017).

Dominica and Saint Lucia are among the first countries in the Caribbean to pilot FAO's DL methodology as a basis to build an integrated data collection system, and to create a baseline for post-hurricane, sargassum and general disaster assessments. Dominica is currently updating its digital register of fishermen and their assets, and revising its data collection forms for the wider information needs of the universal DL methodology for fisheries.

Inland fisheries at Lake Tanganyika

Sustainable management of any resource presupposes availability of good data and information. This principle has been generally overlooked in the case of inland fisheries, where data are essentially weak and generally insufficient for decision-making, contributing to the generally poor state of inland fisheries resources around the world. Better damage and loss assessment requires much more data collection on the inland water environment as well as on the fish and the fishers that constitute essential components of those fisheries (Welcomme, 2003).

FAO is therefore currently supporting the Lake Tanganyika Authority (LTA) in adopting data collection practices for the regular assessment of disaster impact on local fisheries activities. The emphasis is two-fold: technical support in survey methodologies and database management; identifying and implementing inter-institutional best practices for data dissemination and reporting across relevant authorities in both the United Republic of Tanzania and Burundi.



© @Reefscan/Matt Berregaard Walsh



© @Reefscan/Matt Berregaard Walsh

TOP / BOTTOM: Aftermath of Cyclone Idai, Mozambique 2019

FAO is supporting improved data collection practices for Lake Tanganyika's delicate fisheries

Lake Tanganyika is an important fishery for Burundi and the United Republic of Tanzania. It is significantly impacted by changes in water depths caused by floods and droughts. Variations in water levels affect nutrient and food web dynamics. The thermocline of this inland water body – like others in East Africa – is especially delicate and susceptible to wind-induced changes (Naithani *et al.*, 2003). Any deviation from the thermocline's standard pattern can impact the amount of fish landed, with detrimental consequences for the sector. Inland water bodies of this region are also prone to invasive weeds such as the water hyacinth, which block fishing grounds and damage vessels and engines. The weeds are also responsible for an enormous water loss through evapotranspiration. This alters the water balance of entire regions; impedes water flow, which in turn increases sedimentation, causing flooding and soil erosion; and drastically changes the physical and chemical properties of the ecosystem of the invaded water body, with harmful effects on plants and animals (IUCN ISI, 2012).

Aquaculture in Colombia

Colombia's aquaculture activity has been steadily increasing over the past ten years, especially its production of tilapia, shrimp and trout. Climate change is associated with extreme El Niño and La Niña episodes leading to increased water temperatures and more droughts, which significantly impact the interior of the country. Of particular interest is the 'Ola invernal,' a cyclical increase in temperatures during the winter months that can cause significant damage and loss. The 2010–2011 and 2018–2019 events were particularly destructive. Data is still being analysed for the latter but the former is known to have caused a range of impacts. It triggered landslides, floods, heavy gales and avalanches, increasing fingerling deaths and destroying ponds, cages and other aquaculture infrastructure. In Colombia, as in most of the Andean region, ponds are located near marshes. So, floods not only wash away cultivated shrimp and fish, but also increase sedimentation and alter the chemical composition of the water, with a reported loss of over 75 percent of stocks.

According to preliminary damage and loss assessments of the 2010-2011 event, aquaculture accounted for 13 percent of the agricultural sector's total damage and 3.7 percent of its total loss. These figures likely underestimate the event's severity, because aquaculture data are not yet being systematically collected at a national level. The country is currently in the process of institutionalizing an official damage and loss information system – based on the FAO methodology and tailored according to existing national platforms – which will strengthen and streamline disaster impact data collection and assessment for the agriculture sector in general and aquaculture in particular.

Way forward for damage and loss assessment in fisheries and aquaculture

The FAO pilots highlight the need to improve data sharing between disaster management and fisheries authorities, thereby speeding up assessments and rehabilitation, with improved national data enabling more coordinated responses to disasters

Overall, in the five countries piloting FAO's damage and loss methodology, data collection systems for marine capture fisheries were relatively well developed, facilitating easy application of FAO's approach. This is not the case for inland fisheries and aquaculture, where such systems are sorely lacking even though aquaculture data collection is improving in Colombia. The trials highlight the need for increased and systematic data sharing and communication between disaster management offices and fisheries authorities. This would greatly speed up damage and loss assessment and rehabilitation. It would also foster consolidating valuable information about the fisheries and aquaculture sector within the national data collection framework, better enabling coordinated analysis and response, and providing a more accurate picture of the consequences from any given disaster.



Locust control operations, Kenya 2020



PART II

Focus on food chain crises

Chapter IV
Agriculture in
face of a pandemic:
COVID-19 impacts
on food production

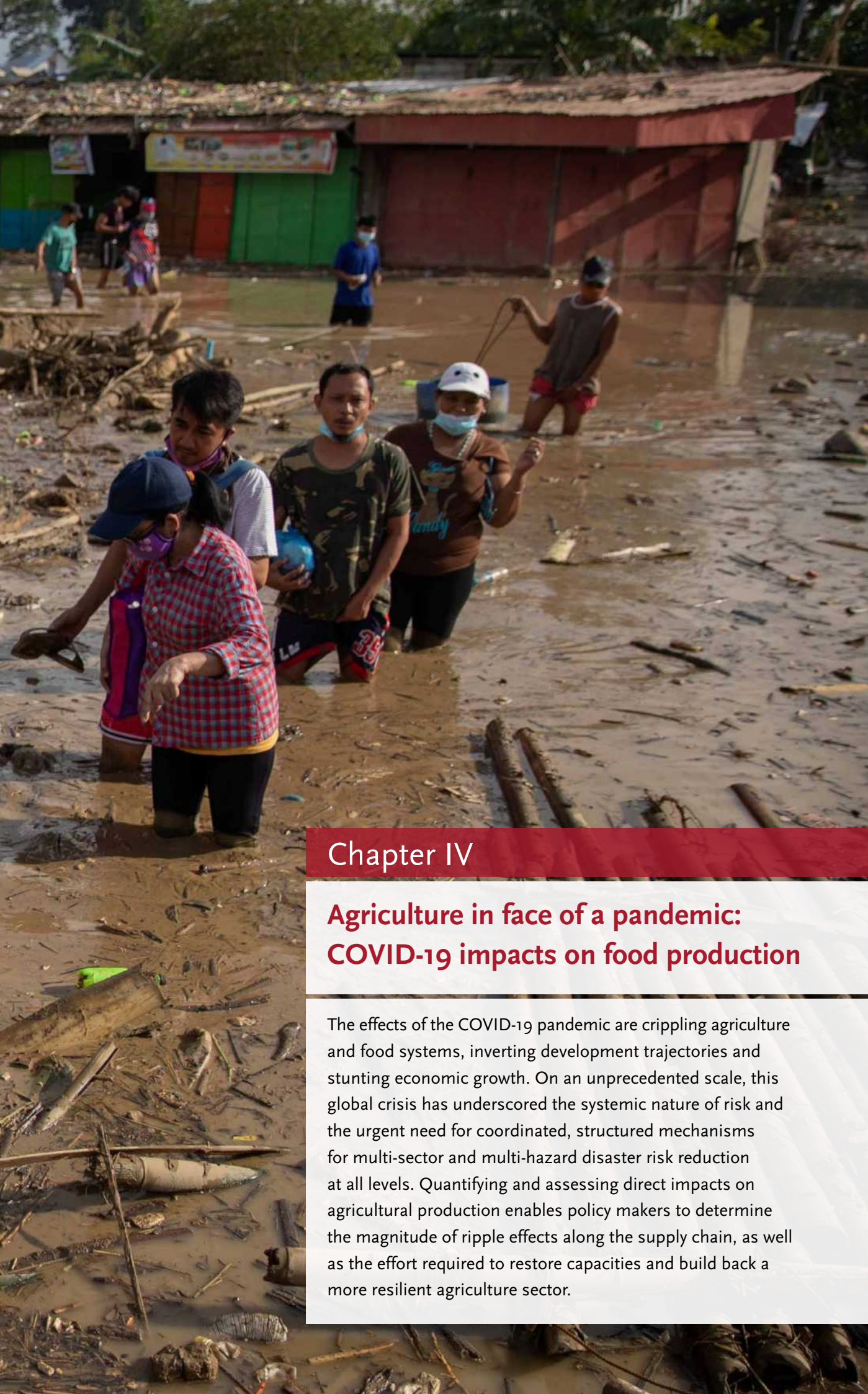
Chapter V
Animal health at
the crossroads:
bridging theory,
assessment and policy

Chapter VI
Locusts, a legendary
pest with a present-day
toll: lessons from
Madagascar



©REUTERS/Eloisa Lopez

Typhoon Vamco aftermath, Philippines 2020



Chapter IV

Agriculture in face of a pandemic: COVID-19 impacts on food production

The effects of the COVID-19 pandemic are crippling agriculture and food systems, inverting development trajectories and stunting economic growth. On an unprecedented scale, this global crisis has underscored the systemic nature of risk and the urgent need for coordinated, structured mechanisms for multi-sector and multi-hazard disaster risk reduction at all levels. Quantifying and assessing direct impacts on agricultural production enables policy makers to determine the magnitude of ripple effects along the supply chain, as well as the effort required to restore capacities and build back a more resilient agriculture sector.

A risk landscape in flux

The COVID-19 pandemic is unfolding with devastating impacts on the world economy. These are being felt by the agriculture sector in ways that are both direct and indirect as necessary measures are instated to halt spread of the SARS-CoV-2 virus. Steps taken by many countries to contain the global health crisis are disrupting both demand for and supply of agro-food products, affecting production, markets and consumers within and across borders. The extent and duration of the pandemic and its economic impacts, still pending quantification, are nevertheless increasingly discernible. It is inflicting an economic crisis of historic proportions, disrupting livelihoods, employment and the fight against poverty and food insecurity. In anticipation of the longer-term and collateral effects of the pandemic, a better understanding of the expected outcomes for agriculture is necessary.

The UN response framework addresses the pandemic on health, humanitarian, and socio-economic fronts

The UN Secretary-General has called for solidarity in raising massive and coordinated efforts to tackle the global health crisis, and provided an integrated framework to help countries protect people and recover from the impacts of COVID-19. It includes strategies to respond on the health, humanitarian, and socio-economic fronts, while protecting the needs and rights of those living under the pandemic's duress, with particular focus on the most vulnerable countries, groups, and people at risk of being left behind.¹

Meanwhile, the Sendai Framework for Disaster Risk Reduction incorporates biological hazards, such as the COVID-19 pandemic, among the major risks of the 21st century. While COVID-19 was officially declared a pandemic, its underlying factors, repercussions and impacts go well beyond the health sector. It epitomizes systemic risk, whereby the negative effects of a single hazard threaten the failure of multiple systems. With its cascading and devastating impacts on the entire economy, COVID-19 demonstrates the interconnected nature of risk today, highlighting the urgent need for a concerted global effort to accelerate risk reduction activities. While the pandemic has emphasized the need to take urgent action on biological hazards, incorporating them systematically into multi-hazard disaster risk reduction plans at national and regional levels, it has also demonstrated that such a systemic approach remains a challenge requiring collective commitments.

The COVID-19 emergency threatens to fundamentally undo progress made thus far towards achieving the SDGs

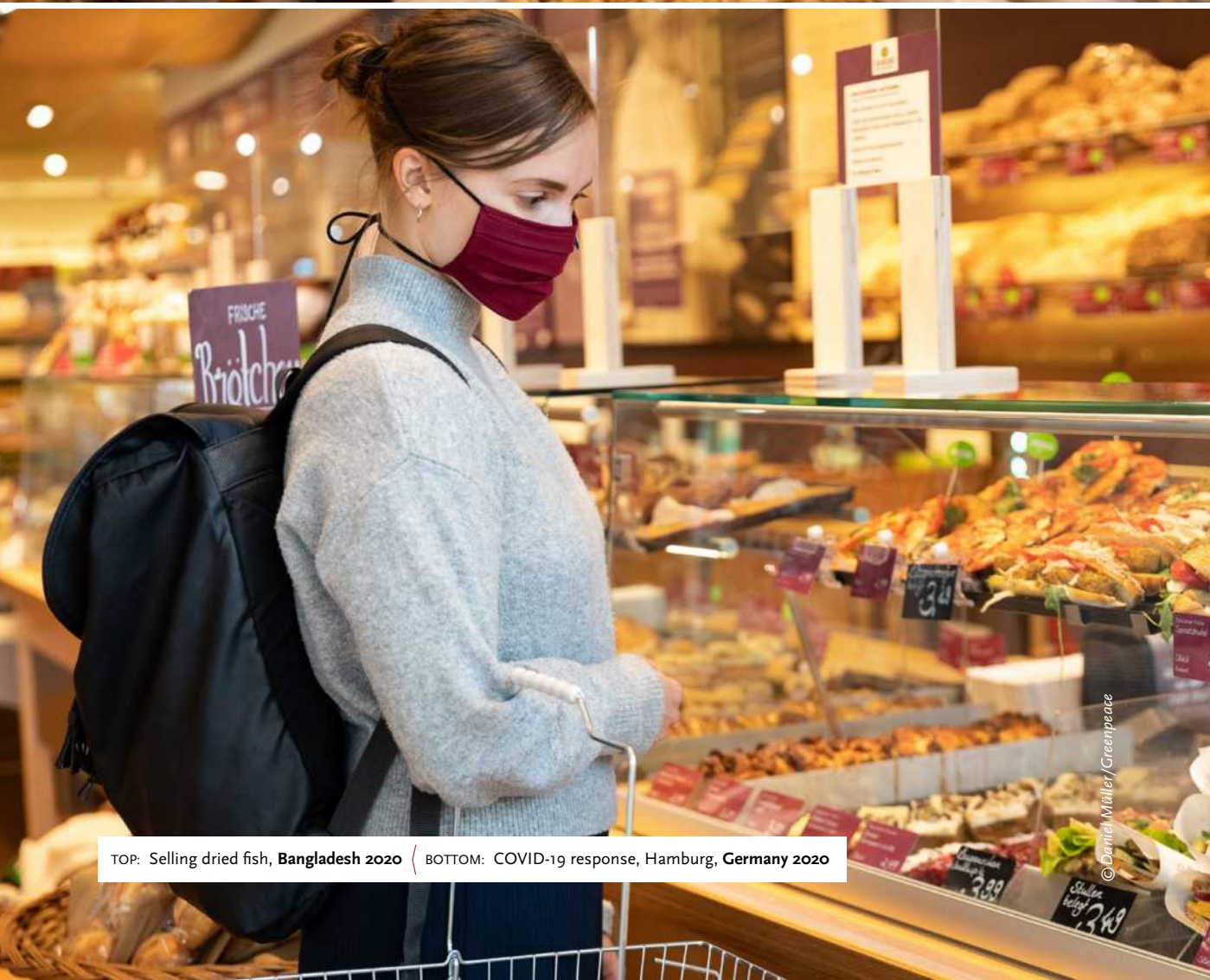
FAO is particularly concerned with consequences for the well-being, livelihoods and food security of farmers, fishers and pastoralists. The situation is highly dynamic. There has been an alarming increase in the prevalence of the virus in many low- and lower-middle-income countries. Extensive measures to prevent its spread and block its economic repercussions at both the global and country levels are affecting smallholders and vulnerable rural populations. The COVID-19 emergency threatens to fundamentally undo the progress made thus far towards achieving the SDGs, particularly SDG 1 (reduce poverty) and SDG 2 (end hunger, achieve food security and improve nutrition and promote sustainable agriculture).

The effects of COVID-19 on food security, nutrition and the livelihoods of farmers, fishers and other food supply chain workers will largely depend on the public policy response over the short, medium and long term. At present, governments must balance multiple considerations. In addition to managing the health crisis and its consequent economic turbulence, they must also ensure the smooth functioning of agriculture and food systems, which are being severely challenged.

¹ UN, March 2020, Shared Responsibility, Global Solidarity: Responding to the socio-economic impacts of COVID-19; and the UN Secretary-General's remarks to the World Health Assembly, 18 May 2020.



© FAO/Kazi Riasat



© Daniel Müller/Greenpeace

TOP: Selling dried fish, Bangladesh 2020 | BOTTOM: COVID-19 response, Hamburg, Germany 2020

Despite the immediate challenges posed by the pandemic to maintaining a well-functioning food system, post-crisis recovery will require accelerated transformations in the agriculture sector to build its resilience to all sorts of systemic shocks, including climate change, food crises and health emergencies such as COVID-19.

Collateral effects on agriculture

The pandemic is directly impacting food supply and demand. It is adversely affecting the lives and livelihoods of millions of farmers in countries battling COVID-19. Disruptions in the local, national and global supply chains have compromised their access to the inputs, resources and services they need to sustain productivity and ensure food security. It is decreasing purchasing power while also affecting the capacity to produce and distribute food. Agricultural exports have faced both demand disruptions and supply-chain issues. Millions of African smallholder farmers who export their crops have lost access to global markets as air freight operations are cancelled and borders restricted. This has been most severe for the flower sector in Kenya, which collapsed after the lockdowns, as well as for exported vegetables, nuts, coffee, and cocoa, which are all affected at various degrees. The main cocoa harvest in West Africa – providing 60 percent of the world's cocoa – was completed by the time local lockdowns were applied. However, export restrictions, demand and price reductions could lead up to a lost value of up to USD 2 billion and affect 2 million farmers in Ghana and Côte d'Ivoire (McKinsey & Company, 2020). Even in countries such as India and Kenya, where services related to agricultural value chains have been declared essential, many service providers have restricted operations due to fear of infection, lack of demand, physical distancing requirements or inability to provide personal protective equipment (PPE) to workers.

Lockdowns caused the collapse of Kenya's flower sector and severely reduced its export of vegetables, nuts, coffee, and cocoa

The disruption of supply chains is also affecting the flow of agricultural inputs such as seeds, fertilizers and insecticides. In many countries, movement restrictions are being imposed during critical times in the agricultural season, reducing access to inputs, labour and farmlands when most needed. As a result, the land area cultivated, the harvesting capacity, and the transport of goods to processing facilities and markets have been severely impacted in many countries. Short- to medium-term impacts range from production loss and reduction of farmer income to the deterioration of nutrition, especially among already vulnerable populations. In Bangladesh, breakdowns in transportation systems are leading to the dumping of perishable food products and dramatic price reductions at the farm-gate, affecting food security for rural producers (FAO, 2020e). Measures taken by the Government of Somalia to curb the spread of COVID-19 will cause a 30 to 50 percent decline in livestock exports, a 30 to 50 percent decline in remittance flows, a 20 to 50 percent increase of imported food prices, and a 20 to 30 percent decline of income among poor urban households and internally displaced persons (IDPs) (FAO, 2020a).

Farmers are experiencing reduced access to inputs, labour and farmlands resulting in production loss, lower household income and nutrition declines

The brunt of COVID-19 on rural livelihoods and food security is of particular concern in fragile and conflict-affected countries. Weak governance and state institutions, unequal access to services for vulnerable populations and, often, mistrust of government are among the challenges that make tackling the pandemic disproportionately hard in countries with already unstable social and economic conditions. These countries may also face compounding challenges, including climate change shocks, forced displacement and food insecurity. In Yemen, curfews and reduced working hours have put an additional burden on agri-businesses and markets. Key food commodities such as fruits, vegetables



© REUTERS/Baz Ratner



© UNICEF/JUNI 233859/Noorani

TOP: Flower production, Kenya 2020 | BOTTOM: COVID-19 response, Sudan 2020

and fresh milk are increasingly scarce, exacerbating the country's already critical levels of malnutrition. Addressing the needs of the world's largest refugee settlement in Cox's Bazar, Bangladesh, is daunting enough by itself. This challenge is compounded by the coronavirus pandemic, creating a crisis within a crisis. Due to movement restrictions, thousands of Rohingya refugees who are already highly vulnerable and food insecure, have been losing their jobs, livelihoods and subsequently their incomes. A rapid assessment highlighted the pandemic's negative effects on agricultural livelihoods, including disruption of harvesting due to a lack of seasonal labour, as well as of planting due to a lack of seed or fertilizer, of transport due to reduced transport facilities, and of market exchange due to lockdowns or physical distancing (OCHA, 2020).

Quantifying the impact on the agricultural sector of measures to contain COVID-19 helps determine the effort required to restore capacities and build back better

In a rapidly changing environment, it is difficult to quantify the exact impact of COVID-19-related containment measures on the agriculture sector at large, and on production in particular. However, it is clear that the sharp contractions in output, farmer income and agricultural markets and trade already underway will continue in the near future. Quantifying and assessing the decline in agricultural production enables policy makers to determine the magnitude of ripple effects along the supply chain, as well as the effort required to restore capacities and build back a more resilient agriculture sector.

Addressing agricultural production loss under COVID-19

FAO provides a set of tools and approaches to identify and monitor risks for overall food security and food systems stemming from the COVID-19 epidemic, as well as to assess impacts along the entire food chain. In line with this corporate global approach, FAO's damage and loss assessment methodology can present a useful mean to help understand how the crisis affects overall agricultural outcomes (i.e. loss), and the production stage in particular. While originally applied to assess the impacts of natural hazards and extreme events, it can further serve as a valuable tool to assess the overall production outcomes (i.e. loss) of agricultural seasons in COVID-19 affected areas.

For the past three years, FAO has been supporting partner countries in developing and implementing information systems to assess disaster-related DL in agriculture. Regions already trained and adopting the FAO DL methodology are: Latin America and the Caribbean, with Chile, Uruguay and Colombia already at the implementation stage; Central Asia, with pilots under way in Kyrgyzstan and Tajikistan; Southeast Asia; Eastern Europe; North Africa and the Near East; and Eastern Africa. The process equips countries with an information system to regularly collect, record and analyse the impact of disasters ranging from large-scale shocks to small-scale localized events, such as abnormal weather fluctuations. The impact is reported in terms of damage (to inputs and assets) and loss (in production flows) in all agricultural sectors including forestry, fisheries and aquaculture. Furthermore, the methodology constitutes a global effort to monitor and reduce disaster impact in agriculture as set by Sendai Framework Indicator C-2 and SDG Indicator 1.5.2.

In sum, the COVID-19 pandemic poses a potential threat to agricultural production via multiple channels, e.g. reduced/altered demand, reduced access to inputs and credit, logistical issues, etc. Disruptions in the factors of production ultimately result in a decline in agricultural output and potential food deficits particularly of high-value, perishable commodities, within affected areas (FAO, 2020b), if not compensated by an increase in food imports.

The seasonality and exact timing of agricultural activities must be carefully assessed in relation to the potential impacts of COVID-19 and its related containment measures. As the crisis evolves differently in every country, it is important to identify the timeframe when control measures and restrictions were in place vis-à-vis the agricultural season. Pandemic-forced lockdowns can disrupt labour mobility, markets and transportation. As a result, farmers may struggle to sow, harvest or sell their crops, leading to widespread production losses with concomitant effects on livelihoods and food security.

Other disasters such as storms, drought, and desert locusts are compounding the pandemic's impact on agriculture in many countries

In addition, while the COVID-19 pandemic is in full swing, other impending disasters such as hurricanes, earthquakes, floods, and pests can compound the already significant effects on agriculture. Some countries have already experienced these dual crises. Such has been the fate of Vanuatu, devastated by category 5 Tropical Cyclone Harold less than a month after the global pandemic was declared; the Republic of Moldova, suffering from both drought and an outbreak of COVID-19; the Philippines and Central America hit by Typhoon Vamco and Hurricane Iota respectively in mid-November; and more than a dozen countries battling the SARS-CoV-2 virus and an upsurge in desert locusts simultaneously. In such situations, it is important to cross-reference the occurrence of a concurrent disaster in order to differentiate respective impacts during the assessment process or account for compound production loss.

Below is an overview of how FAO's DL methodology can be used to assess production outcomes in a COVID-19 context, if the tool has already been institutionalized into national agricultural disaster loss information systems.

1. Conduct assessment of COVID-19-related risks to the production process

These main factors can indicate whether agricultural production is at risk of disruption and potential loss due to COVID-19, thereby indicating the need for an assessment process:

- Timing of COVID-19's spread and respective containment measures vis-à-vis the calendar for agricultural activities (e.g. sowing, harvesting, livestock migration).
- Reduced access to cropland and grazing land given national and regional containment restrictions during key periods.
- Disruption of input supply (seeds, animal feed, fertilizers, tools, etc.) during key periods.
- Disruption of input prices (including tools, fuel, etc.) during key periods.
- Workforce disruption (seasonal and migrant workforce in particular).
- Disruption of demand (due to closure of food-related businesses and processing facilities).
- Fluctuation/increase in interest rates and disruption of access to credit for farmers.
- Presence of concurrent shocks and disasters (any exogenous hazards that may further jeopardize agricultural production, such as drought, flood, hurricanes/cyclones, invasive plant pests, animal disease outbreaks).²




² FAO's DL methodology is tailored to assess the impact of weather- and climate-related disasters and shocks. If any of these are present together with COVID-19, the methodology should be used in a way that allows the impact of those disasters to be disentangled from that of COVID-19.

If any of the above risk factors are disrupting the production process, the DL methodology can be used to estimate the volume and value of resulting production loss in all affected sub-sectors. However, the DL methodology alone cannot attribute those losses to any of the above risk factors, as it does not address causality. Instead, these factors indicate when an assessment process should be made using the FAO DL framework.

Because the COVID-19 pandemic does not entail physical destruction of assets and stocks, the relevant methodological component is production loss

The methodology consists of three main components that together capture the entire production process across all subsectors – production damage, production loss and asset damage (FAO, 2016c; Conforti *et al.*, 2020). The damage category entails physical destruction of assets (such as machinery, tools and structures) and stocks (stored inputs and outputs), which frequently occurs in disasters such as floods, storms, cyclones, landslides, etc. In the context of COVID-19 – a pandemic with no direct physical repercussions for assets and stocks – the relevant methodological component is production loss (Figure 1), which measures the volume and value of foregone production, compared to pre-disaster expectations.

Figure 1. Three components of FAO's damage and loss methodology

	Damage	Loss
Production	Pre-disaster value of destroyed stored production and inputs 	Difference between expected and actual value of production and short-run disaster expense 
Assets	Replacement or repair value of destroyed machinery, equipment, tools 	

The Crop Production Loss component is composed of the following elements (formulas):

- 1) Difference between expected and actual value of crop production in partially affected (but harvested) areas.
 $\rightarrow p_{i,j,t-1} * \Delta y_{i,j,t} * ha_{i,j,t}$
- 2) Pre-disaster value of destroyed standing crops in fully affected (not harvested) areas.
 $\rightarrow p_{i,j,t-1} * y_{i,j,t-1} * \Delta ha_{i,j,t}$
- 3) Short-run post-disaster maintenance costs (expenses used to temporarily sustain production activities immediately post-disaster).
 $\rightarrow P_{short-run}$

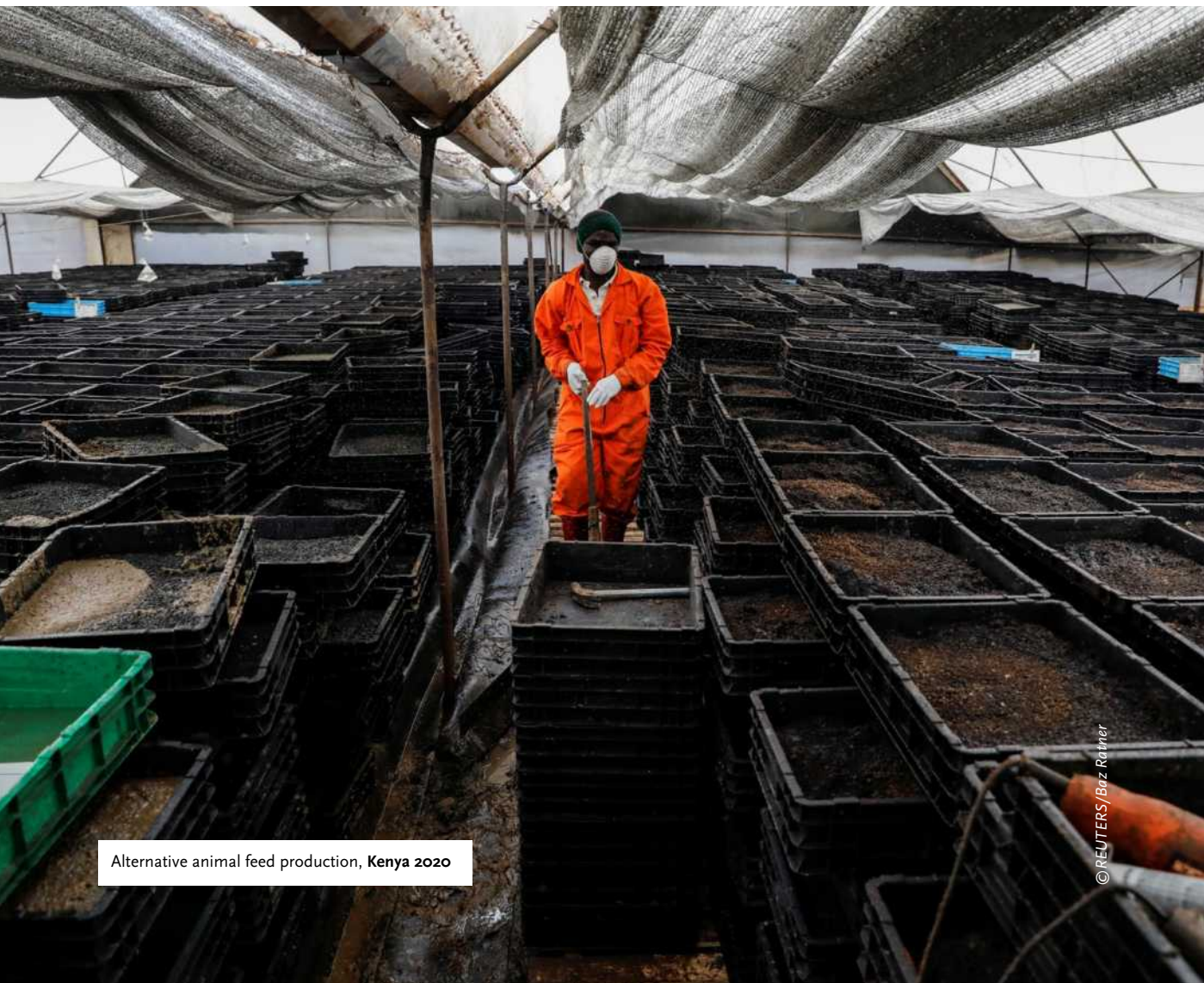
To capture the effects of COVID-19, the first element may be used in scenarios in which production is partially affected. This could be due to reduced availability of inputs (less is harvested if less is sown), shortages of labour, or reduced demand that forces farmers to forego a share of the harvest. In this case, production loss will be calculated based on the difference between actual (materialized) production post-harvesting and the expected production by crop, as estimated from trends in reported volumes in previous years/harvests.

The second element, focused on fully affected areas, is applicable to scenarios where no harvesting at all takes place over the affected area. This could be caused, for example, by disrupted access to agricultural lands. In this case, production loss will be calculated based on the overall expected production from the entire affected area (estimated from trends in reported volumes in previous years/harvests).

The maintenance costs element normally captures all short-term expenses incurred to temporarily maintain production activities in the aftermath of a disaster. In the context of COVID-19, this third element can capture the costs of protective equipment for farmers and workers, disinfection, additional transportation costs, etc. It can also capture possible social transfers to support farmer livelihoods as well as additional support for access to credit (which should be subtracted from the overall costs).

FAO's DL methodology can help decision makers develop and implement targeted, timely and effective COVID-19 responses for farming communities

The DL methodology in itself does not account for any causal attribution of the factors and channels affecting production nor provide any inference in terms of predicting whether production will be affected. Furthermore, the methodology does not account for the wider or longer-term socio-economic impacts of the pandemic and other disasters, beyond agricultural production and along the entire food and non-food value chain (e.g. food security, migration, rural employment, balance of trade, domestic value added, etc.). The methodology and its computation methods focus uniquely on the impact of disasters on agricultural assets and production flows. In the case of concurrent or compound disasters, the DL methodology may not be able to differentiate or attribute the respective impact of the different events in the absence of auxiliary calibrating information. Nevertheless, it is a versatile tool to account and quantify the transpiring production loss that has occurred. In a COVID-19 context, in combination with identified risk factors (see above), the methodology can provide national decision makers with the evidence base to implement timely and effective response to the crisis and promote a swift recovery thereafter.



Alternative animal feed production, Kenya 2020



© FAO



© Antara Foto/Anwarisyah Putra, via REUTERS

TOP: Distributing COVID-19 aid, **Somalia 2020** | BOTTOM: Rice production, **Indonesia 2020**

2. Data and information

An effective and robust COVID-19 recovery will depend on data collection, as well as analysis, but data producers are themselves limited by measures to contain the virus, jeopardizing the ability of national statistical systems to provide timely and accurate production analyses

Quick action is key to ensuring an effective COVID-19 recovery, which also builds resilient food systems globally. To this end, there is an urgent need to provide data and analysis to support policy formulation and programme design to prevent disruption of production, food systems, avoid food insecurity and protect livelihoods. Yet, the capacity of national statistical systems and other data producers has been largely limited by imposed containment measures, thus jeopardizing countries' ability to produce timely and accurate analysis of production outcomes.

At the national level, data collection methods need to be urgently adapted and enhanced, as traditional survey processes – such as face-to-face interviewing – are disrupted by physical distancing measures to contain the pandemic. Innovative methods, such as phone- and web-based interviewing and remote sensing, are better-suited to ensure timely and responsive data to meet the new demands presented by the pandemic. In order to obtain the necessary information for

Data points required to conduct production loss assessment:

- size of area affected;
- crops by area, by type;
- yield by crop from t-1 through t-3 (the years preceding the emergency);
- price by crop from t-1 (pre-pandemic levels).

Note: The volume of crop loss can also provide a basis for estimating nutrition loss, by deriving the caloric and micronutrient charges of foregone crop production.

assessing production outcomes, the availability of already established and proven systems for agricultural data collection are a key advantage. To tailor pre-existing data collection systems for production and productivity assessments to the COVID-19 context, targeted questions should be incorporated into existing surveys.

Information sources and systems that are frequently updated can be used to monitor risk factors and production shifts

At the global level, existing information sources and systems should be prioritized for the monitoring of both risk factors as well as actual shifts in production. This includes the use of frequently updated and reliable national/regional/global databases, as well as relevant analyses from other organizations on observed trends related to direct and indirect impacts of COVID-19. For example, fluctuations in food prices in local markets can be sourced from national and regional market price bulletins and global databases. Similarly, information on COVID-19 spread and containment measures can be extracted from bulletins and analyses produced by governments and organizations like WHO.

Learning from the present to prepare for the future

The COVID-19 pandemic has revealed the systemic nature of risk and highlighted the high exposure of socio-economic systems to multiple hazards with cascading effects. The Global Assessment Report (GAR) 2019 and the Sendai Framework for Disaster Risk Reduction convey with urgency that in an increasingly populous, networked and globalized society, the very nature and scale of risk have changed to such a degree that it surpasses existing traditional risk management institutions and approaches. The future is uncertain as to when the pandemic will be deemed under control and the recovery phase will commence. As recovery plans and instruments are being designed by national and regional entities, they present an opportunity to reiterate the need for multi-hazard, multi-sectoral and multi-stakeholder risk reduction strategies.

Using FAO's DL methodology to understand the pandemic's impact on agriculture can help identify weaknesses, choke points and vulnerabilities in agricultural production systems so they may be strengthened for future crises

In this light, ensuring that food systems are more sustainable, resilient and better prepared for future crises is an ever more urgent priority. In particular, it will be important to examine the resilience toolkits currently available for the food system, with a view toward identifying those policy measures that have proven most effective and determining what new measures may be needed to prepare for and respond to systemic shocks. When institutionalized and operationalized at national level, assessments provided via FAO's damage and loss methodology can form the basis of analysing the various policy measures. Understating the scope of pandemic-related agricultural loss can – in combination with other tools – help build an evidence base to identify weaknesses, choke points and vulnerabilities in agricultural production systems. This is a stepping stone towards increasing preparedness for systemic risks and targeted disaster risk reduction policy and planning. In order to operationalize the DL methodology, it is necessary to establish and enhance data systems at the local, national and global levels so that reliable, detailed and subsector-specific information can be made available for assessment and ultimately inform decision makers.

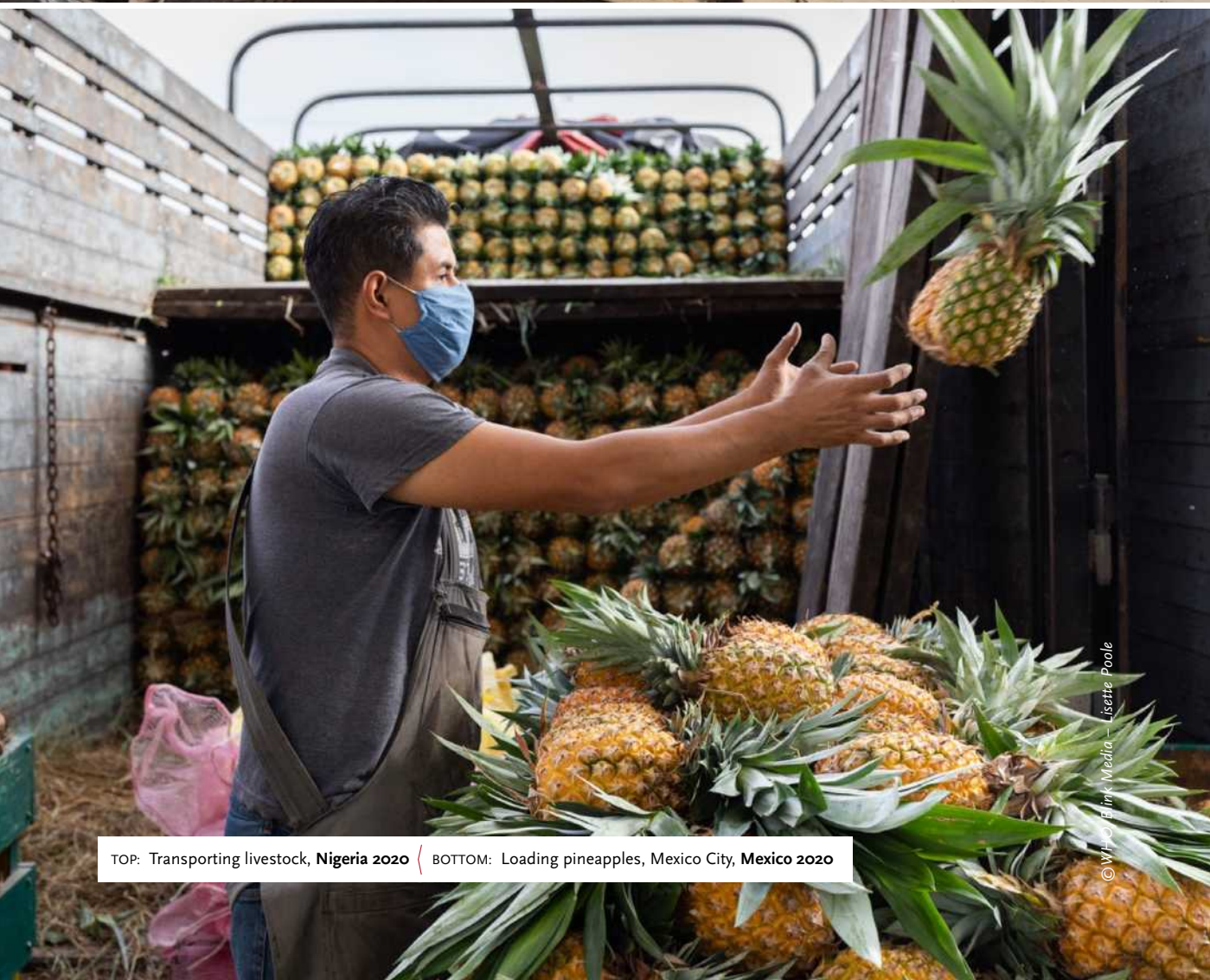
Lessons from the pandemic underscore the need for comprehensive risk management capable of anticipating and responding to diverse challenges in integrated ways

Furthermore, lessons from the COVID-19 pandemic will need to be integrated into wider responses to other challenges confronting agriculture and the global food system. Among those challenges are the ongoing climate emergency as well as the need to build food systems resilient to multiple hazards and systemic risk; ensure food security in a changing climate, while simultaneously reducing the sector's greenhouse gas emissions; preserve biodiversity; and control and prevent a range of animal and plant diseases, including those that affect human health directly, via food borne disease (such as bovine spongiform encephalopathy, or 'mad cow' disease), human-to-human transmission (as with zoonotic coronaviruses), and by inducing human antimicrobial resistance (when antimicrobials are used inappropriately in the livestock sector), as well as those that impact food security by reducing animal and crop production (as with African Swine Fever and fall armyworm).

Against this challenging backdrop, FAO's damage and loss methodology and similar tools must become fully institutionalized. Only in this way can a truly integrated and cross-cutting approach be developed in the future to better capture the multi-hazard impact of various emerging disasters on agriculture and its subsectors.



©FAO



©WHO/Elinor Medina - Lisette Poole

TOP: Transporting livestock, Nigeria 2020 | BOTTOM: Loading pineapples, Mexico City, Mexico 2020





Chapter V

Animal health at the crossroads: bridging theory, assessment and policy

Animal health has broad implications, ranging from livestock sector development and sustainability, to the well-being of human communities and issues of global security. The direct impacts of animal disease vary from reduced production and productivity to the elimination of entire herds, and often bring about restrictions impeding access to local markets and regional or international trade bans. Preventing and managing animal disease risk is a complex process that requires proportionate investment to support the achievement of several SDGs. This chapter explores the impact of major animal disease threats on the livestock sector, making the case for improved assessment techniques and a rethinking of the entire animal health system.

Protecting livestock to strengthen livelihoods and save lives

Animal health is at a crossroads. Disease risks are being amplified by various factors, including advancements and integration of commercial systems, the intensification of global food, agriculture and animal production, climate change dynamics, urbanization and human incursion into wildlife habitats. Infectious disease spreads along a pattern that cuts across wildlife, livestock and human populations. Few diseases are limited to one group only, and the shifting dynamics of interactions among host populations set the scene for further disease emergence and spread. Over 70 percent of new diseases in humans are of animal origin, with the potential of becoming local or global public health threats (FAO, 2017a). The impacts of these dynamics are evident in the most recent spread of the novel coronavirus SARS CoV-2, which causes COVID-19 and has sparked a global pandemic with spiralling impacts.

Good animal health promotes more efficient use of natural resources, lowers GHG emissions, reduces need for antimicrobials, safeguards human health and livelihoods, and strengthens food security

The livestock sector plays a central role in the livelihoods of over a billion people worldwide and contributes around 40 percent of global agricultural value-added. Promoting good animal health and welfare in the livestock sector yields benefits beyond improved productivity alone. It contributes to: more efficient use of natural resources; lower greenhouse gas emissions from the production of goods such as milk, meat, eggs, wool and hides; reduced need for antimicrobials; protection of farmers and consumers from food-borne illness and other zoonoses; secured livelihoods for farmers; and, ultimately, food security. Thus, animal health and welfare relate to all the sustainability dimensions of the 2030 Agenda and remain equally relevant considerations in capital-intensive, labour-intensive, and pastoralist systems across the world.

Main factors in disease dynamics

Despite public health and veterinary health improvements in recent decades, the livestock sector and its animal populations remain highly vulnerable to a wide range of health threats. In many LDCs and LMICs, uncontrolled re-emergence of infectious diseases endangers the main asset of smallholder farmers – their livestock – compromising their livelihoods, incomes and food security. Typically, animal diseases have strong negative impacts on production, disturb livestock farming systems and disrupt markets and trade. African swine fever (ASF), foot-and-mouth disease (FMD), peste des petits ruminants (PPR), and lumpy skin disease (LSD) are only a few examples of high-impact livestock diseases known to cross borders and jump between species. Even though they do not infect humans, they cause significant disruptions in livelihoods of rural communities and smallholders, impacting food security and nutrition of the most vulnerable populations.

Spread of infectious disease cuts across wildlife, livestock and human populations, and over 70 percent of new diseases in humans are of animal origin

On the other hand, certain infectious animal diseases can be contagious to humans or compromise food safety, posing direct public health concerns. Zoonotic diseases such as the H5N1 and H7N9 avian influenzas, the 2009 H1N1 pandemic influenza, Rift Valley fever, brucellosis, rabies, and some coronaviruses have serious repercussions for human health, causing morbidity and mortality. These highly contagious diseases spread rapidly, inflating into local epidemics and even global pandemics.

Cattle diseases increase GHG emissions up to 24 percent per unit of milk produced and up to 113 percent per unit of beef carcass Additionally, the animal morbidity and mortality generated by infections elevates the livestock sector's emission of greenhouse gases, thus raising an environmental issue and contributing to climate change. Deteriorations in livestock health due to disease are associated with behavioural and metabolic changes, which can significantly affect GHG emissions. Animals fighting an infection will need more energy for maintenance, thus increasing emission rates from digestive processes. Cattle diseases have been found to increase GHG emissions up to 24 percent per unit of milk produced and up to 113 percent per unit of beef carcass (Grossi *et al.*, 2019). Furthermore, diseases that temporarily stunt livestock growth increase the time it takes to reach maturity, thus prolonging emission periods. On the other hand, emissions produced during livestock rearing are a net loss if the animal dies in an outbreak before its productive value is harvested.

Understanding the environmental, epidemiological and social factors that lead to emerging infectious diseases in animals is critical in preventing, responding to, and managing outbreaks. Despite substantial improvements in pathogen detection and control – and sometimes eradication¹ – of many endemic diseases, new animal health threats continue to emerge. The rapid pace of infection occurrence observed in recent years is connected with the increased pervasiveness of suitable conditions for pathogen emergence and spread. In LDCs and LMICs in particular, there has been relatively little progress in limiting the growing prevalence and impacts of many debilitating livestock diseases. The main drivers for infectious disease occurrence – most of them anthropogenic in origin – revolve around ecosystem change, ecosystem intrusion, agricultural practices and movement of people and livestock.

Key factors behind the changing dynamics of animal health include:

- Intensification of animal production systems, which has changed practices for animal nutrition, increased the use of antimicrobial agents, expanded the occurrence of high densities of animals with suboptimal husbandry conditions, and reduced genetic diversity.
- Climate change-related factors and the growing occurrence of disasters, which introduce ecological disturbances into finely-tuned ecosystems, modifying interactions between pathogen vectors and animal hosts.
- Population growth and the movement of people, especially migration, which exacerbates conditions for pathogen spread and transmission.
- Rapid and large-scale trade of animal food products, which enables pathogens to spread faster and over a wider geographic expanse.
- Accelerated urbanization and deforestation encroach on wildlife habitats and place wildlife, humans and livestock in greater proximity to one another. It is a common scientific understanding that most zoonotic diseases originate in wildlife.
- Socio-economic factors, such as poverty, inadequate living conditions and overpopulation, are generally associated with closer contacts between humans and animals and can bring greater exposure to vectors and higher risk of disease emergence.
- Lack of disease control and prevention capacities in countries with poor public health and animal health management capacities.

¹ An undeniable achievement in this regard has been the progressive control of rinderpest, leading to its global eradication in 2011.

Measuring impacts, assessing outcomes

The ability to report and share information on livestock diseases and their impacts is as crucial as the ability to detect them. In fact, a prerequisite for effectively controlling and responding to emerging diseases is a broad understanding of the impact such epidemics can – and do – have on the livestock sector.

FAO's standardized methodology provides a set of procedural and computational steps for consistent damage and loss assessment for the livestock sector across disasters and countries. It covers all aspects of livestock production – from the availability of inputs to deteriorations in weight, body condition and production of animal goods such as meat, dairy, wool, eggs, etc. Applying FAO's tailored methodology to assess the outcomes of animal diseases helps build a better understanding of the economic loss associated with the resulting morbidity and mortality of livestock. In turn, this allows for better-informed national resilience policy and action, addressing economic loss as well as considering related recovery and rehabilitation costs. It also contributes to the adequate representation of the livestock sector in the global monitoring of DRR targets under the Sendai Framework and the SDGs.

FAO's standardized methodology enables consistent damage and loss assessment across disasters and countries, informs national policies, and improves representation of the livestock sector against global targets

While the assessment foundation is there, improved data and information structures are necessary to both inform and successfully apply this methodology for the livestock sector according to its potential. While recent trends point towards improvements in the global availability and quality of animal disease data, large areas of '*terra incognita*' persist on the livestock morbidity and mortality map.

The impacts of animal disease outbreaks can follow a direct channel, i.e. causing animal mortality and livestock production loss, or extend to further disruptions along the supply chain, e.g. supply and demand shocks, trade restrictions, logistical interruptions. Most of the impacts result from control measures implemented by industry, governments and farmers to curb spread of the disease, e.g. movement restrictions, culling, etc. Table 1 indicates the main categories to be considered when applying FAO's damage and loss methodology to animal disease outbreaks.

Table 1. Impacts of animal diseases on livestock production and marketing

Direct disease effects	<ul style="list-style-type: none"> → higher animal mortality → susceptibility to other diseases due to deteriorated body condition → loss of production caused by deteriorated body condition → farmers may discard perishable feed and animal products
Effects of control measures	<ul style="list-style-type: none"> → culling → animal product waste → hindered access to supplies, medicine and equipment → reduced access to markets and inability of farmers to sell their products → price fluctuations → trade disruptions → import and export restrictions and reduction

For the decade of 2000–2010, the direct cost of zoonotic diseases is estimated at over USD 20 billion, while indirect loss exceeds USD 200 billion globally (World Bank, 2010; World Bank, 2012). The combined economic loss from six major outbreaks of highly fatal zoonoses between 1997 and 2009 amounts to USD 80 billion (World Bank, 2012). This does not include the numerous indirect impacts of animal disease, which span multiple domains – from immediate disruptions of market access, trade restrictions, delays in restocking and price fluctuations, to longer-term effects on the food security, livelihoods and even political stability of affected communities, countries and regions.

Collecting and analysing data as part of regular animal disease damage and loss assessment, based on FAO’s methodology, requires the ready availability – preferably electronically and in a georeferenced format – of livestock inventories as well as data on resulting mortality, morbidity and productivity impacts. A high degree of standardization is also necessary so that the different assessment and input data may be integrated at all levels of government and private sectors.

Apart from FAO’s methodology, there is no unified and consistent system for collecting, analysing and accounting for damage and loss from animal health threats at a global level

Currently, national animal disease reporting systems vary considerably in quality, representativeness, timeliness and coverage of events. Yet, global statistics inevitably rely on regional and country data, reflecting their respective strengths and weaknesses. This means that – apart from FAO’s new methodology – there is presently no unified and consistent system for collecting, analysing and accounting for damage and loss from animal health threats at a global level. This deficiency substantially restricts governments’ abilities to develop comprehensive and well-integrated strategies to effectively address key issues around animal health, food safety, sector productivity, food security and public and environmental health.

A functional information system for animal health should include: diverse types of health indicators; the implementation of surveillance plans that are scientific and objective; health event observations; field data collection exercises; data systems for collecting and storing damage and loss information; analytical data processing and the ability to disseminate its results; as well as decisions and actions taken in response to surveillance and impact assessment information. The type, scale and intensity of animal production systems may affect the way disease outbreak and impact data are collected and aggregated. The timing of outbreaks relative to the production cycle, the cropping season or concomitance with other disasters causing mortality in livestock are important considerations when assessing damage and loss. What is more, the coping strategies adopted by livestock farmers tend to be either insufficient or excessive, missing the mark because they are based upon farmers’ subjective experiences of previous outbreaks rather than the objective reality of the current episode. This poses additional challenges when it comes to relying on household survey data to estimate impacts at the farm level.

When outbreaks become pandemics: livestock in the COVID-19 era

A pandemic can have catastrophic effects on animal, livestock as well as human life, and even trigger environmental and economic shocks and crises. The SARS (2002-2004), H5N1 (2008), and H1N1 (2009) pandemics illustrate the persistent risk of emerging infectious, zoonotic diseases and the grave economic consequences that can transpire. While the precise origin of SARS CoV-2 remains under investigation, as of yet, no detected link to domestic livestock production has been detected.

Global monitoring and early warning systems can help curb the spread of livestock diseases across national borders

As the global offensive against SARS CoV-2 and COVID-19's long-term economic impact necessarily continues, existing practices in livestock disease surveillance can serve as an example of general zoonosis management and long-term pandemic preparedness. Global monitoring and early warning systems can help curb the spread of livestock diseases across national borders. A broad range of best practices in farm and facility management, animal nutrition, veterinary diagnostics and treatment exist which are advancing the management of zoonotic diseases in many parts of the world. Lessons learned from the livestock sector can inform the continued development of more robust early warning systems for wildlife-related diseases, facilitating the timely detection and control of pathogenic viruses like SARS CoV-2.

While SARS CoV-2 is not infecting livestock, COVID-19 is harming the sector indirectly, though it will take time for these consequences to be fully felt, let alone thoroughly quantified. As of late 2020, comprehensive formal assessments have not been possible. However, observations reveal significant disruptions to livestock value chains. Animal production worldwide shows signs of having been significantly impacted by reduced access to animal feed, inputs and services, brought about by physical distancing measures and movement restrictions. Wide-spread closures of animal markets means that producers are unable to sell their goods. Disruptions of logistical channels and declines in demand are causing significant reductions in sales and prices. For example, as of July 2020, pig prices in the U.S. market dropped by over 27 percent compared to pre-pandemic levels. In addition, limited demand and market access has forced farmers in the United States of America, Canada and elsewhere to dump their milk production, inflicting significant production loss. Meanwhile, because producers of small ruminants and poultry in LDCs tend to be predominantly women, disruptions in those sectors have hit them the hardest, compromising household food security.

Understanding the impact of animal diseases – a case study approach

FAO's DL methodology can be tailored to the relevant production system and specific animal disease, while other concurrent hazards must be disentangled

While FAO's damage and loss assessment methodology can be used to assess the impact of animal disease in different contexts – including in the current COVID-19 pandemic² – it must be tailored to the relevant production system and specific animal disease. Quantitative data collection, interviews, stakeholder discussions, semi-structured questionnaires, and participatory rural appraisals are some methods used to provide the information necessary to conduct such analysis. Unless a more elaborate multi-assessment process is conducted, it is important that the impact is attributed only to a specific animal disease and not to other animal diseases or hazards that may be occurring in the system simultaneously. However, increased mortality rates during an outbreak may be harder to disentangle and attribute in the case of concurrent disasters, such as drought or poor weather conditions.

² A set of methodologies and examples of socio-economic assessment are presented in the 2016 *FAO Guidelines on Economic Analysis of Animal Diseases*. A precise formula is presented in the Technical annexes of the 2017 and 2021 editions of FAO's *The impact of disasters and crises on agriculture and food security*.

Table 2. Scale of impact of animal health threats along key domains

Animal health threat	Livelihoods	Value chains and markets	Food security	Human health
African swine fever (ASF)	●●	●●●●	●●●	—
Antimicrobial resistance (AMR)	●●	●	●●●	●●●●
Brucellosis	●●	●●●	●●	●●●
Contagious bovine pleuropneumonia (CBPP)	●●●●	●	●●●	—
Foot-and-mouth disease (FMD)	●	●●●●●	●●	—
Highly pathogenic avian influenza (HPAI)	●●	●●●●	●	●●●●●
Newcastle disease (NCD)	●●●●●	●	●●●●●	—
Peste des petits ruminants (PPR)	●●●●●	●●	●●●●	—
Rabies	●●	—	●	●●●●●
Rift Valley fever (RVF)	●	●●●	●	●●●●●

Legend: — No impact ● Very low impact ●● Low impact ●●● Moderate impact ●●●● High impact
 ●●●●● Very high impact Source: FAO, 2016a

Table 2 indicates the intensity of impacts due to various animal diseases in the domains of livelihoods, value chain and market access, food security, and human health (zoonoses). It provides a concise point of reference to guide the design and implementation of impact assessments by indicating the method, data requirements, and potential sector(s) or specific questions to be addressed.

Several high-profile animal diseases provide illustrations of the risk, damage and loss associated with such outbreaks, as well as the challenges in quantifying their effects, and the associated opportunities for their control.

Foot-and-mouth disease (FMD)

FMD is highly contagious and triggers more embargoes on the international trade of meat than any other animal disease

FMD is one of the most contagious animal diseases and can quickly spread across national borders. This transboundary animal disease (TAD), causes severe sectoral losses as well as socio-economic consequences. FMD is still widespread and endemic in many regions of the world, especially large parts of Africa, the Middle East and Asia. It decimates livestock populations rapidly, causing fever, blisters, foot and mouth erosions, reduced milk production, and rare mortality in young animals. In other parts of the world, where FMD has been eradicated (Oceania, Western Europe, North and Central America) or controlled (South America), countries are still at risk of incursion.

According to the World Organisation for Animal Health (OIE), the FMD virus is present in up to 77 percent of the global livestock population, and an estimated 75 percent of impacts associated with the disease are borne by LDCs and LMICs (OIE, 2020). FMD triggers more embargoes on the international trade of meat, especially beef, than any other animal disease, and this is responsible for most FMD-related loss. FMD outbreaks in countries where the disease had previously been eradicated continue to cause loss of approximately USD 1.5 billion per year.

Although more difficult to assess, loss in endemic regions is roughly estimated at over USD 6.5 billion a year (FAO, 2018a). Table 3 shows the impact FMD inflicted on the livestock sector 2017–2019 worldwide, based on OIE’s World Animal Health Information System (WAHIS) and FAO’s Global Animal Disease Information System (EMPRES-i).

Controlling FMD requires close cooperation among national, regional, and global actors and the mobilization of appropriate resources

Endemically infected countries are prohibited from exporting livestock products to FMD-free countries and regions, where commodity prices are generally higher, implying significant revenue loss for would-be exporters in the global south. The disease also involves localized impacts on food availability. In endemic areas, FMD is found most often in small-scale farming systems. It can reduce milk production, limiting the availability of milk for communities that are severely affected. If this coincides with gaps in other food products such as crops, an FMD outbreak can have serious and direct consequences on food security, livelihoods, and incomes.

Reducing FMD incidence in endemic countries by a coordinated control strategy at national and regional level is of global interest and should continue to be a priority of animal health systems worldwide. Controlling FMD and reducing its impact on livestock and livelihoods would have a hugely positive economic impact on both FMD-infected and FMD-free countries. However, this requires close cooperation among national, regional, and global actors and the mobilization of appropriate resources.

Table 3. FMD 2017–2019

Year	Number of outbreaks across 65 countries	Morbidity (cases)	Mortality (deaths)	Culling
2017	3 357	162 121	4 556	20 317
2018	4 099	353 030	23 775	18 243
2019	5 328	245 066	7 315	80 477
Share of impact by production system (commercial vs backyard)			23% / 77.7%	

Sources: OIE WAHIS, EMPRES-i.

Peste des petits ruminants (PPR)

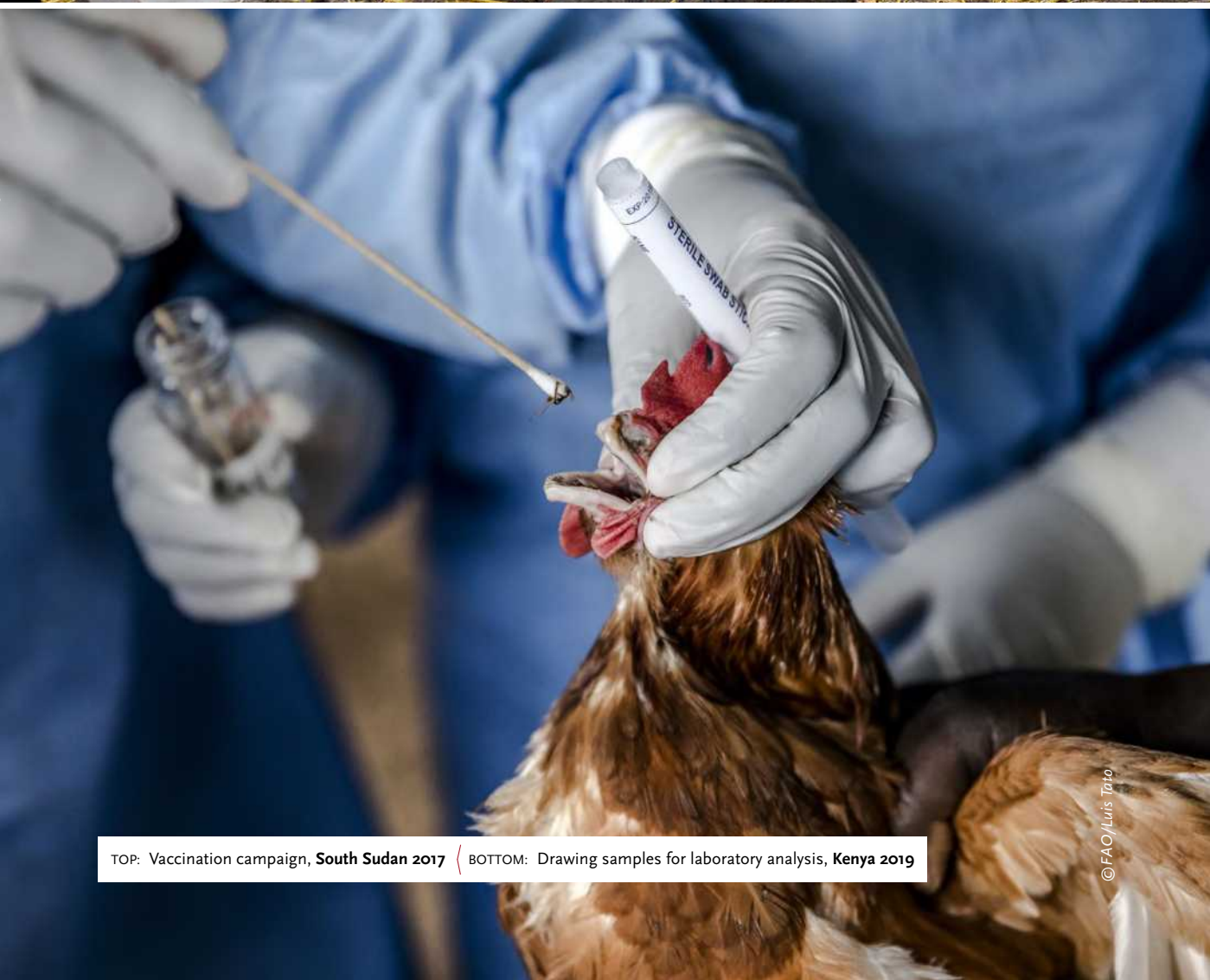
Highly contagious PPR is endemic across Africa, the Middle East and Asia, regions that are home to roughly 80 percent of the global sheep and goat populations

Also known as sheep and goat plague, PPR is a highly contagious viral disease affecting small ruminants. Once present, it can quickly infect up to 90 percent of an animal herd, killing anywhere from 30 to 70 percent of infected animals. First identified in Côte d’Ivoire in 1942, PPR is now present in more than 70 countries across Africa, the Middle East and Asia. Combined, these regions are home to approximately 1.7 billion head of sheep and goats – roughly 80 percent of the global population. Many more countries are considered at-risk of the disease being introduced to their territories.

Annual global loss associated with PPR is between USD 1.4 billion and USD 2.1 billion (FAO, 2016b), however the impacts extend far beyond. PPR-related impacts often force pastoralists and rural farmers in developing countries to migrate away from their lands in search of alternative livelihoods, inducing poverty, malnutrition, social and economic instability, and conflict. In India, PPR’s annual morbidity and mortality rates for small ruminants have been estimated at 8 percent and 3.45 percent respectively. At this level, the country’s associated economic loss is between USD 653 million and USD 669 million each year (Bardhan *et al.*, 2017).



©FAO/Sarah Wright



©FAO/Luis Tinto

TOP: Vaccination campaign, South Sudan 2017 | BOTTOM: Drawing samples for laboratory analysis, Kenya 2019

In neighbouring Pakistan, PPR's annual negative impact is estimated at USD 342 million (Hussain *et al.*, 2008). In some cases, the flock became unsustainable and incapable of reproducing. At the national level, household incomes derived from livestock-rearing in Cameroon registered drops ranging from 21 to 100 percent. Table 4 shows the impact PPR inflicted on the livestock sector worldwide 2017–2019.

As of 2019, 70 countries have reported infection, or suspected infection, to the OIE, and another 50 countries are considered to be at risk. Of the former, more than 60 percent are in sub-Saharan and North Africa. Unlike other infectious diseases however, PPR is readily diagnosed and preventable through a reliable and affordable vaccine. FAO and OIE are currently leading a campaign to eradicate PPR by 2030. While such action is feasible and necessary, continued international and national support and investment are needed to enhance laboratory diagnostics, scale-up vaccination programmes and improve surveillance capacity to prevent further spread and resurgence.

Table 4. PPR 2017–2019

Year	Number of outbreaks across 50 countries	Morbidity (cases)	Mortality (deaths)	Culling
2017	2 535	81 084	40 761	1 326
2018	2 512	90 704	39 409	9 231
2019	2 434	170 692	75 306	316
Share of impact by production system (commercial vs backyard)			Not available	

Source: OIE WAHIS.

Newcastle disease (NCD)

In LDCs, NCD can inflict up to 100 percent mortality in unprotected flocks

The NCD virus causes more direct loss to poultry production systems worldwide than any other animal disease, and is the major constraint on the production of village chickens in many developing countries. In LCDs, where poultry is often the responsibility of women and children, and a key asset for small-scale farms, NCD can inflict up to 100 percent mortality in unprotected flocks. In Bangladesh, economic loss attributed to NCD is estimated at USD 288.5 million annually. In Chad, NCD kills on average more than 55 percent of poultry in rural villages every year. Table 5 shows the impact inflicted by NCD outbreaks on the livestock sector 2017–2019 worldwide.

Table 5. NCD 2017–2019

Year	Number of outbreaks worldwide	Morbidity (cases)	Mortality (deaths)	Culling
2017	2 584	1 143 333	1 919 900	133 529
2018	2 434	1 053 082	1 036 262	466 743
2019	2 358	6 239 713	3 515 158	1 594 847
Share of impact by production system (commercial vs backyard)			No complete dataset available but presumably most of these outbreaks are reported in small backyard systems	

Source: OIE WAHIS.

Rift Valley fever (RVF)

RVF is an acute, mosquito-borne viral disease that poses a significant global threat to livestock production and marketing, as well as to human health. RVF outbreaks in Africa and the Middle East have caused high morbidity and mortality of livestock, disruption of markets, the meat sector and associated industry due to bans on livestock trade and reduced export of animals and animal products. In humans, the clinical presentation ranges from a mild flu-like illness to severe haemorrhagic fever that can be lethal.

RVF has significantly disrupted livestock exports from East Africa (e.g. Djibouti, Ethiopia, Kenya, Somalia, and the United Republic of Tanzania) to the Middle East and Arabian Peninsula. For example, from 2000–2009, Saudi Arabia banned livestock imports from Somalia due to an RVF outbreak in the Horn of Africa. To comprehend the scale of the loss inflicted on Somalia, consider that the country's livestock sector accounted for 40 percent of its GDP or USD 384 million in 2014, a year in which it exported 5 million goats to Saudi Arabia. As climate change and weather-related events continue to alter the landscape of Africa's ecosystems, it is anticipated that RVF epidemics will occur more frequently in both West Africa and the Horn, with serious consequences for livestock production, livelihoods of pastoralists, food security, and access to markets throughout the continent.



Pastoralists from the village of Pupu in Karamoja District, Uganda 2020

Highly pathogenic avian influenza (HPAI)

Scientific evidence suggests that wild birds, especially waterfowl, are natural reservoirs for influenza A viruses, such as the H5N8 sub-type, which cause the HPAI disease. In efforts to better control the disease, it is essential to eliminate potential contact of wild birds with the poultry production sector. Ongoing circulation of avian influenza viruses in poultry pose a global public health risk and cause extensive damage to the livestock industry. HPAI impacts poultry production, the dynamics of meat and egg prices, as well as human health. The pan-African outbreak of H5N8 HPAI in 2016–2018 demonstrated for the first time just how quickly a vast transcontinental propagation can occur. Likely originating in the northern Palearctic (China's Qinghai Lake) around May 2016, the virus was first detected through active surveillance at lake Usbu-Nur, Russian Federation in June 2016. Facilitated by the movement of migratory birds, the virus was able to spread through North, West and East Africa within a year, arriving in South Africa by May 2017 and inflicting substantial losses on the poultry industry all along its deadly path.

African swine fever: the other pandemic

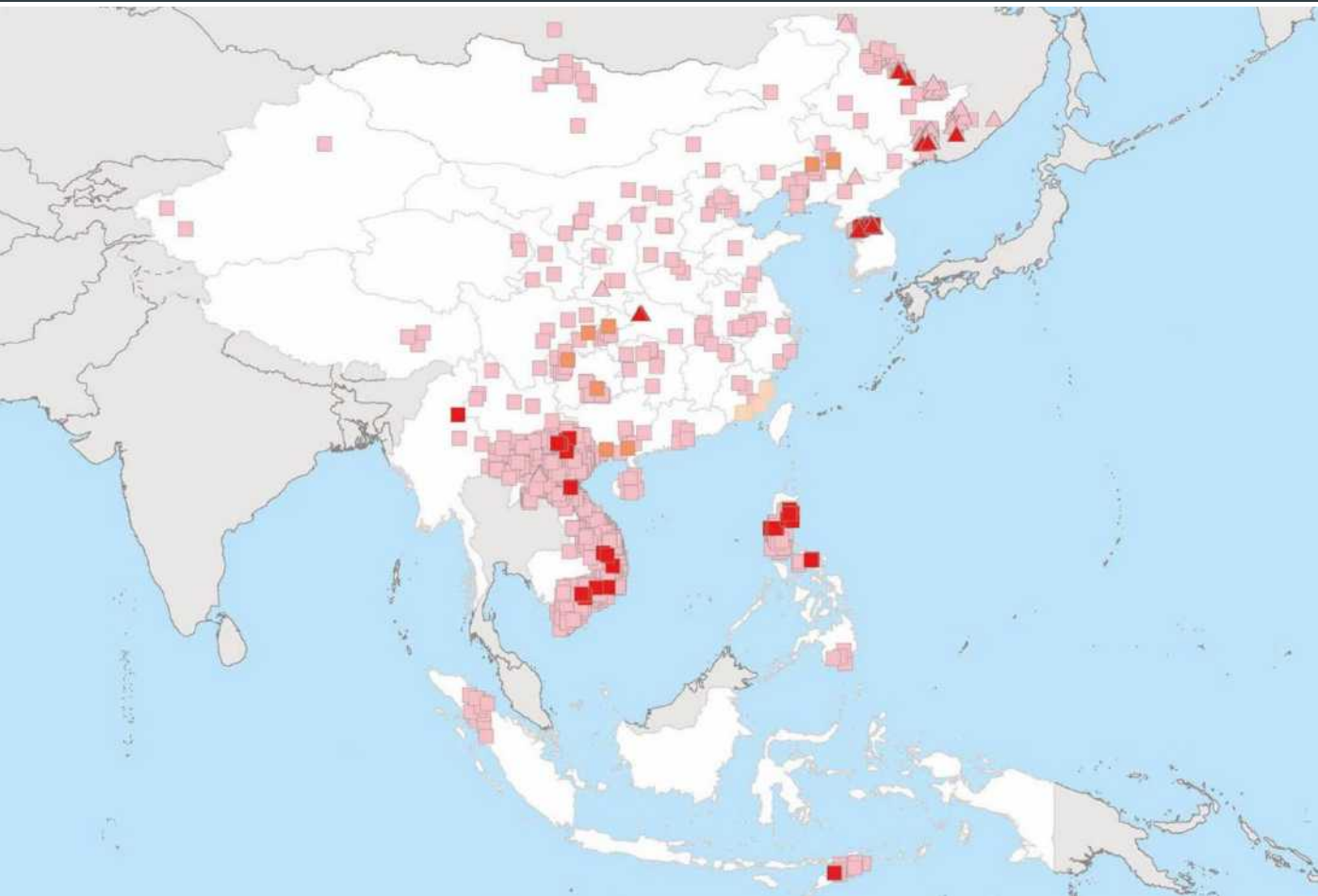
ASF, for which there is no vaccine, kills infected animals within a few weeks, and has claimed at least 8.2 million pigs across 12 Asian countries August 2018–June 2020

ASF is a contagious and deadly viral disease that affects pigs and wild boars, causing high fever and internal bleeding. While harmless to humans, the disease can kill up to 100 percent of infected animals within a few weeks. Currently, there is no approved vaccine to control or prevent the spread of ASF.

The first outbreak of ASF in Asia was detected in northeast **China** in August 2018, and from there it spread rapidly across the continent. By June 2020, ASF was reported by 12 Asian countries (Figure 1), and at least 8.2 million pigs had perished. OIE data for 2020 shows that, by the end of June, the global number of ASF-affected animals had already exceeding that of 2019. The primary focal points of the outbreak are China, Vietnam, the Philippines and a wide swath of Eastern Europe.

Since its initial appearance, ASF has reached almost every province in **mainland China**, which has culled at least 1.2 million pigs in its efforts to halt the contamination, still underway. In January 2019, **Mongolia** was next to report an outbreak. The disease reached **Viet Nam** in February 2019 and spread to all 63 administrative divisions of the country, killing almost 20 percent of the national herd. Between May and August 2019, ASF outbreaks were reported in **Cambodia, the Democratic People's Republic of Korea, Lao People's Democratic Republic, the Philippines and Myanmar**. In September, the disease spread to the **Republic of Korea** and the **Democratic Republic of Timor-Leste**; in December 2019, it reached **Indonesia**. Spread of the disease continued throughout 2020, despite actions taken by the national veterinary authorities of each country, which include: restrictions on transporting pigs across provinces, cessation of slaughterhouse activities in areas affected by the disease, and prohibition of swill feeding. For example, in May 2020, the first case of ASF was confirmed in **India**.

Figure 1. Geographical spread of African swine fever in Asia, August 2018 to March 2020



Sources: China – Ministry of Agriculture and Rural Affairs (MARA); Viet Nam – WAHIS and news media; other countries – WAHIS

- Legend:
- New outbreaks reported 19 February–5 March 2020
 - Outbreaks reported before 5 March 2020
 - ▲ New detection in free wild boar before 19 February 2020
 - ▲ Detection in free wild boar before 19 February 2020
 - Drifted on the coast
 - Intercepted

ASF spread is driven largely by small-scale pig farmers who often fail to adopt proper biosecurity measures

One of the epidemic’s main drivers is the dominance of small-scale pig farmers in the region’s pig industry, who often do not employ the biosecurity measures that can help halt disease spread. Additionally, small-scale producers normally feed their animals with table scraps or uncooked organic refuse (swill) in which the virus can persist. The pork industry in most of the impacted countries also lacks vertical integration. As a result, piglets and sows must be transported between farms and sometimes even across regions. This is conducive to rapid and far-reaching spread of the disease, either via the introduction of infected animals or the entry of contaminated vehicles and equipment into pig confinements. Finally, intra-regional trade of pig meat products, which may be contaminated, has also contributed to the high prevalence of infection.

Asia's 2020 pig meat production is expected to be 30 percent lower than the pre-ASF average

ASF impact on production and trade

As of June 2020, pig meat production in Asia was expected to further decrease to 45.3 million tonnes (carcass weighed equivalent), 17 percent below the already impacted 2019 levels and 30 percent below the pre-ASF average. The contraction reflects a sharp decrease in mainland China, where output during 2020 is estimated to have shrunk by almost 40 percent compared to average pre-ASF levels. Sizable production decreases are also estimated in Viet Nam, the second-largest pig meat producer in Asia.

The rapid depletion of pig inventories in endemic countries, particularly mainland China and Viet Nam, could result in a serious gap in the supply of protein with a consequent increase in imports. FAO estimates Asian countries imported 5.6 million tonnes of pig meat in 2019, almost 20 percent above the 2018 level and well above the previous five-year average. In 2020, imports of pig meat were projected to continue to increase and reach a record level at 6.8 million tonnes. Looking at China alone, the aggregate pig meat imports between January and June 2020 totalled 2.1 million tonnes (carcass weight equivalent), more than double the quantity imported during the same period in 2019, according to China Customs Statistics (GACC).

ASF impact on markets

In **mainland China**, after soaring in February and March 2019 (Figure 2), pig meat prices stabilized between April and June due to two main factors: the release of frozen stocks into markets in response to the high prices; and increased sales of fresh meat after producers slaughtered more animals than normal as part of measures to halt ASF spread. Between June and October, however, prices resumed their increasing trend, more than doubling, a reflection of the tightened market availabilities of pig meat. Between November and July 2020, prices have sharply fluctuated and remained at near record highs.

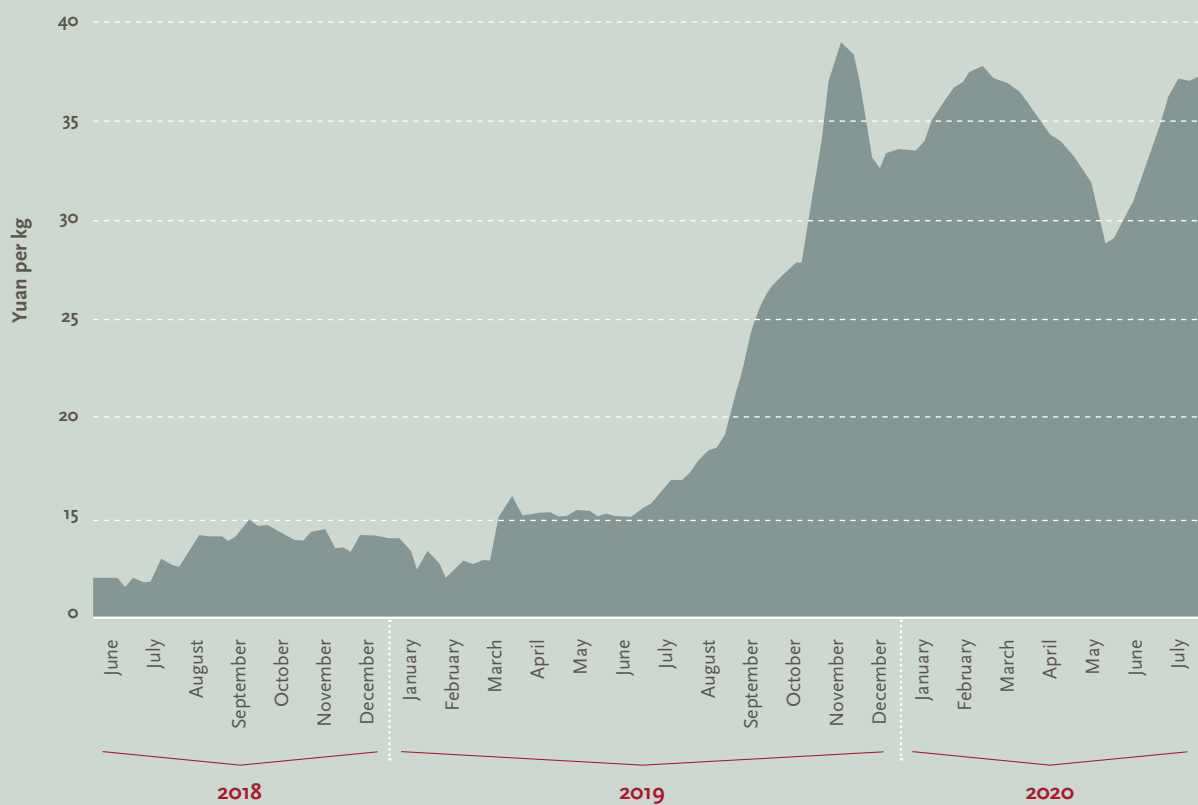
ASF impact on livelihoods and food security

The spread of ASF in Asia raises concerns about the livelihoods and food security of millions of people dependent on pig farming. Small-scale pig farmers, who rely on production of pig meat for their own consumption as well as for income generation, are among the most affected because they usually lack the expertise and/or financial resources necessary to protect their herds from the disease.

Because pork is the most-consumed meat in ASF-endemic countries, concerns are mounting about food insecurity, nutrition and shrinking incomes for small-scale pig farmers

In **mainland China**, about 130 million households are engaged in pig farming and roughly 30 percent of the national pig output is produced by small-scale producers. In **Viet Nam**, pig farming is the main livelihood activity of about 2.5 million households. Similarly, in **Lao People's Democratic Republic, Cambodia, Myanmar and the Philippines**, small-scale pig production significantly contributes to the incomes of large segments of the population. Reports from those countries indicate that animal mortality attributed to ASF infection or associated culling has substantially reduced farmers' incomes. This is compounded by government restrictions imposed to contain spread of the disease, including limitations on transportation and sale of live pigs and pork products from regions where ASF has been detected. These cautionary measures also severely constrain the trade of healthy animals, further impacting livelihoods, given households' heavy reliance on markets for income. Because pork is the meat most consumed in these ASF-endemic countries, the disease is expected to have serious implications on consumption patterns, particularly in poor households. The decline in pig meat production and the depletion of frozen stocks were expected to keep prices at a high level during the second half of 2020, negatively affecting food security of the most vulnerable population.

Figure 2. China's national pig spot prices, June 2018 to July 2020 (Yuan per kg)



African swine fever, Changtu, China 2019

© REUTERS/Ryan Woo



© FAO/Luis Tato



© FAO/Hkun Lat

TOP: Vaccination program, Kenya 2017 | BOTTOM: Livestock distribution, Myanmar 2016

Antimicrobial resistance: the rise of 'superbugs'

As antimicrobial drugs get stronger and more widely used, bacteria and viruses become resistant, evolving into virtually untreatable superbugs, such that AMR probably represents the single greatest threat to animal health, welfare and public health

Antimicrobial resistance (AMR) occurs when microorganisms such as bacteria, viruses and parasites are exposed to antimicrobial drugs (antibiotics, antifungals, antivirals, antimalarials and anthelmintics), causing the microorganism to mutate or acquire defence genes in order to survive. As antimicrobial drugs get stronger and more widely used, bacteria and viruses develop more resistance and can evolve into virtually untreatable microorganisms, known as 'superbugs.'

The emergence of AMR probably represents the single greatest threat to advances in animal health, welfare and public health. It reduces livestock production by making animals more vulnerable to drug resistant endemic diseases. AMR can spread along food chain systems, from livestock production to consumption by humans, and even throughout the environment (e.g. soil and water), potentially affecting wildlife. Experts calculate that AMR is already responsible for 700 000 human deaths every year, although the true toll of resistant infections remains largely uncertain. If unabated, this number could increase to 10 million human deaths annually, causing massive losses on the global economy in excess of USD 1 trillion every year (World Bank, 2019). In addition, reductions in livestock production due to the death of animals infected by untreatable diseases could potentially reduce international trade by 1.1 percent by 2050, i.e. bringing it down to 3.8 percent, thereby reducing GDP and increasing malnutrition (World Bank, 2017).

Resistant bacteria developing either in humans, animals or the environment may spread from one to the other, and from one country and region to another. Resistance develops naturally, but is greatly enhanced by the extensive use of antimicrobials. If agriculture hopes to continue to benefit from the efficiency of antimicrobial veterinary treatments, reducing their use as much as possible is critical. Although the scale of the livestock sector's contributions of resistant microbes to the human population is not well documented, the most reasonable option remains keeping the use of antimicrobials in livestock to the minimum necessary, as a measure to limit the propagation of AMR and curb transmission to humans, animals and the environment.

Failure to reduce dependency on antimicrobial veterinary treatments increases livestock vulnerabilities and deaths, which could reduce international trade by 1.1 percent by 2050

Furthermore, there are substantial geographic and regional variations in both access to and use of antimicrobials, creating a complex pattern of AMR prevalence and potential spread. Compounding this situation are the significant differences at country level in approaches to the enforcement of regulations for antimicrobial use, as well as public attitudes and awareness.

However, unconditional reduction in the use of antimicrobials is not the answer. Livestock farmers must have access to effective and affordable alternatives. Otherwise, they will see increased outbreaks of those endemic animal diseases the AMs currently keep at bay, resulting in asset and production losses and negatively impacting food security and livelihoods, particularly in lower- and middle-income countries. Holistic measures such as animal vaccinations and the application of biosecurity measures can promote a safe reduction in the use of antimicrobials across livestock systems.

Smallholder farmers at the forefront of animal health challenges

Smallholder farmers – for whom the loss of a single animal has proportionally greater impact – have limited cash to survive or recover from disease outbreaks, especially when animals are culled without compensation

Livestock plays an important role in smallholder farming systems, especially in LDCs and LMICs. Animal products and animal-source food are vital to the income, nutrition, food security, livelihoods and resilience of a vast number of communities across the globe, especially those that are most vulnerable. Animal disease poses significant challenges to these communities: the animals of poor people are particularly vulnerable to disease due to the forbidding cost, unavailability or lack of access to adequate animal-health and production inputs. Poor farmers often have fewer animals and limited cash or capital reserves on which to survive during – or while recovering from – lean times, so the loss of individual animals has a proportionally greater impact. Furthermore, when animal disease outbreaks occur as a result of climatic or natural hazard-induced disasters such as flood or drought, the socio-economic impact can be substantially amplified, and may endure beyond the specific outbreak. These circumstances have serious economic and food security implications for farmers' households and surrounding communities.

Increased poverty levels and chronic food insecurity can result when there is an outbreak of an animal disease for which no effective containment or mitigation measures exist (e.g. vaccines, antimicrobials) or if access to them is inadequate. In such cases, communities dependent on livestock production may experience extended periods without access to markets where they can sell their production, or to the milk or meat needed for their own consumption. Animal diseases may also increase vulnerability of rural households to other shocks by taking away a safety net, or if animals are culled without compensation.

Nevertheless, establishing clear causal links between high-impact animal diseases and food insecurity remains challenging. This is because food systems are dynamic and resilient; because families and communities employ coping mechanisms to deal with crises; and because world markets adjust themselves to fill supply gaps. Given the importance of ensuring food security for all as a priority goal under the 2030 Agenda as well as its contribution to the achievement of a number of other SDGs, further research is warranted to identify systematic links between the occurrence of animal disease and food insecurity in the socio-economic dimension.

Way forward to a healthier sector

FAO's methodology – combined with a comprehensive data collection system – fosters an integrated analysis that considers the interconnectedness between disasters, animal health and the effects of both across the production process

As understanding grows of the impact animal disease has on LDCs and LMICs, so does the diversity of opinions and approaches among different actors and disciplines regarding priorities and how best to tackle them. The challenge is to combine the technically feasible with the economically important and the societally acceptable. Inevitably, however, institutions, governments and development organizations must be selective in addressing the various animal health constraints to sustainable livestock development, basing their decisions on evidence, resource availability and national and local contexts.

Certainly, more data and evidence are needed to encourage and guide the investment increases required to improve animal health system capacities and prevent and mitigate the impact of animal diseases, at all levels. FAO's damage and loss assessment methodology brings us one step closer to an integrated analysis of the impact of animal disease outbreaks on the livestock sector and makes it possible to take into account the interconnectedness between disasters,

animal health and the effects this has across the production process. The methodology further offers a basis for strengthening national institutions and their statistical capacities for effective monitoring and data collection related to damage and loss caused by animal disease outbreaks in the livestock sector. It also emphasizes the need to foster cooperation and partnerships in support of statistical capacity development in developing countries.

Efforts are underway to meet that need. For example, in 2018, the University of Liverpool, together with partners including FAO and OIE, launched the Global Burden of Animal Diseases as a platform to collect, validate, analyse, and disseminate data on the input and output relationships of livestock production at the system level. This will provide a baseline from which to estimate the species-specific impacts associated with animal diseases and other health or nutritional problems. It will include information on production loss and expenditure at farm-level to determine the wider societal impacts of the disease through specific modelling work.

Investments in prevention, preparedness and resilience

Investing sufficiently in the combination of early warning, surveillance, early detection of and early response to animal disease can substantially reduce loss while stabilizing food security and nutrition and protecting human lives

Investments in animal health systems must address the real impact of animal disease to effectively enhance prevention and the overall resilience of the livestock sector. Investment in prevention and response practices and good practices such as vaccination, biosecurity, and capacity development are cost-effective and reduce the socio-economic consequences of disease outbreaks. And while there is still insufficient data to pinpoint the most effective targets and levels of investment in animal health, we know that the combination of early warning, surveillance, early detection, and early response can significantly reduce the impact of disease outbreaks. Investing sufficient resources in these areas can substantially boost national and community resilience to high-impact animal diseases, reducing loss while simultaneously stabilizing food security and nutrition in ways that save time, money – and in the case of zoonoses – human lives.

The growing number of outbreaks caused by both existing and emerging threats to the food chain have increased the need to better understand their impact on the agriculture sector, and on livestock in particular. Quantifying and assessing damage and loss associated with animal disease outbreaks is key to designing effective disease prevention, control and response mechanisms. While FAO's damage and loss assessment methodology provides a basis for an integrated analysis of the impact of such outbreaks on the livestock sector, it is important that assessment is substantiated with a comprehensive data collection system, taking into account the interconnectedness of various threats and focusing on the whole food chain.

Preventing and managing disease risks is a complex process, requiring a solid evidence base. Nevertheless, it should be at the centre of efforts to sustain and improve livestock sector productivity. Threats to animal health affect production, food chain values, food systems, food security and livelihoods. As a result, animal disease outbreaks seriously impede the achievement of several SDGs – especially numbers 1 (no poverty), 2 (zero hunger) and 15 (life on land) – and the overall 2030 Agenda. Proportionate investment is required to significantly strengthen the livestock sector's resilience against animal diseases.



Malagasy migratory locust swarm, Madagascar 2014

A large, dense swarm of locusts is shown flying over a green field. The locusts are numerous and appear as a thick, greyish-brown cloud against the green background. The field below is lush and green, with some yellow flowers visible. The overall scene depicts a significant locust infestation.

Chapter VI

Locusts, a legendary pest with a present-day toll: lessons from Madagascar

Throughout 2020 and into 2021, sustained efforts to contain East Africa's worst invasion of desert locusts in decades forged ahead despite challenges stemming from the concurrent COVID-19 pandemic. Swarms of the world's most dangerous migratory pest – whose voracious appetite is unmatched in the insect world – threaten to further undermine the livelihoods and food security of already vulnerable communities. Action to prepare for and manage locust swarms relies on robust surveillance, early warning, and timely response. Lessons learned from Madagascar's historic 2012–2016 infestations of Malagasy migratory locusts make this abundantly clear and help frame assessments of agricultural damage and loss while underscoring the criticality of preparedness.

The battle against a devastating pest continues

From the beginning of 2020, following several seasons of heavy rains and exceptionally wet cyclones in locust breeding areas, the Horn of Africa became the hotspot of the worst desert locust crisis in over 25 years, and the most serious in 70 years for Kenya and Uganda. As swarms spread across the region, the situation quickly spiralled into an unprecedented threat to the food security and livelihoods of affected communities – raising the risk of further suffering, displacement and potential conflict on top of that already imposed by extended droughts, floods, and geopolitical fragility.

A locust swarm can consume as much food in one day as 35 000 people

In favourable winds, mature swarms of desert locusts can travel up to 150 km per day in search of food, migrating across long distances and – in the worst-case scenario – spreading from one continent to another. A single locust can consume its own weight in vegetation daily; a small swarm spanning one square kilometre in size has the potential of eating as much food in one day as 35 000 people. Grazing lands that pastoralists depend upon are not immune. The 2020–2021 outbreak has affected the Greater Horn of Africa, both sides of the Red Sea, the Islamic Republic of Iran, India and Pakistan. Even countries such as Uganda and the United Republic of Tanzania, not often touched by the pest, have been affected, while food insecure communities in the Sahel – already coping with other stressors – faced the threat of yet another incursion of the pest. In India, swarms moved beyond their usual stumping grounds to reach several central states, something that has not occurred since 1961. A few outlier infestations even made it to Nepal (Figure 1). In January 2020, FAO, affected countries and donors swiftly initiated a massive scale-up to contain the upsurge and mitigate its impacts on livelihoods. Those efforts are continuing in 2021, even intensifying in some areas.

Figure 1. Countries affected by the 2020–2021 desert locust upsurge



Source: Map indicative of the extent of the upsurge based on FAO Locust Hub

Desert locusts are considered the planet's most devastating migratory pest

In general, pests such as locusts and the fall armyworm, along with diverse plant pathogens and a vast array of various weeds, are estimated to reduce global crop yields by an estimated 30–40 percent (Savary *et al.*, 2019). While global trade in agricultural products has facilitated the spread of some of these threats, others need no assistance in moving from one place to the next. Of these, desert locusts are considered the planet's most devastating migratory pest. They attack a wide variety of crops and wild plants and have a truly staggering capacity to consume. Their populations can quickly grow to catastrophic levels, form dense bands of juvenile, wingless 'hoppers,' and swarms of winged adult locusts that can wreak havoc across vast areas within a short period of time.

As loss can affect up to 100 percent of both crop and fodder production, the threats this pest poses to the human food chain can have massively detrimental effects on food security, livelihoods and national economies. To illustrate: in the 2003–2005 Sahel upsurge, crop loss ranged from 80 to 100 percent in Burkina Faso, Mali, and Mauritania. Nearly 8.4 million people across six countries (Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal) were affected, with many households requiring food aid (FAO, 2006). Locust impacts combined with poor rainfall limited feed availability, leading to the early migration of livestock and greater tension between transhumant pastoralists and local farmers over resources, compounding an already fragile situation.

In the Greater Horn of Africa as in the Sahel, the majority of people in desert locust-affected countries depend on agriculture or pastoralism for their livelihoods (up to 80 percent of the population in Ethiopia and 75 percent in Kenya). These farming and herding communities rely heavily on rainfed production systems, with the timing, duration and quantities of rainfall playing a critical role in rangeland rejuvenation and crop production. Six of the last eight crop seasons were below average or failed in the region. Shocks such as the desert locust outbreak do not just have immediate, short-term effects, they also exacerbate prevailing food insecurity and undermine livelihoods and development gains that have taken years to build. Even before the impacts of the COVID-19 pandemic and desert locust began to fully register, some 42 million people across ten countries – Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Uganda, the United Republic of Tanzania, and Yemen – were already in a state of acute food insecurity (IPC/CH Phase 3 and above, figures as of June 2020).

Locust control measures are expensive: battling the Sahel's 2003–2005 infestation cost USD 500 million; FAO has so far sought USD 348.4 million to fight the 2020–2021 upsurge

Locust-associated costs are not just limited to crop loss. Locust control programs involve surveillance and control operations, both air- and ground-based, large amounts of pesticides and other material, as well as large staffs of people. As a result, they can be very expensive. In the Sahel in 2003–2005, efforts to control desert locust infestations spanning 13 million ha across more than 20 countries cost a total of USD 500 million. In 2020–2021, FAO's global desert locust appeals so far totaled USD 348.4 million to support surveillance, control coordination, livelihoods protection and restoration in East Africa, Yemen, the Sahel, and Southwest Asia.

Understanding past disasters is critical to helping countries plan, mitigate and prepare for future hazards. Madagascar's historic 2012–2016 locust event – its most severe in 60 years – offers clear evidence that locust-related production loss can be substantial and a major driver of food insecurity, particularly in the contexts of multiple shocks and already high vulnerability. An assessment of its impact – using FAO's methodology to determine damage and loss caused to staple crops – highlights key priorities for designing effective prevention and control strategies.

Assessing the impact of locusts on agriculture – the Madagascar case

Agriculture in Madagascar – vulnerable livelihoods

Malagasy agriculture is characterized by small family subsistence farms; 60 percent of farms are below 1.5 ha and are comprised of fragmented plots

Agriculture is a mainstay of Madagascar's economy, accounting for over one-fourth of its GDP and employing about 64 percent of the population (ILOSTAT). The chief food crop is rice, which is grown on about half of the agricultural land. Other important food crops are cassava, sweet potatoes, fresh vegetables, bananas, maize and beans. In general, Malagasy agriculture is characterized by the pre-eminence of small family subsistence farms, most of which cultivate a mix of crops and livestock; 60 percent of farms are below 1.5 ha and are comprised of fragmented plots. There are very few specialized farms. Production is diversified in all regions, as rice cultivation is almost always supplemented by other crops and several types of livestock. Large farms, defined as those with an area per active worker of 1.2–2.6 ha, account for only 6 percent of Madagascar's farms. The other 94 percent have an area per active worker of 0.12–0.86 ha. This makes agriculture predominantly a subsistence activity with approximately 60 percent of production consumed within the household. From the surplus that is marketed, 47 percent is maize, 20 percent is cassava and 20 percent is rice.

Madagascar is among the poorest countries in the world; three-quarters of the Malagasy population live below the international poverty line of USD 1.90 purchasing power parity (PPP) per day.¹ Food poverty – inadequate access to sufficient and nutritious food for a healthy diet – affects a large portion of the population, with undernourishment currently above 44 percent (FAOSTAT), and stunting affecting nearly half of children under the age of five (FAO *et al.*, *SOFI* 2019). In rural areas, where subsistence farming is the primary economic activity, up to 86 percent of households live in poverty. For most of these households, there is a predictable gap of five months per year when staple food production – mostly rice – is not sufficient to meet dietary needs. During this lean period, when rice yields are either typically low or destroyed by cyclones or flooding, cassava or sweet potatoes serve as replacement crops, comprising a predominantly carbohydrate-based diet for smallholder farmers.

Locust invasions amidst the island's multi-hazard risk exposure

As one of ten countries considered most vulnerable to climate risks, Madagascar is regularly battered by powerful cyclones and rainfall patterns are becoming ever more erratic and intense

Given its location, topography, and socio-economic conditions, Madagascar is highly exposed to multiple hazards such as storms, floods, drought and outbreaks of animal and plant pests and diseases. Every year, the damage and loss caused by disasters have negative impacts on the country's development. Moreover, Madagascar is one of ten countries considered most vulnerable to climate risks (Eckstein, 2019). It is regularly subject to powerful cyclones that damage ecosystems and infrastructure, particularly in the coastal regions, and climate change is predicted to increase both their number and severity. Rainfall patterns are already becoming ever more erratic and intense, leading to frequent flooding and erosion in some areas, while radically decreasing in others. In particular, prolonged drought in the already more disadvantaged southern regions has put a strain on the livelihoods, incomes and food security of local communities. The toll of climate change on Madagascar's biological resources has yet to be fully assessed. Increased carbon dioxide levels in the atmosphere are leading to rising sea temperatures and ocean acidity levels, which threaten coral ecosystems and other marine habitats of high economic and ecological value. Finally, sea level rise around the island – which possesses the longest coastline in Africa – will subject communities and habitats to increased damage from cyclonic and flooding events and may permanently force many people from their homes.

¹ In 2019, Madagascar ranked 162nd out of 189 countries on the UNDP Human Development Index.



© FAO



© FAO/Nasrwanji Chirba

TOP: Walking through swarming locusts, Madagascar 2014 | BOTTOM: Locust swarm on the ground, Madagascar 2011

Alongside increasing exposure to extreme weather events and climate change impacts, Madagascar is subjected to various biological hazards, of which locust invasions pose the single greatest agricultural threat. Madagascar has two locust species: the Malagasy migratory locust or *locusta migratoria capito* (Lmc), the more destructive of the two, and the red locust or *Nomadacris septemfasciata* (Nse). The red locust was once considered a secondary pest, but deforestation has led to its changed behaviour in some areas. In the southwest, where the two species can overlap, mixed infestations are possible. While locust swarms are a regular sighting in the country's extreme south, there are increasingly frequent outbreaks of both red locusts and migratory locusts spreading over the entire country from south to north. Such were the infestations of 1996–2000 and 2000–2003 (Lecoq *et al.*, 2011).

While in the solitary phase of their lifecycle, locusts are harmless to crops, but swarms of gregarious locusts cause immense damage

Locusts can be formidable pests when they reach the gregarious phase, forming hopper bands and swarms of mature adults. While in solitary phase, locusts are harmless to crops, mainly due to low population densities and the fact that they consume a narrower range of foods (e.g. they do not consume all grasses). That is not the case for gregarious locusts. These have much higher population densities, more active metabolisms, eat a wider range of vegetation, and often move over great distances in search of food, causing immense damage to agriculture.

The real danger arises from the number and density of locusts. Each adult Lmc weighs over 1 gram and is capable of consuming half its own weight every day. Because population density in a swarm can exceed 500 adults per square meter, a single swarm can consume about 2.5 tonnes per ha every day.

In its gregarious phase, the diet of the Malagasy migratory locust is predominantly focused on both grass species – which include those found in the pastures and grazing areas in south and southwest Madagascar – and cereal crops. Depending on the time of year, the Lmc attacks green grass leaves, stubble, or regrowth. In the rainy season, swarms decrease the quantity and quality of grasses available for livestock consumption, slowing livestock weight gain and worsening health conditions of vulnerable animals already affected by other stressors (Aublet, 2011). Also, damage to grass may allow the development of parasites that affect livestock health and productivity. These impacts are primarily experienced as loss due to decreased livestock productivity. In some cases, herders may be able to avoid some locust impacts by shifting rangeland.

Cereal crops are a primary target, but damage depends on when during the season locusts strike, e.g. if farmers still have time to replant, even though the late start may lead to decreased harvests

Because green vegetation is favoured by gregarious locusts, cereal crops are also a primary target, especially during the dry season, when alternative grasslands are sparse and dry. Lmc-related crop damage depends on when during the season a swarm of a particular generation hits (Table 1). Farmers may be able to recover from an attack early in crop development, at seedling emergence (maize) or transplanting (rice), if they can access stocks to re-sow/re-plant in time. Even if they are able to replant, however, a later start to the season may still lead to decreased harvests. If the attack occurs when rice is at the booting stage (before the panicle emerges), loss is generally modest. By eating a few rice sprigs, locusts will limit tillering (resulting in decreased yield) but grain formation can still occur. Maize does not tiller and is more vulnerable at this stage of development. If locusts attack at grain filling (milk) stage, the plants are very vulnerable and loss can reach 100 percent. Loss can be similarly high from attacks on mature crops, as feeding on stems causes them to bend under the weight of the mature grain panicles, which then fall to the ground and are lost to production.

Malagasy migratory locust

Like other locusts, the Lmc is a gregariapt, i.e. it has a phase transformation process that causes individuals to gather together and form larger bands, groups, or swarms. Population density is the main trigger in that transformation, with each locust species having a typical threshold for phase transformation or gregarization. Threshold density for the Lmc is around 2 000 adults per ha. Above this threshold, locusts gradually transform from a solitary phase (isolated individuals) to a gregarious phase (large numbers grouped together). Lmc can produce three to four generations in a year, with transition from a solitary to gregarious phase requiring at least three generations. The first stage of its phase transformation comes when particular environmental conditions cause solitary adults to congregate in smaller, more contained areas. Rainfall is the abiotic factor with the greatest impact on Lmc population dynamics. Physiologically, gregarious individuals are more able to tolerate difficult ecological conditions than solitary ones, which leads them to take up a larger geographical area. The locust moves in a permanent search for moderately wet areas, which are optimal for its development, avoiding areas made unfavourable by too little or too much rainfall. A close correlation has been demonstrated between monthly rainfall and locust population dynamics.

Table 1. Madagascar crop calendar and locust development

Month	Rainfall period	Rice	Maize	Lean period	Generations of gregarious Lmc locusts
January					Second generation
February					
March					
April					Third generation
May					
June					
July					Fourth generation/ generation zero
August					
September					
October					Generation zero
November					First generation
December					

Legend ● Rainfall period ● Sowing ● Growing ● Harvesting ● Lean period

Each month is divided into three ten-day locust surveillance periods

Taking stock – agricultural damage and loss due to the 2012–2016 Malagasy migratory locust plague

Over the past 30 years, Madagascar has seen numerous locust outbreaks that have caused billions of dollars in economic damage. Between 2012 and 2016 however, a Malagasy migratory locust plague reached unprecedented crisis proportions. The critical situation, in which populations of solitary insects transformed into – and maintained themselves as – unified populations, developed from an April 2010 infestation in southwest Madagascar, the area most prone to locust outbreaks.

FAO and MAEP implemented a three-year (2013–2016), USD 37 million programme that saved livelihoods and prevented further deterioration of Madagascar’s already pronounced condition of food insecurity

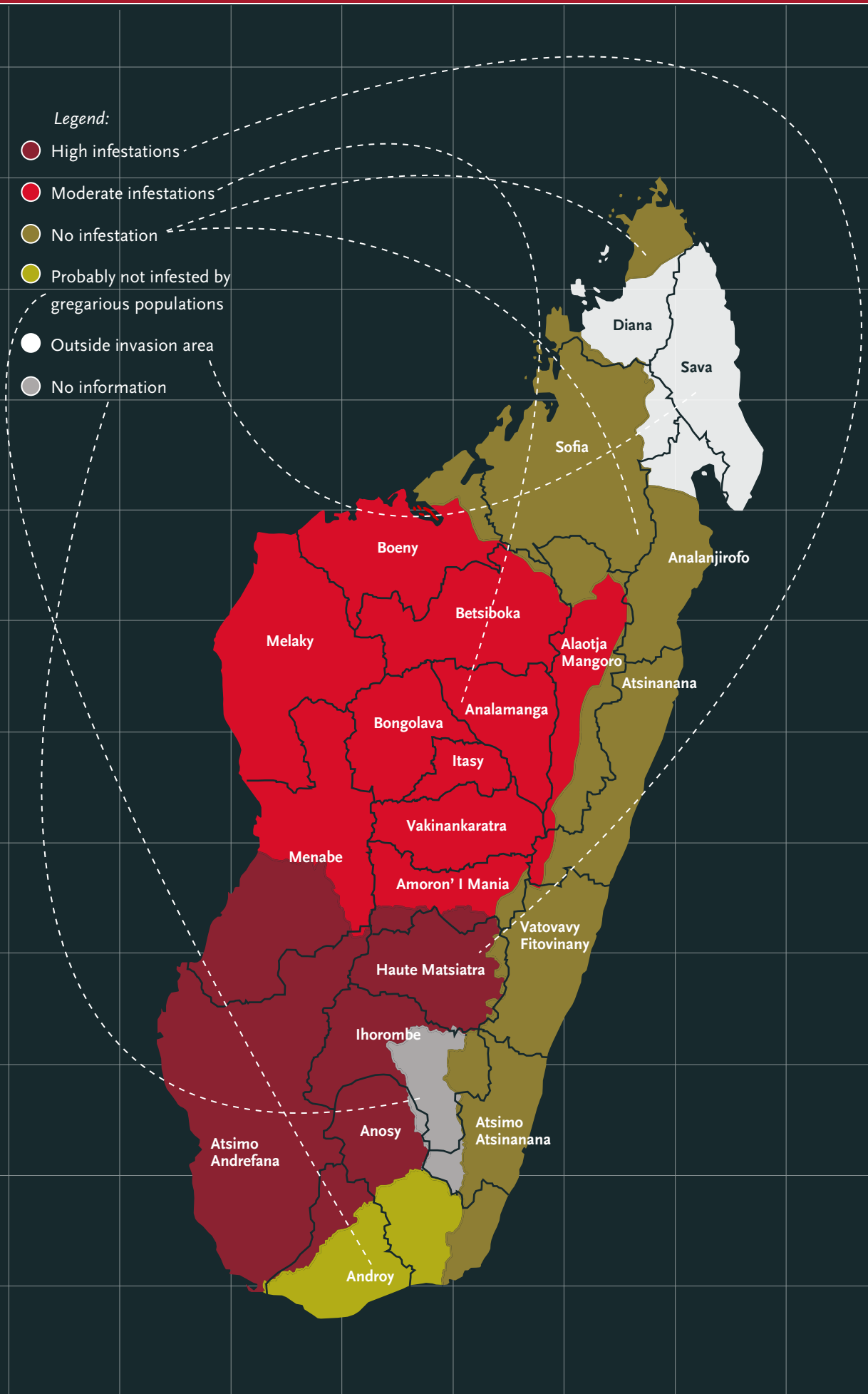
Though control campaigns during the 2010–2011 and 2011–2012 seasons limited the damage, locust populations continued to grow and the outbreak was out of control by April 2012. In November 2012, the Ministry of Agriculture, Livestock and Fisheries of Madagascar (MAEP) declared a state of locust alert and public disaster for the whole country. However, no control campaign was implemented during the 2012–2013 season due to lack of funding, considerably aggravating the situation. By the end of March 2013, nearly half the country was affected, with individual swarms containing as many as a billion insects. Pastures and crops (mainly rice) were under threat of major damage. It was estimated that the food security of 13 million people (60 percent of the population), including 9 million dependent on agriculture for their livelihoods, could be affected in the absence of large-scale locust control operations (FAO, 2013). To address this catastrophic situation, an emergency response programme was jointly prepared by FAO and MAEP in December 2012 and implemented over three years (2013–2016) at a cost of USD 37 million. It helped save the livelihoods of the Malagasy population, avoiding a further deterioration of the country’s already pronounced condition of food insecurity.

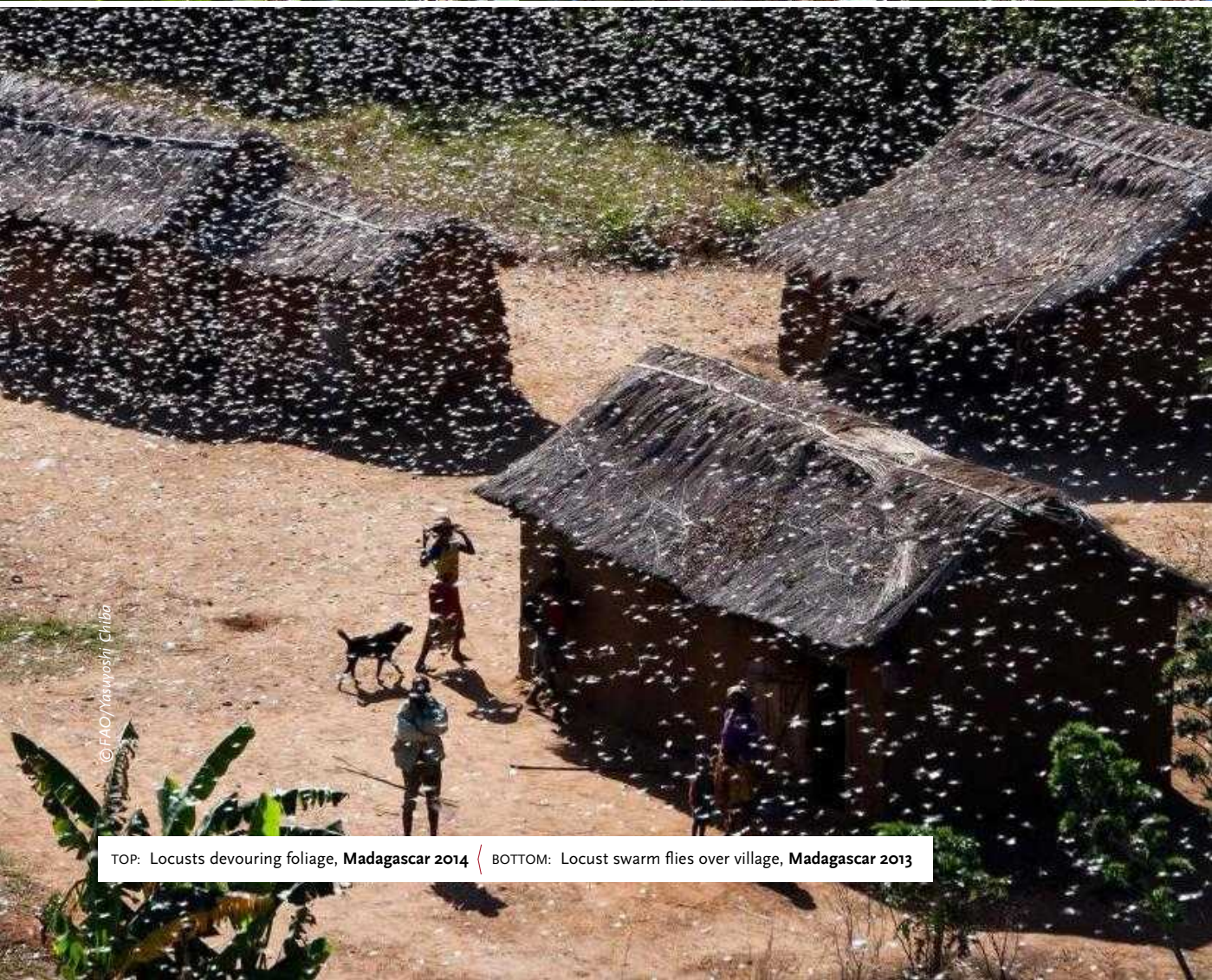
FAO’s DL methodology helps produce the first comprehensive account of the most severe locust plague Madagascar had seen in 60 years

While the 2012–2016 locust plague was the country’s most severe in 60 years, a detailed and comprehensive account of its economic impact on the agriculture sector has thus far been lacking. By employing its damage and loss assessment methodology and cross-referencing data from different reports and sources, especially FAO/WFP CFSAM reports, FAO is now able to categorize and assess the impacts of this locust invasion. While the methodology does face the challenges of data availability, spatial and temporal variability of impact observations and the overlaying effects of compound disasters (e.g. 2013 Cyclone Haruna), it does provide a basis for calibrating the overall locust-related damage and loss sustained by the sector. The focus is primarily on the 2012–2013 and 2013–2014 agricultural seasons. The former is the season during which the Government declared the locust crisis to be a public disaster but carried out no targeted control operations; the latter is the first year large-scale control operations were jointly implemented by FAO and MAEP as part of the designated three-year emergency programme.² This analysis concentrates on damage and loss in rice and maize production, as these are Madagascar’s main crops and the targets of choice for the locust swarms. Geographically, the focus is on locust hot-spot areas in the south and southwest regions of the country (Figure 2).

² The 2014–2015 and 2015–2016 seasons are not considered in this case study because CFSAM reports for those years indicate that the 2013–2014 control operations, which treated over 1.2 million ha, considerably limited crop damage.

Figure 2. Madagascar's maximum monthly infestation during the first locust control campaign, 2013–2014





TOP: Locusts devouring foliage, Madagascar 2014 | BOTTOM: Locust swarm flies over village, Madagascar 2013

Crop season 2012–2013

The 2013–2014 locust plague was compounded by the onset of Cyclone Haruna, which made landfall on the southwest coast (mainly Atsimo-Andrefana) and exited to the far southeast, leaving behind significant damage from floods and strong winds. The effects of these concurring disasters are difficult to disentangle, since they affected the same production areas and were mutually reinforcing (well distributed heavy rains associated with the cyclone provided favourable conditions for locust reproduction). Both crops and pastures were significantly affected by this cyclone-locust disaster cocktail.

In 2013, production of key crops dropped significantly in Manabe due to multiple factors, including the locust plague: 40 percent for rice, 70 percent for maize

The southern region of Manabe is traditionally self-sufficient and frequently has a surplus of rice production. Nevertheless, a significant drop in production was recorded in 2013 (Table 2), due to a combination of unfavourable factors (prolonged interruption of rains during the rice tillering phase and frequent locust attacks). Although the impact on regional production was not felt at national level, the livelihoods of people in the affected areas were hit hard.

Locust damage was most severe in the southwestern regions (Atsimo-Andrefana and Manabe), which together contribute about 7 percent of national rice production (FAO/WFP, 2013). In Atsimo-Andrefana, the average farm size was 2.3 ha, but half of farmers had small holdings of less than 1.5 ha. The average annual agricultural income was MGA 917 000 per household, and 24.2 percent of agricultural households cultivated rice, with total paddy production estimated at 139 370 tonnes. This is one of two regions with the least favourable geological and climatic conditions for rice compared to the rest of the country. More than half of all rice production in this region was for self-subsistence; only one-quarter was for sale. Table 2 shows that loss due to Lmc was estimated at 30 percent for rice and 40 percent for maize.

In Manabe, the average farm size was 1.8 ha and 61 percent of farms were less than 1.5 ha. The average annual agricultural income was MGA 828 000 per household. Some 70 percent of agricultural households cultivated rice, with total paddy production for 2013 estimated at 108 211 tonnes. About 40 percent of rice production was for self-subsistence and 30 percent for sale. Around one-quarter of farm households grew maize, and a similar proportion grew cassava. Locust attacks on rice and maize became widespread and resulted in disastrous loss of 40 percent for rice and 70 percent for maize.

Decreased production was due to the locust plague and a combination of other factors

In addition to locust- and climate-related loss, production also declined because many farmers limited seeding/planting (and therefore cultivated areas) for fear of having their crops destroyed. Moreover, even if there was a real willingness among some farmers to reseed after locusts attacked, access to seed on the market was constrained by cost or supply. Finally, many farmers harvested early (both rice and maize) to pre-empt locust attacks, leading to overall lower yields.

Table 2. Production and loss in southwest Madagascar, 2012–2013 crop season

Region	Anticipated production (tonnes)		Actual production (tonnes)		Estimated loss (tonnes)		Estimated loss (%)	
	Rice	Maize	Rice	Maize	Rice	Maize	Rice	Maize
Atsimo-Andrefana	199 100	9 933	139 370	5 960	59 730	3 973	30	40
Manabe	180 352	24 623	108 211	7 387	72 141	17 236	40	70

Crop season 2013–2014

Contrary to the general expectation that farmers would reduce planting in response to the preceding poor season, rice area planting actually increased in 2013–2014. While the locust plague continued to be the main factor affecting crop productivity, the impacted southern regions also experienced poorly distributed rainfall, with late onset and early cessation, further limiting yield potential and offsetting the increase in planted area. Poor seed quality and poor water management further strained production.

The campaign halted the locusts' geographic expansion and limited loss of pastures and crops

On average, the area lost due to locust attacks varied between 8–37 percent across municipalities, with maize recording the highest loss. Despite some significant but localized damage to rice and maize in the south and west, the locust control campaign halted the geographical expansion of the plague and limited the loss of pastures and crops.

Table 3. Production and loss in southwest Madagascar, 2013–2014 crop season

Region	Anticipated production (tonnes)		Actual production (tonnes)		Estimated loss (tonnes)		Estimated loss (%)	
	Rice	Maize	Rice	Maize	Rice	Maize	Rice	Maize
Atsimo-Andrefana	159 280	8 403	111 496	5 966	47 784	2 437	30	39
Menabe	118 999	4 784	86 274	2 631	32 725	2 153	27.5	45

In the Atsimo-Andrefana (southwest) region, actual total paddy production was estimated at 111 496 tonnes (20 percent lower than 2013 production), and maize at 5 966 tonnes (similar to 2013 production) (Table 3). Average crop loss was estimated at 30 percent for rice and 39 percent for maize.

In Menabe, total paddy production was estimated at 86 274 tonnes (20 percent lower than 2013), and maize at 2 631 tonnes (64 percent lower than 2013). Average crop loss was estimated at 27.5 percent for rice and 45 percent for maize.

Many farmers harvested early to protect their crops from locusts, resulting in lower yields

The persistent locust threat during the 2013–2014 crop season led many producers to adjust timing of crop activities to preserve their crops. In some localities, rice transplanting operations were delayed by two to three weeks with a high risk of water deficit at the end of the crop cycle. In others, some producers had to harvest their maize and rice plots early to protect them from locust attacks. These cultivation practices also resulted in lower yields due to incomplete crop maturation.

Because nationally aggregated data can mask regional disparities, data collection and assessment must be calibrated geographically to reveal the true impact of the plague on smallholders

Loss of the magnitude experienced in both of the worst affected regions can have severe impacts on regional and national markets and can significantly disrupt the food supply and food security of local populations. While nationally aggregated production data can mask large regional disparities linked to the effects of the locust plague, the region-specific impacts reveal the true loss caused by the pest at sub-national level. So, it is crucial that data collection and assessment efforts be targeted and calibrated at the relevant geographical unit to capture local impacts. Household-level damage and loss data are, therefore, fundamental to a better understanding of the impact pest outbreaks and other disasters have on agricultural livelihoods and to identifying the most at-risk categories of farmers. Aggregate and national-level figures – which are heavily skewed towards the big picture – do not provide a reasonable estimate of loss for smallholders, who constitute the vast majority of farmers in Madagascar and other locust-prone countries. FAO's methodology offers a basis for strengthening the statistical capacities of national data producing institutions for the effective monitoring and data collection related to damage and loss. It also emphasizes the need for cooperation and partnerships in support of statistical capacity development in vulnerable countries.



Locusts swarm over vegetation, Madagascar 2014

Methodological advances and challenges

Understanding the impact of locust outbreaks on production, livelihoods and food security is a key building block towards establishing an evidence base for preventive and control action. The above assessment of the 2012–2016 locust plague in Madagascar, conducted within the framework of FAO's damage and loss methodology, uses secondary data sources and yield estimates to derive credible, if modest, estimates of the extent to which crop production can be affected by the locust pestilence. It demonstrates the methodology's potential to deliver reliable damage and loss assessment results even in the context of limited data availability. It can be concluded, therefore, that the methodology constitutes a useful and versatile tool for conducting systematic analysis. This, in turn, will help build a holistic information system to record the impact of locust outbreaks – among other disasters – on agriculture in vulnerable and exposed countries.

Because the impacts of pests, disease, climate change and other disasters such as cyclones are interconnected, FAO's DL methodology must be used in a way that disentangles concurrent factors

Measuring impact to crops and pastures during a pest outbreak, however, is extremely challenging in a context of crisis response, scarce resources and limited data. While FAO's damage and loss assessment methodology moves us one step closer to a comprehensive analysis of the impact of biological hazards – such as locust outbreaks – on both crops and livestock, it is important this assessment be approached in a systematic and integrated manner, taking into account the interconnectedness of pests and diseases as well as other disasters such as cyclones and climate change factors, while focusing on the whole food chain.

To this end, the methodology requires additional calibration, and there are challenges and limitations to be addressed. For example, more accurate results can be obtained by adapting the methodology to assess the cumulative effects of multiple and/or simultaneous hazards. It is particularly difficult to disentangle the effects of cyclones – a frequent occurrence in Madagascar – from those of a locust upsurge, especially as these two phenomena may be linked. Well-distributed heavy rains provide favourable conditions for locust breeding, and violent winds lead to a redistribution of the locust population. Furthermore, the assessment process can and should integrate land-use maps and remote sensing technologies as additional sources of information. It will also benefit from increasing the overall availability of baseline data at the household level.

Although agricultural censuses and statistics have improved considerably in recent years, the quality of household survey data can fluctuate from country to country, frequently resulting in the availability of only limited historical information. Additional efforts are therefore needed to improve agricultural data collection and reporting at the sub-national, national, regional and global levels. Standardized damage and loss data collection, monitoring and reporting processes should be established for both medium- to large-scale disasters, as well as for recurrent, smaller-scale events.

Data gaps on pasture biomass must be filled to better articulate locust-related impact on livestock, and the 2020–2021 desert locust upsurge proves that the need to do so is urgent

Additionally, there is limited data on pasture biomass in Madagascar, as well as in other LDCs and LMICs exposed to locust outbreaks, making it difficult to attribute any changes in livestock productivity to the pest impacts. The challenge remains to integrate the lesser-represented domains of pasture and livestock assessment into the assessment and analysis of locust impact in agriculture.

While the overall framework exists, prevailing data gaps hamper further trials. It is important to meet these challenges quickly. The need for a more precise understanding of the impact of disasters and crises on agriculture is urgent, as the ongoing desert locust crisis in the Greater Horn of Africa, the Arabian Peninsula and Southwest Asia further demonstrates.



TOP: Residents observe locusts swarm, Madagascar 2014 | BOTTOM: Spraying pesticide, Madagascar 2011

Lessons for future outbreaks

Evaluations of previous large-scale locust outbreaks, such as the one in Madagascar 2012–2016, provide convincing evidence that prevention is the only efficient strategy for dealing with locust emergencies. The implementation of such a strategy can avoid destruction of crops and pastures, considerably limit control costs by intervening at an early stage with control operations on a limited scale, and allow use of safer and environmentally friendlier control measures.

A preventive control strategy monitors locust numbers in the outbreak area and aims to keep locust populations in a state of long-term recession.

It involves specific and early control operations to keep locust numbers below the gregarization threshold. The bio-ecological knowledge of most locust species is now sufficient to understand the annual bio-geographical cycles while locating the main sites, including gregarization areas. By monitoring population dynamics and the distribution of relevant ecological conditions, it is, in theory, possible to assess and locate the risk of infestation and gregarization or, more precisely, of phase transformation.

Outbreaks can easily go undetected because locust aggregations occur over vast and sparsely populated areas

In practice, however, and despite many decades of intensive research, the general ability to predict spatiotemporal dynamics of locust populations remains sub-optimal. As a result, locust outbreaks are mostly unforeseen and unscathed by popular locust management strategies. The main reason for this inefficiency is that the areas of initial locust aggregations are usually scattered over a vast and sparsely populated territory (Latchininsky, 2013). For example, the area of incipient gregarization of the desert locust covers 16 million square kilometres, which is roughly equal to the territory of the United States and Australia combined (Duranton & Lecoq, 1990). Despite national and international efforts to implement efficient locust monitoring, there is always a threat that in some locations, locusts may produce an undetected gregarious population, leading to a large-scale outbreak. As a result, curative insecticide treatments are applied to enormous areas to minimize crop loss. For example, in Central Asia, over 2 million ha were treated annually against the Italian, migratory, and Moroccan locusts in 2008–2012 (Latchininsky, 2013). Furthermore, locusts produce outbreaks (and thus require control) at irregular intervals, which makes the sustainability of management infrastructure very challenging. Survey programs and logistical expertise do not survive through long recession periods and end up deteriorating and becoming inefficient.

Pesticides are the most common and effective weapon against locusts in an emergency context, but have a significant environmental impact; preventative locust control strategies are by far the best option

Local communities often try artisanal means of managing the pests, such as shooping and setting fires, in an attempt to scare them off, but the efficacy of such measures is highly dubious and often problematic. Pesticides are also commonly used to treat infected areas, and represent the only effective solution when confronting large locust numbers. Other control options also exist, such as growth inhibitors and slower-acting biopesticides. In Madagascar, 4.2 million ha were treated with locust pesticides between 1997 and 2000 at a cost of USD 50 million (Lecoq, 2001). Such large-scale pesticide treatments can have significant environmental impact, especially on non-target organisms.

In Madagascar, with its unique biodiversity and already vulnerable ecosystems, use of pesticides in locust control raises a number of environmental concerns. In all control operations, FAO recommends that governments implement extensive spotting and targeting to focus spraying on locusts and avoid sensitive areas, use low-volume formulations of pesticides, and adhere to international standards for safety and environmental protocols.

To mitigate impacts on the lives of millions of people across the vast expanse of at-risk areas, locust outbreaks must not be allowed to evolve into actual disasters, as happened in Madagascar in 2012. Effective anticipatory action to face any locust crisis – including desert locusts – relies on building and maintaining capacity at national and regional levels, maintaining regular monitoring over vast areas, establishing sophisticated early warning systems, and programming timely responses. In concrete terms, this means:

- conducting an effective and regular collection and analysis of relevant field data;
- having an early warning system to capture the transition phase from solitary to gregarious;
- and possessing the ability to carry out rapid control operations as required.

Data-based risk maps indicating the location of locust phase transformation become the basis for efforts to maintain vigilance

A warning system that employs field data mapping must be put in place to obtain reliable locust diagnoses and forecasts that identify areas where vigilance should be increased, guide control operations, and assess risks of a renewed outbreak when locusts are receding. This system would consist of collecting locust, rainfall and bio-ecological data according to previously established spatial and temporal paths (well-reasoned distribution of survey points in the outbreak area on ten-day and monthly bases). Because there is a close correlation between monthly rainfall and locust population dynamics, analysis should be based on the spatialized crossing of three data layers: the biotope map of a given locust species in its outbreak area; the rainfall map of the last three ten-day periods; and the locust map with phases, phenology and densities. The expected result of the analysis would be a risk map with the location of the locust phase transformation. This map, in turn, becomes the basis for maintaining vigilance.



Controlled burning to scare locusts away, Madagascar 2011

The warning system enables monitoring of locust population dynamics as well as the spatial and temporal distribution of relevant ecological conditions. Infestations and gregarization sites are identified and assessed, allowing locust events to be anticipated and action taken in areas where population density is likely to reach or exceed the gregarization threshold. Early and rapid control operations are carried out against the first locust aggregation in a very localized and targeted manner and on small areas.

Though it cannot solve all locust problems, remote sensing provides real-time information about conditions favourable to locust breeding and gregarization, allowing on-the-ground teams to target prevention measures on specific sites

The implementation of a preventive locust control strategy – consisting of appropriate monitoring of locust habitats at key periods of their development to allow early detection – is much more effective and requires far fewer resources than the curative and defensive control measures applied in an emergency context. However, this can only be achieved through strengthening capacities and systems for regular collection and analysis of eco-meteorological and locust data. The monitoring and warning system will be reliable and efficient only if the network for data collection, transmission and analysis is efficient, sustainable and calibrated at sub-national level.

From a cost-benefit perspective, the advantages of relying on a forward-looking preventative strategy are clear. While implementing such a control system would cost Madagascar an estimated USD 1–2 million per year, this compares favourably to the cost of large-scale control operations (USD 50 million for the 1997–2000 period; USD 37 million in 2012–2016), not to mention the devastating damage and loss experienced by farmers and pastoralists, and the profound impacts on food security. The case for investing in national capacity for continuous monitoring – and not just during locust outbreaks – is evident.

What is more, as knowledge of the bio-ecology of different locust species advances, allowing annual bio-geographical cycles and main sites to be identified, satellites and processing software are becoming ever more available. As a result, remote sensing is gradually becoming a routine and efficient tool in the practice of locust management, especially forecasting. The role of geospatial technologies may further increase as locusts expand their habitats, both latitudinal and altitudinal, due to climate change. Remote sensing empowers easier, real-time identification of areas with emerging green vegetation and the assessment of the ecological conditions favourable for locust breeding and gregarization. This contributes to rapid decision-making and planning of control interventions. Use of satellite imagery means locust management teams can target specific, high-risk locust gregarization sites. This significantly reduces costs and contributes toward changing the paradigm of locust control efforts from curative to preventive. However, despite important progress in this direction, remote sensing alone cannot solve all locust problems. The pest can still get out of control, as the 2020–2021 desert locust upsurge illustrates.

Overall, a strong institutional framework that supports effective implementation is the foundation without which prevention strategies cannot succeed. Each country should have an autonomous and operational national locust control structure, with the authority to make technical and administrative decisions about locust control operations. This structure must be granted effective financial, material and policy support by the governments concerned.



©FAO



©FAO/Yasuyoshi Chiba

TOP: Sheltering from swarming locusts, Madagascar 2014 | BOTTOM: Locust control operation, Madagascar 2011



Hurricane Matthew aftermath, Haiti 2016



PART III

Towards the future of damage and loss monitoring

Chapter VII

Extreme exposure: a clearer picture of agriculture in the climate crisis

Chapter VIII

From farm to space: exploring remote sensing applications for disaster impact analysis in agriculture



Flood, Pakistan 2010



Chapter VII

Extreme exposure: a clearer picture of agriculture in the climate crisis

Quantifying impacts on agriculture caused by climate-induced extreme weather events has so far gained little analytical traction within climate negotiations. This could change with the rapid advancements in attribution science, which considers the effect of climate variability and change on slow-onset and extreme weather events and how these factors interact with other drivers of risk to influence damage and loss in agriculture. Framed through a disaster and climate risk management perspective, the FAO damage and loss methodology provides a tool to quantify economic impacts of extreme events, thereby offering a quantitative dimension to climate change discussions.

The impact of disasters in the context of the global climate change agenda

In 2019, global warming reached 1.1 °C above pre-industrial levels (World Meteorological Organization, WMO, 2020). Agriculture is feeling the effects. Increased greenhouse gas (GHG) concentrations are bringing about profound changes in climate that ultimately affect agricultural production. These include an increase in the number of days with extreme temperatures, more severe and more frequent droughts, floods and storms, changes to the onset or length of growing seasons, greater spreading of pests and disease, and the migration of fish stocks. Such impacts will be further amplified if global warming reaches 1.5 °C and become even more severe at 2 °C (Intergovernmental Panel on Climate Change, IPCC, 2018).

The combined impacts of disasters and climate change erode capacities of farmers and rural communities, especially the most vulnerable, to cope with risk and maintain livelihoods

Across crops, livestock, forestry, fisheries and aquaculture, the agriculture sector already absorbs approximately 26 percent of the impact caused by climate-related disasters in LDC and LMIC countries (FAO, 2018c). Combined, the impacts of disasters and climate change erode the capacities of farmers and rural communities, especially in highly vulnerable and poor countries, to cope with risk and maintain their livelihoods. The overlaying nature of disasters and climate change impacts on agriculture, therefore, calls for integrated approaches and working methods towards building resilience to shocks and climate.

Preliminary foundations for that are already in place. Representing an evolution beyond long-standing debates, the current international climate discourse now recognizes as a main objective related to both adaptation and mitigation “the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change” (Paris Agreement Article 8). Simultaneously, scientific evidence of the part climate change plays in climate-related hazards is rapidly evolving. As a result, climate-induced *loss and damage* now constitute an urgent and important workstream within the climate change agenda.

Climate-related disasters and their impacts on natural and human systems have been acknowledged by both the Sendai Framework for DRR and the global climate change agenda since their respective inceptions. **However, there is a difference in terminology. Sendai’s ‘damage and loss’ (DL) and the Paris Agreement’s ‘loss and damage’ (LD) are not identical. Each expression derives from different domains.**

On one hand, as a disaster risk reduction notion, DL relates to natural hazards (including climate-related, geophysical, biological) as well as technological hazards. DL is in the traditional spotlight of this *Impact of disasters and crises on agriculture and food security* report series and is well-defined in the disaster risk reduction literature (e.g. Comisión Económica para América Latina y el Caribe, CEPAL, 1991; FAO *et al.*, *SOFI* 2018). The term is acknowledged and used consistently in assessments by countries through the Sendai Framework Monitor (SFM).

LD, on the other hand, comes from the climate change policy discourse as guided by the Warsaw International Mechanism (WIM), but still lacks a uniform definition. Speaking of the negative impacts of climate change, WIM uses *LD* in reference to both extreme events (climate-related natural hazards such as cyclones, floods, drought) and slow-onset events (such as sea level rise, glacial retreat, desertification) (Framework Convention on Climate Change, UNFCCC, 2013 – Decision 2/CP). Unlike DL, however, WIM’s *LD* explicitly includes both economic and non-economic losses (UNFCCC, 2013). Hence, the differences in terminology and definitions between DRR and climate change workstreams are not trivial. This creates real challenges for consistency in data collection, analysis and integration across the sectors.



©FAO/Luis Tinto

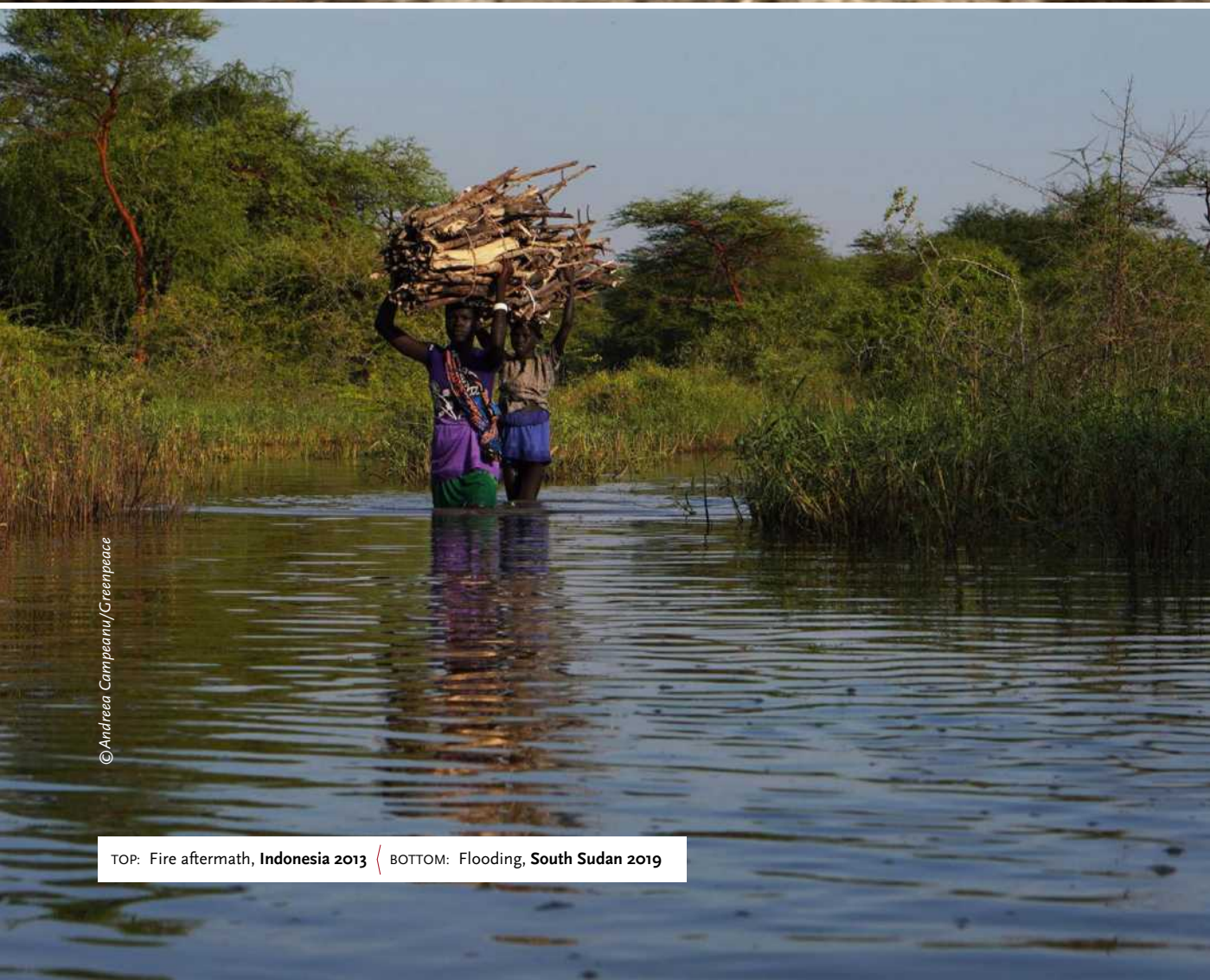


©FAO/John Vessels

TOP: Dry Sahelian landscape, Niger 2019 | BOTTOM: Fishmongers awaiting fresh catch, Senegal 2020



© Ulet Ifansasti / Greenpeace



© Andreea Campeanu / Greenpeace

TOP: Fire aftermath, Indonesia 2013 | BOTTOM: Flooding, South Sudan 2019

The ambiguity surrounding *LD* is due largely to the political dimension and contestation between low- and high-income/industrialized countries about residual impacts of climate change, the recognition of which might give rise to liability and compensation claims. In fact, the concept of *LD* can indeed be linked to the absence of mitigation efforts (Roberts & Huq, 2015; UNEP, 2016). The UNFCCC also acknowledges that *LD* “includes, and, in some cases, involves more than that which can be reduced by adaptation” (Decision 2/CP). While the Paris Agreement says nothing about financial compensation, *LD* discussions are frequently intertwined with climate finance as a means to fund mitigation/adaptation efforts.

Yet agreement does exist within the climate change community on this: *LD* can and should be addressed as part of WIM’s mandate to enhance knowledge and promote comprehensive short- and medium-term risk management, including risk assessment, risk reduction, risk transfer and risk retention (Gall, 2015).

The Santiago Network provides vulnerable countries a platform for collaboration and knowledge exchange on climate change adaptation, and access to urgently needed resources

While few WIM outputs focus on the agricultural sector as such, many are relevant to agricultural *loss and damage*. As part of its review of WIM, the 2019 Conference of the Parties (a.k.a. COP25) created the Santiago Network to heighten WIM’s focus on *LD*. For those developing countries most vulnerable to the adverse impacts of climate change, the network provides quick access to experts as well as to planning tools and solutions, and constitutes a platform for collaboration and knowledge exchange, all with an eye toward assessing, averting and minimizing the risks of climate change impacts, and monitoring the effectiveness of various measures.

While the DRR- and climate-focused perspectives differ, each is capable of enhancing the other. For example, because FAO’s standardized DL methodology quantifies economic impacts resulting from extreme events on agriculture, it could contribute a quantitative dimension to WIM discussions with regard to the sector. Conversely, WIM’s *LD* approach addresses and complements the non-economic/monetary aspects of slow-onset, long-term climate change, which the FAO methodology does not address. And because FAO’s methodology does not provide a way to attribute any share of agricultural DL to climate change per se, this may become possible later on given advances in attribution science, which are emerging under the climate change umbrella.

The potential for extending and combining DL/*LD* methods is evident in efforts currently underway in Uruguay, for example, where FAO’s DL methodology is being used in the context of the National Climate Change Adaptation Plan to estimate crop loss due to extreme climatic events.

Estimating agricultural damage and loss in Uruguay for climate change adaptation planning

Uruguay's National Climate Change Adaptation Plan (Ministry of Livestock, Agriculture and Fisheries, MGAP, 2019) emphasizes the importance of quantifying climate-related *loss and damage* in agriculture so that the actions necessary to recover and prevent climate risks may be identified. Extreme climate events such as drought, excessive rainfall, heat waves, frost, storms, strong winds, hail and extreme temperatures are key challenges to agriculture in Uruguay.

FAO's DL methodology was used in Uruguay to analyse damage and production loss caused by extreme climate events across key commodities over a 40-year period

Using FAO's DL methodology, an assessment was carried out in 2019 to help formulate Uruguay's 'National Adaptation Plan to Climate Variability and Change for the Agriculture Sector' (NAP-Agro). The analysis monitored damage and production loss caused by adverse climatic extreme events in the country's main commodity groups (cereals and oilseeds, livestock, dairy, horticulture and fruit production) compared to the value of the 'expected' production, as determined by average productivity in the five years prior to each event. Climate projections point towards a trend of increasing interannual climate variability in Uruguay, indicating both increased rainfall and continued occurrence of drought.

In the 40 years analysed, the USD value of agricultural damage and loss was highest during drought years (2007–2008, 2012–2013, and 2017–2018), especially for soybean and wheat (Table 1 and Figure 1), though this may be due partly to the expansion of cultivated areas over the past decade.

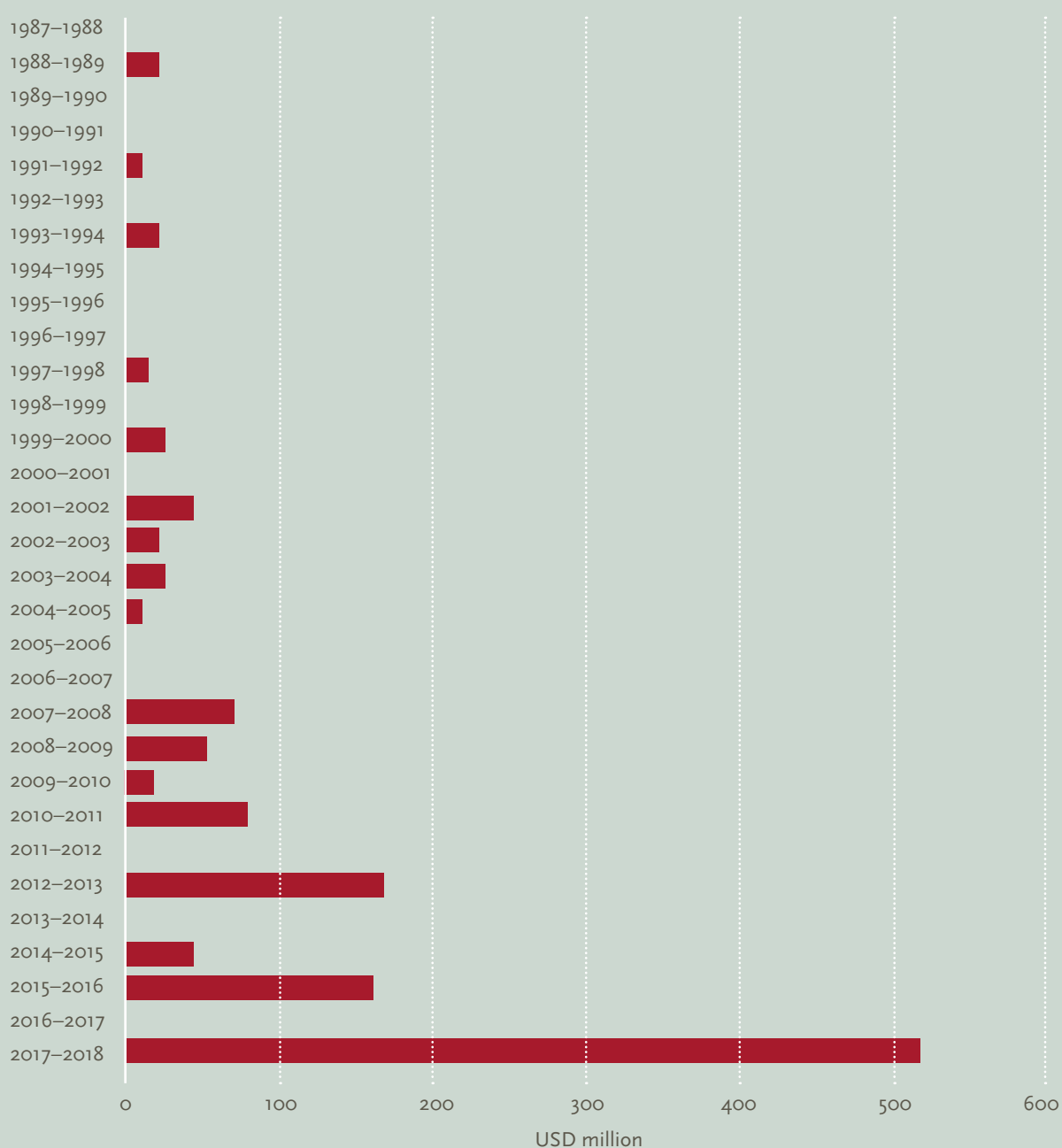
Analysis of historic damage and loss feeds Uruguay's disaster risk assessment and the forecasting of the probabilities of future production system losses due to various threats. This data was used to help design climate risk management and adaptation policies intended to avert or minimize *loss and damage*, such as the design of financial protection instruments that transfer risk to the insurance market. The data also contributed to the design of cost-benefit analyses of those investments designed to prevent and reduce risks, and to the creation of risk maps illustrating the spatial distribution of risks throughout the country, thereby enabling the informed prioritization of public resources. As a result of the assessment, NAP-Agro's national management and evaluation system now includes indicators on *loss and damage* due to extreme events, distinguished by relevant agricultural subsectors. This contributes to regular assessments of overall effectiveness of climate adaptation policies.

Table 1. Annual average and maximum loss of total production in main crops due to climate-related extreme events in Uruguay, 1978–2019

Crop	Annual average loss (USD)	Annual average loss (%)	Maximum loss (USD)	Maximum loss (%)
Soybean	19 680 841	8.0	472 493 263	57.5
Corn	3 008 570	6.3	31 987 025	48.3
Sorghum	704 403	5.5	4 971 016	50.3
Rice	1 191 490	2.1	17 919 717	17.1
Wheat	7 323 292	6.8	132 505 493	52.3
Barley	2 880 877	7.2	33 987 511	59.0

Source: Hernandez et al., 2018

Figure 1. Aggregated annual loss in main crops due to climate-related extreme events in Uruguay, 1987–2019, USD



Source: Hernandez et al., 2018

Main crops: soybean, corn, sorghum, rice, wheat, barley

Though progress is being made, ‘event attribution’ – determining the extent to which anthropogenic GHG emissions contributed to the probability or intensity of any given extreme event – remains challenging

Understanding the complexities of extreme events and climate-related disasters is a prerequisite for developing both climate change adaptation and disaster risk management strategies. Extreme weather and climate events can be the result of compound interactions between natural climate variability and anthropogenic-induced climate change. It has long been known that climate change includes variations in the frequency, intensity, spatial extent, duration, and timing of extreme weather events and disasters (IPCC, 2012). However, determining the extent to which anthropogenic GHG emissions increase the probability of any given extreme event remains extremely challenging (WMO, 2019). Early attempts focused on the attribution of long-term changes in climate (i.e. slow-onset changes such as temperature, precipitation, sea-level rise), and then of extremes (extreme temperature, extreme precipitation, drought) to anthropogenic GHG emissions, first at global level and then increasingly focused on regional and local scales. Since the early 2000s, understanding of ‘event attribution’ – mainly regarding extreme events such as heatwaves, floods, droughts – has progressed significantly. Attributing extreme events to climate change remains an evolving area of science, but one with the potential to inform WIM and other decision-making processes related to both disaster risk management and climate change adaptation.

Event attribution approaches

The risk-based approach is more common and offers higher confidence for temperature-related events than for those pertaining to excessive or reduced precipitation

Broadly speaking, scientists distinguish between two ways of attributing individual extreme events to climate change (Jézéquel *et al.*, 2018): the ‘risk-based approach’ and the ‘storyline approach’ (Figure 2). The most commonly applied risk-based approach quantifies the extent to which anthropogenic and natural forces contribute to the event occurrence by using climate models to compare the probability and intensity of the event in factual (i.e. current) and counterfactual (i.e. without anthropogenic climate change forcing) conditions (Stott *et al.*, 2016; Knutson *et al.*, 2017). Attribution confidence of risk-based studies is highest for temperature-related extreme events such as heat waves and cold waves (National Academies of Sciences, Engineering, and Medicine, 2016). Due to the great internal variability of precipitation, complexity of land-surface feedback, and the high-resolution spatial simulations required, only lower confidence can be achieved when attempting to attribute extreme precipitation, drought, hurricanes, severe convective storms, and other extremes (Zhai *et al.*, 2018).

The storyline approach attempts to describe how climate change influenced the physical processes leading up to a particular event by posing questions such as “How much did climate change affect the severity of a given storm?” (Shepherd *et al.*, 2018). Here, emphasis is placed on understanding the driving factors, the plausibility of those factors, and changes in those factors. For example, total precipitation during an abnormally heavy rain episode in Japan in July 2018 was estimated to have increased by approximately 7 percent due to recent rapid warming around Japan (Kawase *et al.*, 2020).

Because linking extreme events to climate change is so difficult – due largely to the absence of reliable weather records and other statistics – attribution studies have yet been conducted on only eight of the 71 disasters for which PDNAs exist

Difficulties in attributing extreme events to climate change rather than natural climate variability are pronounced. For example, the ability to attribute regional events is hindered by the vast differences in climate across regions, the quality and availability of long-term observational data, and the reliability of climate models to simulate the climate conditions generating an extreme weather event (Otto *et al.*, 2014). Consequently, existing attribution studies have focused on events in mid-latitude climates and high-income countries, where data is more readily available (Otto *et al.*, 2015; Pidcock, Pearce & McSweeney, 2020). In addition, the most severe and impactful events are not always assessed by attribution studies. Of the 71 disasters for which PDNAs and Rapid Assessment Reports have been conducted since 2007 (available at the GFDRR databases), only eight had corresponding attribution studies and five of those concerned drought. Various initiatives have been launched to reverse the situation, including: the European Prototype Demonstrator for the Harmonisation and Evaluation of Methodologies for Attribution of Extreme Weather Events (EUPHEME), the Copernicus Climate Change Service (C3S), and the World Weather Attribution service.

The most fundamental difficulty of all, however, is access to reliable observational weather records and high-quality statistics on disaster-related impacts on agriculture. This prerequisite applies not only to impact attribution studies but also the ability to draw comparisons between disasters and countries.



Aftermath of Typhoon Vamco, Philippines 2020



© Thoudy Bada / Greenpeace



© FAO / Luis Tato

TOP: Escaping flood, Indonesia 2020 | BOTTOM: Rehabilitating irrigation canal, Kenya 2019

Adding impact to injury: exploring new grounds for impact attribution in agriculture

Impact attribution approaches

Impact attribution tries to connect both the event and its socio-economic consequences to climate change using either a single-step or more advanced multi-step process

The scope of attribution modelling is evolving to attribute not only hydro-meteorological events themselves to climate change, but also their impacts on human and natural systems, e.g. heat-related mortality, coral reef bleaching, changes in marine and terrestrial ecosystems, crop failure. ‘Impact attribution,’ as it is known (Figure 2), adds to a related stream of practices that assess socio-economic impacts of slow-onset events – e.g. gradual long-term temperature change, sea level rise, ocean acidification – because those events are typically easier to link to anthropogenic GHG emissions. This leads to ‘complete impact attribution,’ which is achieved via so-called ‘multi-step’ or ‘joint attribution’ studies. Such studies employ advanced methodologies to first link a change in a mean or extreme climate variable to anthropogenic GHG emissions, and in a second step, link impacts to that change. However, coupling these links renders impact attribution prone to cascading uncertainties along the causal chains, and this is so through both steps. So, it is not surprising that most studies conducted to date limit themselves to assessing and linking socio-economic impacts to climate- and weather-related events (‘single-step’ studies or ‘direct’ attribution) without trying to draw a causal connection from the impact to anthropogenic GHG emissions (Burger *et al.*, 2020).

Just as event attribution studies require high-quality data on weather and disaster-related impact, so impact attribution relies on the availability of suitable socio-economic data at local, national, and global levels.

Long-term crop impact attribution to climate change and extreme events

Impact attribution studies link climate change to the decline in global yields of maize and wheat from 1980 to 2008; and to West Africa’s reduced yields of millet and sorghum during the 2000–2009 timeframe

Over the previous two decades, impact attribution studies in agriculture have attempted to quantify impacts of climate-related events and climate change at different spatial and temporal scales. While they mostly do not distinguish between slow-onset and extreme events – or their definitions deviate from those in policies – they do provide interesting insights to the scale and extent of the impact climate change may have on agricultural production over longer timespans (James *et al.*, 2019). For example, the global mean yields of maize and wheat are estimated to have declined due to climate change by 3.8 percent and 2.5 percent respectively from 1980 to 2008 when carbon dioxide fertilization is considered (Lobell & Field, 2007; Lobell *et al.*, 2011). Process-based modelling shows that global mean yields of major crops have decreased: the average annual value of production loss due to climate change for the most recent years of the study (2005–2009) is USD 22.3 billion for maize, USD 6.5 billion for soybeans, USD 800 million for rice, and USD 13.6 billion for wheat (Iizumi *et al.*, 2018). Looking at long-term impacts on crop production at a regional scale reveals that more frequent heat and rainfall extremes from climate change results in average yield reductions of 10–20 percent for millet, and 5–15 percent for sorghum in two crop models for West Africa during the 2000–2009 timeframe. This indicates that the average annual production loss associated with historical climate change, relative to a non-warming counterfactual condition, was USD 2.33–4.02 billion for millet and USD 730 million–2.17 billion for sorghum (Sultan *et al.*, 2019).

Crop impact attribution to climate change for a single event at local scale

Because multi-step impact attribution studies present various challenges, most follow the single-step approach, which is useful even though it cannot isolate the proportional contribution of human influence on any given impact

Complete attribution of localized discrete agricultural impacts of extreme events to climate change via multi-step studies is challenging for several reasons. First, many non-climate variables (both natural and human) must be accounted for to evaluate the extent to which anthropogenic climate change is responsible for those impacts. Long-term datasets, including socio-economic data, are often not available. For example, long-term natural variability of fish populations, land use changes, or technological innovations in crop production, can significantly affect changes in agriculture system productivity of each subsector. Second, the relationship between impacts on agriculture and changing climatic variables may be non-linear, requiring use of numerical models (e.g. process-based crop models) to account for that complexity, though few such models are robust or treat non-crop subsectors. Third, a single extreme event and its impacts depend partly on climate and environmental conditions prior to the event (e.g. soil moisture, water levels, vegetation), which means the event cannot be treated as a totally independent phenomenon. Finally, the spatial and temporal scale of an impact may be too small to capture with models and statistical methods.

As a result, only a few studies attribute impacts on crops to climate change for an individual weather/climate event, and most of these can be characterized as ‘single-step’ studies, which focus only on the relationship between impacts and observed changes in extreme events. While ‘multi-step’ approaches are complex and challenging, ‘single-step’ studies – despite their inability to isolate the proportional contribution of human influence on that impact – remain highly useful for their simplicity and years of scientific research history.

Spatial distribution and severity of agricultural drought can be monitored by remote sensing products such as FAO’s ASIS

It has nevertheless been possible to attribute crop production changes to specific extreme events such as drought, though the influence of anthropogenic climate change upon the latter has not yet been accounted for separately. Spatial distribution and severity of agricultural drought can be monitored by remote sensing products such as FAO’s Agriculture Stress Index System (ASIS) (see Chapter 8). Using empirical relationships among crop yields, a drought index, and annual precipitation, it is estimated that – globally and on average – drought-induced yield loss from 1983 to 2009 per drought event was 8 percent for wheat (0.29 tonnes/ha), 7 percent each for maize and soy (0.24 and 0.15 tonnes/ha respectively), and 3 percent for rice (0.13 tonnes/ha), accounting for a cumulative loss of USD 166 billion (Kim, 2019). Globally averaged, a single drought event decreases agricultural gross domestic production by 0.8 percent, with the magnitude of impacts varying by country.

Impact attribution in non-crop agriculture

Similar methods are being applied to impact attribution studies in non-crop agricultural subsectors.

In forestry, wildfire risk is studied using fuel aridity as a proxy, i.e. the drying out of forests and other burnable ecosystems. As anthropogenic emissions have caused rising temperatures and vapor pressure deficits, fuel aridity has escalated across the western United States over the past decades. This led to nine additional days per year of high fire potential during the 2000–2015 period, and torched an additional 4.2 million ha (95 percent confidence: 2.7–6.5 million ha) of forest area during the 1984–2015 period (Abatzoglou & Williams, 2016). Furthermore, 86–91 percent of the area burned in Canada’s extreme wildfire season of 2017 has been attributed to anthropogenic climate change (Kirchmeier–Young *et al.*, 2019).

Figure 2. Three kinds of climate attribution studies

Progress in attribution science ↓	Types of attribution studies	Example of subjects	Attribution approach
	Attribution of long-term change	Trends in: temperature precipitation sea level rise extreme weather events	
	Slow-onset changes in average climate as well as the frequency and intensity of extremes		
	Event attribution	Extreme temperature Drought Extreme precipitation Cyclone/hurricane	Risk-based approach Storyline Approach
	Single extreme events		
	Impact attribution	Heat-related mortality Wildfire Coral reef bleaching Fish population Changing crop productivity	Single-step (direct) approach Multi-step (joint) approach
Human, natural, physical system; marine, terrestrial ecosystems			

Source: Adapted from Zhai *et al.*, 2018

In fisheries and aquaculture, the 2015–2016 El Niño and the anthropogenic-induced long-term warming trend decreased food availability, thereby depleting planktivore populations, and reduced coral cover, thereby diminishing fish species dependent on live coral (Brainard *et al.*, 2018). Assessments also exist about how extreme high ocean temperatures impacted marine ecosystem such as coral reefs (Lewis & Mallela, 2018).

Slow-onset and extreme events

Both extreme event attribution and impact attribution models are facilitating the quantification of agricultural loss due to climate-/weather-induced disasters attributable to climate change. However, in the context of scientific attribution, these models do not distinguish the impacts of slow-onset changes from those of extreme events, because the same climate variables input pertain to both event types. Moreover, climate change impact assessments for agriculture are considerably more accurate in simulating the impact of slow-onset changes (e.g. seasonal rainfall, temperatures and length of growing period), but are not designed to comprehensively quantify or predict climate change-related loss from extreme events. This is a significant gap as climate-related disasters create and perpetuate rural poverty and are key drivers of severe food insecurity. Efforts are underway to improve the ability of crop models to account for extreme events (e.g. the European Union-funded MODEXTREME project). Also, some studies compare the size of extreme event impacts on crop productivity by turning on/off the model module that deals with extremes. One such study quantified maize yield under projected climate changes in South Africa’s three main maize growing areas. Accounting explicitly for the impact of extreme weather events such as extreme heat and drought showed lower simulated yields by 9 to 21 percent – depending on location, time horizon, and Representative Concentration Pathway¹ – compared with the model version that considers only slow-onset changes (Mangani *et al.*, 2019). This approach allows for separating impacts of climate change caused by extreme events (e.g. drought, flood, cyclones) from slow-onset changes (e.g. mean changes in temperature and rainfall).

Attribution studies cannot yet distinguish between impacts of slow-onset and extreme events because the same climate variables apply to both, but efforts are underway to improve the situation

¹ Representative Concentration Pathways (RCPs) indicate various GHG concentration trajectories or ‘what if’ scenarios, each based on a different volume of GHG emissions in the years to come.

Looking into the future: modelling crop yields in climate change scenarios

In attribution science, the difference between simulated productivity under future climate data and that under present climate data is considered the impact of climate change

The models used in statistical and process-based attribution studies to demonstrate the historical relationship between agriculture and climate can also be used to project future changes in agricultural systems under various climate change scenarios. In this case, projected climate data is used as inputs to models.

These models are calibrated on observed impacts and events, emphasizing the usefulness of rigorous impact/damage and loss assessments in agriculture (including DL from geophysical events). The difference between simulated productivity under future climate data and that under present climate data is considered the impact of climate change.

FAO's Modelling System for Agricultural Impacts of Climate Change (MOSAICC) helps countries project potential crop loss. Historical yield time series adjusted for non-climatic variations (e.g. changes in production systems) can be analysed for correlations with climatic variables (average, minimum and maximum temperatures and precipitation) as well as soil water-related variables (evapotranspiration, soil water balance, etc.) derived from those same climatic variables. Based on these correlations, a performance function quantifies relative contributions of selected climatic and water variables to the yields, location by location, crop by crop. Calibrated with past climate and yield data, this performance function can then be used with downscaled climatic variables from future climate simulations provided by Global Climate Models (GCM) – a product of the Goddard Institute for Space Studies, a laboratory of the National Aeronautics and Space Administration (NASA) – to project future yield. The computed difference between future and past yields provides an estimate of the expected climate-induced change in crop productivity.

By simulating future changes in productivity and comparing that to historic yields, FAO's MOSAICC can estimate climate-induced changes in the 20- to 30-year average future yield

MOSAICC, like other modelling tools, uses daily temperature and rainfall data to simulate future changes in productivity. Both slow-onset changes (e.g. rising temperature or decreasing rainfall on average over years and decades) and extreme events (e.g. drought, extreme precipitation, extreme heat waves in specific years) manifest agricultural climate risks on different time scales, albeit from the same temporal daily data. Both types of climatic change – slow-onset/extreme – are accounted for as daily climate data are input into the model. The yield projection results are available annually under potential future climate scenarios, but are presented as changes in the 20- to 30-year average future yield compared to the present yield level. From the same results, it is also possible to analyse future changes in year-to-year yield variability and largest yield reductions, revealing changes in frequency and intensity of impacts from extremes. The model results should always be interpreted as changes in statistical characteristics of yield (e.g. average, variability, maximum, minimum), not as yield predictions for a specific year in the future.

Statistical methods as used in MOSAICC do not treat rapid extremes explicitly, but the regression model includes climate variables and derived water variables, which are highly correlated and serve as proxies for extremes whenever extremes are significant factors that explain historical variations in yield.



© Nick Cobbing/Greenpeace



© Qiu Bo/Greenpeace

TOP: Flooding, Oxfordshire, United Kingdom of Great Britain and Northern Ireland, 2007 | BOTTOM: Dried-out farmland, Inner Mongolia, China 2013

Table 2. Climate- and water-related variables and their coefficients in regression models for maize

Country/Region	Water satisfaction index (%)	Water deficit at initial growth stage (mm)	Total precipitation (mm)	Maximum temperature (°C)
Malawi/Blantyre	0.0192	- 0.774	-	-
Zambia/Western province	0.0366	- 0.0245	-	-
Uruguay/Western part	-	-	0.0043	- 0.53

Table 2 shows a sample yield regression model with the climate and water variables. For example, the water deficit stress index may be considered as a proxy to drought, as has been observed in Malawi and Zambia at the initial stage of crop growth. In these two countries, the corn yield showed a high positive correlation with the water satisfaction index (WSI), and a negative correlation with water deficit stress during certain periods (e.g. initial stages in Malawi and Zambia). During El Niño years, both are often signs of drought.

In a study of the potential climate change impacts on corn yield in Uruguay in the medium- and long-term (2040 and 2070 respectively), MOSAICC shows yield has a negative correlation with maximum air temperature, and a positive correlation with rainfall for the entire corn-growing season (Borges *et al.*, 2020).

A maximum temperature increase of 1 °C will decrease maize yields by 0.53 tonnes/ha and each decrease of 1 mm in total precipitation will decrease maize yields by 0.0043 tonnes/ha (Table 2). Depending on the climate model and scenario, changes in maximum temperature up to 1.2 °C decreases yield by 0.64 tonnes/ha; while increases in rainfall, predicted to rise up to 80 mm, increases yield by 0.34 tonnes. So, for example, a 1 °C increase in temperature paired with a 50 mm increase in rainfall would cause 0.27 tonnes/ha decrease in corn yield. Overall, the negative effects of rising temperature and heat stress are expected to become more prominent, causing a slight decrease in Uruguay’s future corn yield.

MOSAICC shows that, in Uruguay, a 1 °C increase in temperature paired with a 50 mm increase in rainfall would cause 0.27 tonnes/ha decrease in corn yield

The empirical statistical models can thus predict the quantitative impacts of slow-onset and rapid extremes on crop yield to forecast yield changes under future climate conditions, assuming the relationship between climate and yield remains unchanged.

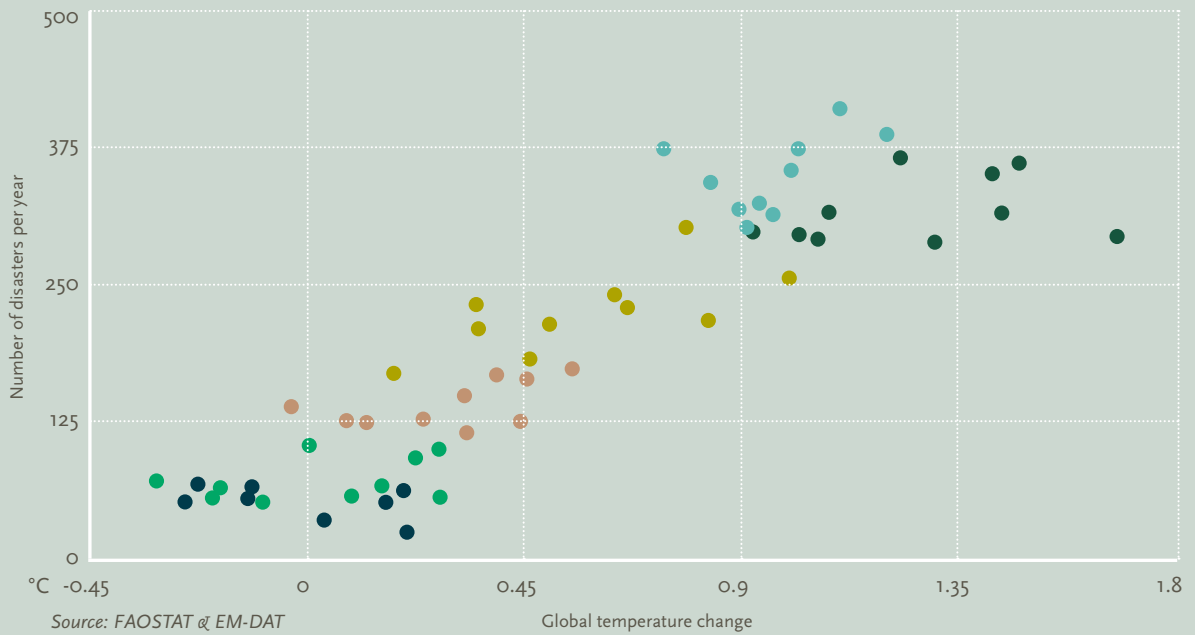
Global trends on disaster occurrence, agricultural loss and global mean temperature rise

Science is detecting a stronger link between the planet’s warming and its changing weather patterns. The past two decades have witnessed not only the highest global temperatures ever recorded, but also the greatest number of disasters. Though it can be difficult to specify whether climate change intensified a particular weather event, the trajectory is clear: hotter heat waves, drier droughts, larger storm surges and greater snowfalls are more frequent overall. The intensified occurrence of disasters – particularly storms, drought and floods – coincides with a simultaneous global temperature rise throughout the past 60 years (Figure 3).

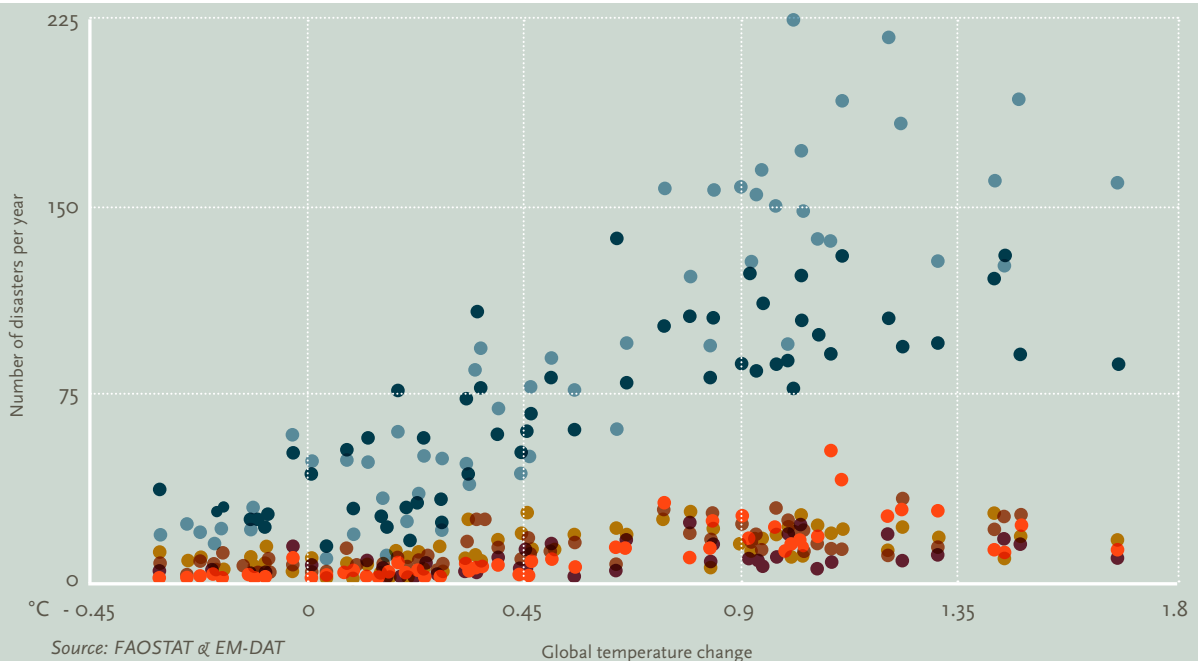
Correspondingly, more frequent and intense climate-related disasters are likely to contribute to more severe damage and loss – with the effects of droughts and heat waves being clearly identifiable in national yield statistics. For example, more recent droughts (1985–2007) caused cereal production losses averaging 13.7 percent of

national production in drought-affected LDCs and LMICs, which was 7 percentage points greater than earlier droughts (1964–1984) (Lesk *et al.*, 2016). Looking at loss from climate-related events 1980–2014,² the trend is one of increasing loss not only for key crops such as rice, maize and wheat (Figure 4) but for all crops and livestock (Figure 5). Currently observed trends also already point towards an impact of increased temperature variations over recent decades on the frequency and magnitude of events.

Figure 3. Observed relation between climate-related disaster occurrence and global temperature change



Legend: ● 1961–1969 ● 1970–1979 ● 1980–1989 ● 1990–1999 ● 2000–2009 ● 2010–2019

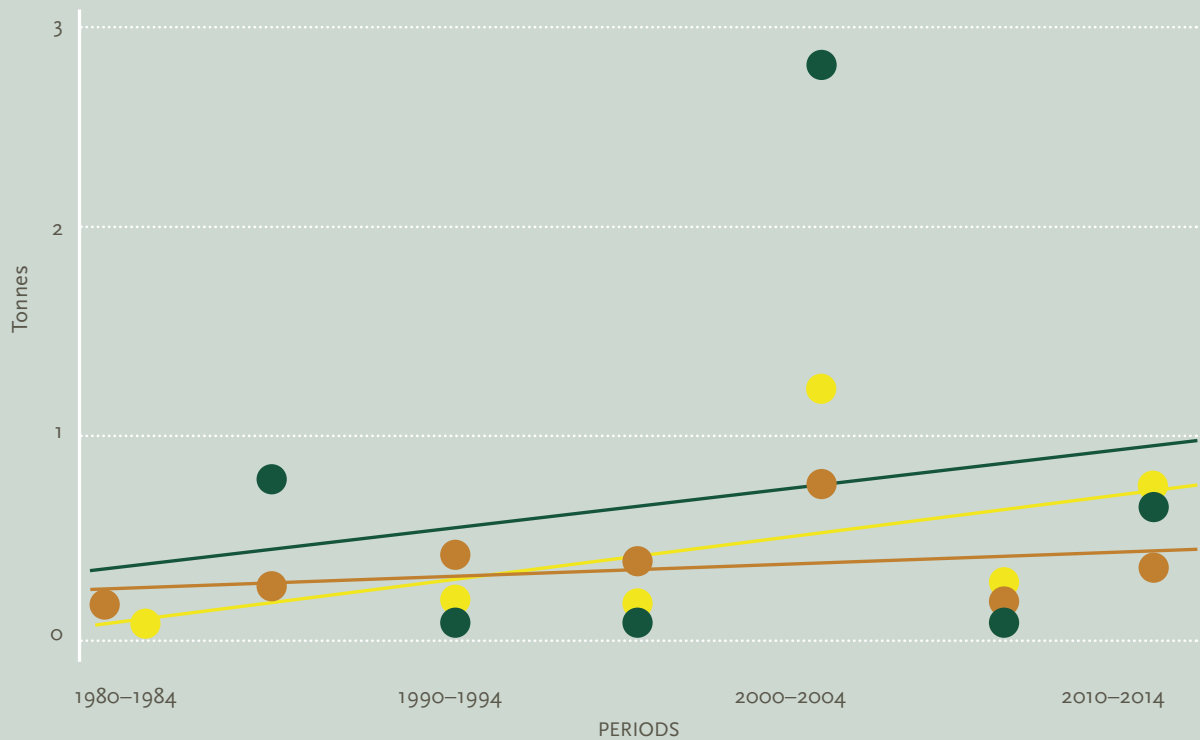


Legend: ● Drought ● Extreme temperatures ● Floods ● Landslides ● Storms ● Wildfires

Each dot represents a single year. Global temperature change is measured as a particular year's global mean temperature deviation from the long-term mean of the period 1951–1980. The upper chart shows the total number of disaster events per year; the lower chart presents the same data disaggregated by disaster type.

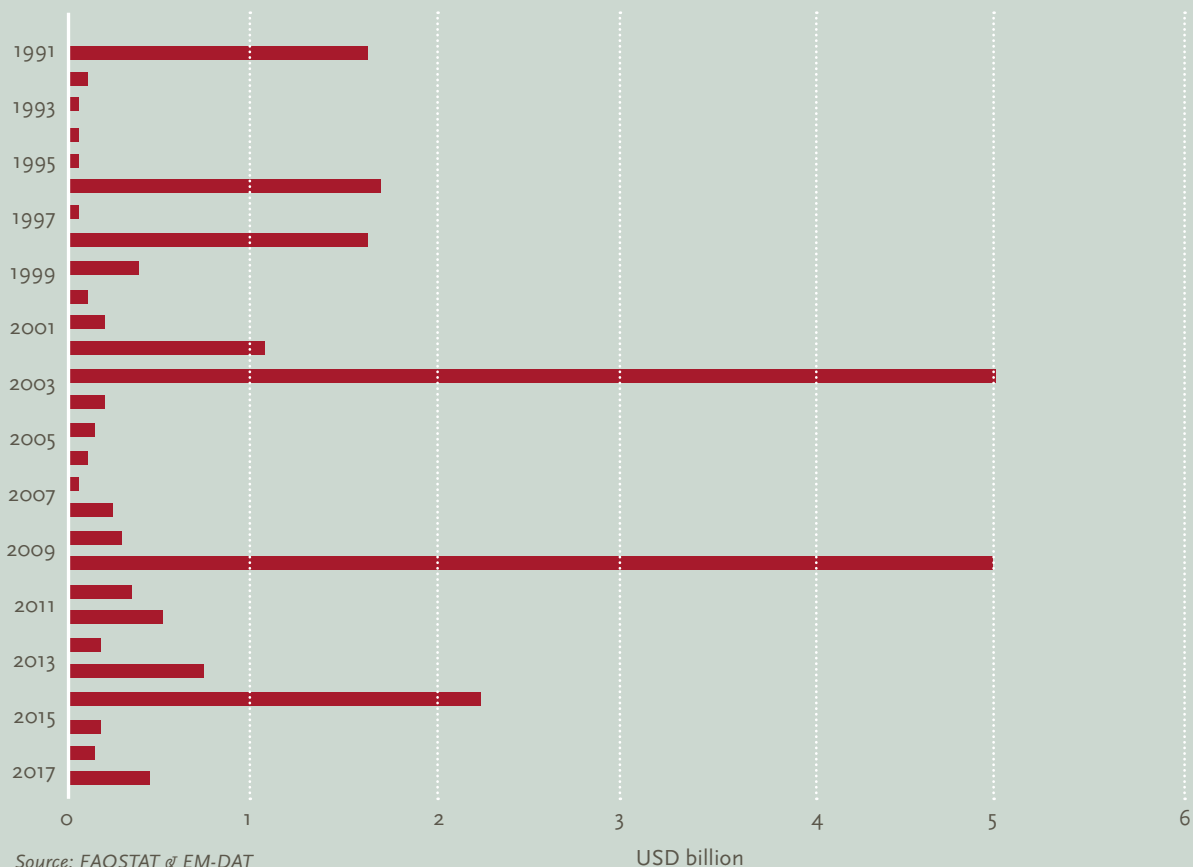
² Analysis based on: changes in cultivated area and yields as reported in FAOSTAT; loss based on EM-DAT CRED events with estimates from randomly sampled fictitious event years. The calculation of losses follows the analysis in Chapter 1, i.e. estimating the deviation of country yields from the time trend.

Figure 4. Loss trends in major crops (tonnes), 1980–2014



Legend } ● Loss in rice per period (tonnes) ● Loss in maize per period (tonnes) ● Loss in wheat per period (tonnes) } Data calculated according to Chapter 1 Box 2.
 — Trend in rice loss — Trend in maize loss — Trend in wheat loss } Source: FAOSTAT & EM-DAT

Figure 5. Aggregated loss in crops and livestock due to climate-related disasters, 1991–2018



Source: FAOSTAT & EM-DAT

Legend: Data calculated according to Chapter 1 Box 2

Because long-term trends indicate that global temperatures will continue to increase or remain at historically high levels, their negative impacts on crop yields and livestock production are likely to become increasingly problematic in the future. The latter graph (Figure 5) additionally demonstrates the stark variability in disaster-related loss over the years, highlighting the irregularity of disaster occurrence.

The current approach to climate change modelling focuses on long-term average changes, which seems to conceal – or at least make it harder to spot – the significance of individual disasters

However, quantifying the relationship between climate change, disaster frequency and agricultural loss remains challenging, due to concurrent shifts in levels of vulnerability and exposure, early warning efforts, overall economic development and varying data availability. The current approach to climate change modelling focuses on long-term average changes, which seems to conceal – or at least make it harder to spot – the significance of individual disasters. This affects overall preparedness. It is crucial that – within the overall climate change context – modelling practices be enhanced to also evidence the true magnitude of impacts received from extreme weather-induced disasters. Only in this way can disaster management capacities and mechanisms be proactively strengthened with the built-in elasticity and flexibility necessary to accommodate these irregular extremes – which are increasing in both number and ferocity – and thereby provide farming communities and other vulnerable groups with the protection they so urgently require.

Challenges and challengers: building an impact evidence base to support comprehensive risk management

As a major stakeholder in the climate change debate, agriculture must take a leading role in WIM's loss and damage discussions

The agricultural community should take a leading role in the *loss and damage (LD)* climate discussions, particularly under WIM. Agriculture is a major stakeholder in that debate, absorbing 26 percent of damage and loss (DL) from disasters (both slow-onset and extreme events combined, see the Introduction of this report). As illustrated above, long-term climate change leads to substantial yield reductions in key staple crops such as rice, maize, and wheat. As impact and event attribution methodologies advance, the agriculture and climate science communities are learning how to best attribute agricultural DL/LD from both slow-onset and extreme events to climate change. FAO's DL methodology can contribute to standardized and coherent data on the impacts of climate-related extreme events by providing detailed, spatially and temporally explicit impact data that can be disaggregated per agricultural subsector (e.g. crop) by geography (e.g. district), hazard type and key commodities. This is essential to multi-step attribution studies assessing climate change-induced loss and damage, as well as to developing crop models that account for both extreme and slow-onset events. This improves the potential for localized attribution and separation of climate- and non-climate drivers of LD/DL. In the long-run, reporting impact from climate change-related disasters in the context of the Sendai Framework would further promote the collection of globally-standardized data.

Standardized reporting of disaster-related impact data under both the Sendai (FAO methodology) and WIM frameworks will enable more rigorous impact attribution studies, which would validate and advance achievement of WIM's mandate

Such impact data is what enables rigorous attribution studies in the first place, and both are innately dependent upon high-quality observational data. Establishing methodologies and protocols to estimate agricultural LD and demonstrating their effective application at country and regional levels would constitute a concrete exemplar for operationalizing LD, which would in turn validate and considerably advance achievement of WIM's mandate. While some uncertainties in event and impact attribution will diminish with improved modelling capabilities and more precise climate change markers, others will persist. Nevertheless, because attribution science improves our understanding of climate and non-climate drivers of LD in agriculture, it can and should be used to inform policy and practice today.

Broadly speaking, climate change modelling and research is already able to inform prevention, recovery, and rehabilitation efforts, thereby bolstering both disaster risk management and climate change adaptation. Its potential applications for averting, minimizing and addressing *LD* are manifold. The case of Uruguay demonstrates how modelling slow-onset changes in yields, coupled with standardized assessment of agricultural DL from extreme events can generate data that informs risk assessment and enhances the design of long-term adaptation policies.

WIM's increased focus on risk assessment and comprehensive risk management approaches validates the value of FAO's DL methodology and suggests that its potential contribution to the climate change-oriented *LD* discussion should be further explored

Disaggregated DL data can indicate regions and crops most susceptible to extreme events. Spatially explicit and commodity specific modelling of long-term trends in yields highlight key areas for adaptation to slow-onset events by indicating the distribution of risks. Consequently, DL information helps prioritize allocation of public resources. Including a continuously monitored DL indicator in systems to manage and evaluate climate change adaptation can also help monitor, evaluate and optimize the performance of comprehensive risk management approaches, thereby contributing to cost-benefit analyses. The increased focus on risk assessment and comprehensive risk management approaches that has followed the 2019 WIM review substantiates the value of FAO's DL methodology and suggests that its potential contribution to the climate change-oriented *LD* discussion should be further explored. Synergies between the two will likely become clearer with additional advances in both fields, but especially in attribution science, as well as in data quality and availability.

To manage and reduce disaster and climate risks, potential impacts must be forecast and actual impacts monitored. Through various channels (including model validation and trend analysis), post-disaster assessments can play an important role in analyses to anticipate and reduce current and future climate risks. In this respect, the DL data already being reported by countries under the Sendai Framework and the Paris Agreement must be further consolidated, and countries should step up even their voluntary reporting of disaggregated data. Existing data sources and collection mechanisms should be used to the maximum extent possible to enhance the *LD* knowledge base. In so doing, they should be as explicit as possible about the role of slow-onset changes and/or extreme events. This will demonstrate the strengths, weaknesses and relevance of existing collection structures for *LD*. While current scientific methods do not always distinguish impacts from slow-onset and extreme events, more explicit knowledge about how these distinct event categories impact agriculture is crucial for adaptation planning. This is because measures and capacities to adapt to slow-onset events differ substantially from those for extreme events.

Understanding climate-related *LD* in agriculture entails combining impact evidence from extreme events with the modelling and/or monitoring of impact evidence from slow-onset event

For coherent risk management and reduction, the quantification of socio-economic impacts of climate change ought to comprise immediate damages and medium- to long-term loss from both slow-onset as well as extreme events, as recognized by WIM. A complete picture of climate-related *LD* in agriculture would thus entail combining impact evidence from extreme events (specifying the attribution of climate change upon these to the extent possible) with the modelling and/or monitoring of impact evidence from slow-onset events. A generic framework for long-term monitoring of post-disaster DL for both slow-onset and extreme events as proposed above could make concrete contributions to truly comprehensive risk management in agriculture.



© Will Rose/Greenpeace



© Gabriel Lintoso/Greenpeace

TOP: Melting glacier ice, Norway 2019 | BOTTOM: Drought, Brazil 2015



© REUTERS/Luc Gnago

Drone demonstration in northern Abidjan, Ivory Coast 2019



Chapter VIII

From farm to space: exploring remote sensing applications for disaster impact analysis in agriculture

High-resolution remote sensing imagery plays a fundamental role in delineating the impact of catastrophic events. Rapid spatial analysis often combines low altitude images (from drones or planes, for example) with space-based data (i.e. satellite imagery), Geographic Information Systems, and Information and Communication Technologies. When combined with ground truthing and traditional statistical analyses, these technologies – and emerging approaches like disaster robotics and machine learning – are opening new opportunities for initial post-disaster estimates to provide swift and accurate reports on damage and loss in agriculture, the environment, and infrastructure and to inform disaster risk management.

Real time assessment of disaster impacts on agriculture through geospatial technology

Disasters, while destructive in nature, can also serve as catalysts for the adoption of innovative and advanced technologies. Catering to the need for rapidly available information for disaster management, technological innovations make it possible to conduct damage and loss assessments directly after disasters and extreme events with improved ease, efficiency, precision and speed. In addition, the use of information technologies enables tracking and monitoring of emergency response and recovery efforts, helping to guide their progress.

Because it can monitor slow-onset changes as well as sudden-onset disasters such as hurricanes, map topography, track ocean currents and temperatures, et al., RS is inherently useful for disaster management and impact assessment

Remote sensing (RS) – the practice of acquiring information about various phenomena using remote instruments – is inherently useful for disaster management and impact assessment. Utilizing special cameras and other imaging and non-imaging sensors mounted on satellites, drones, aircraft, etc., RS measures – actively or passively – energy/radiation emitted/reflected from the Earth. It can monitor slow-onset developments such as city expansion, changes to shorelines, farmland and forests that have occurred over time; it can map topography, including the ocean floor; and track cloud formation and movement, cyclones, hurricanes, typhoons, dust storms, ocean currents and temperatures, forest fires, and volcanic eruptions. It is capable of providing precise, immediate and regular data over large areas anywhere in the world. Wherever and whenever a large-scale disaster strikes, RS technology offers a reliable way to understand what is happening on the ground in real time, even in hard-to-access areas.

The field is fast evolving. Multiple satellites in orbit are now equipped with diverse RS payloads, whose outputs can be easily supplemented via airborne remote sensing, including by unmanned aerial vehicles such as drones. Recent advancements in affordability, availability, coverage, spatial resolution and accessibility have further expanded the role of geospatial data and information technologies in both monitoring disaster impacts as well as assessing the performance of agriculture and ultimately of food security situations in vulnerable or affected areas. Its ability to cover large and often difficult-to-reach regions – and to do so at a fraction of the cost of ground-based surveys – enables RS technology to provide a range of information about agricultural operations that can be applied for major disaster types at each stage of DRM (Table 1).

These innovations do not substitute traditional assessment methods. Indeed, they require on-the-ground observation (ground truthing) and must be calibrated using traditional data collection and analysis methods. Nevertheless, they do represent a valuable addition to the DRR, DRM, and emergency response toolbox and constitute an important new front for future exploration and innovation.

Use of RS in data collection and screening is skyrocketing for post-disaster emergency response and recovery efforts

Post-disaster assessments are increasingly incorporating RS technologies into data collection and screening. The use of satellite, areal and drone remote sensing images for disaster impact assessment in agriculture has skyrocketed in recent years, especially in assessing hurricanes, cyclones and other storms. For emergency response, RS provides images to support rapid damage assessment, orient field assessment to hotspots and detect potential yield changes. For recovery, remote sensing information supports rehabilitation and reconstruction, and contributes to estimating agricultural damage and loss.

RS data can help detect the arrival of drought well in advance, allowing for early implementation of anticipatory and impact-mitigating action

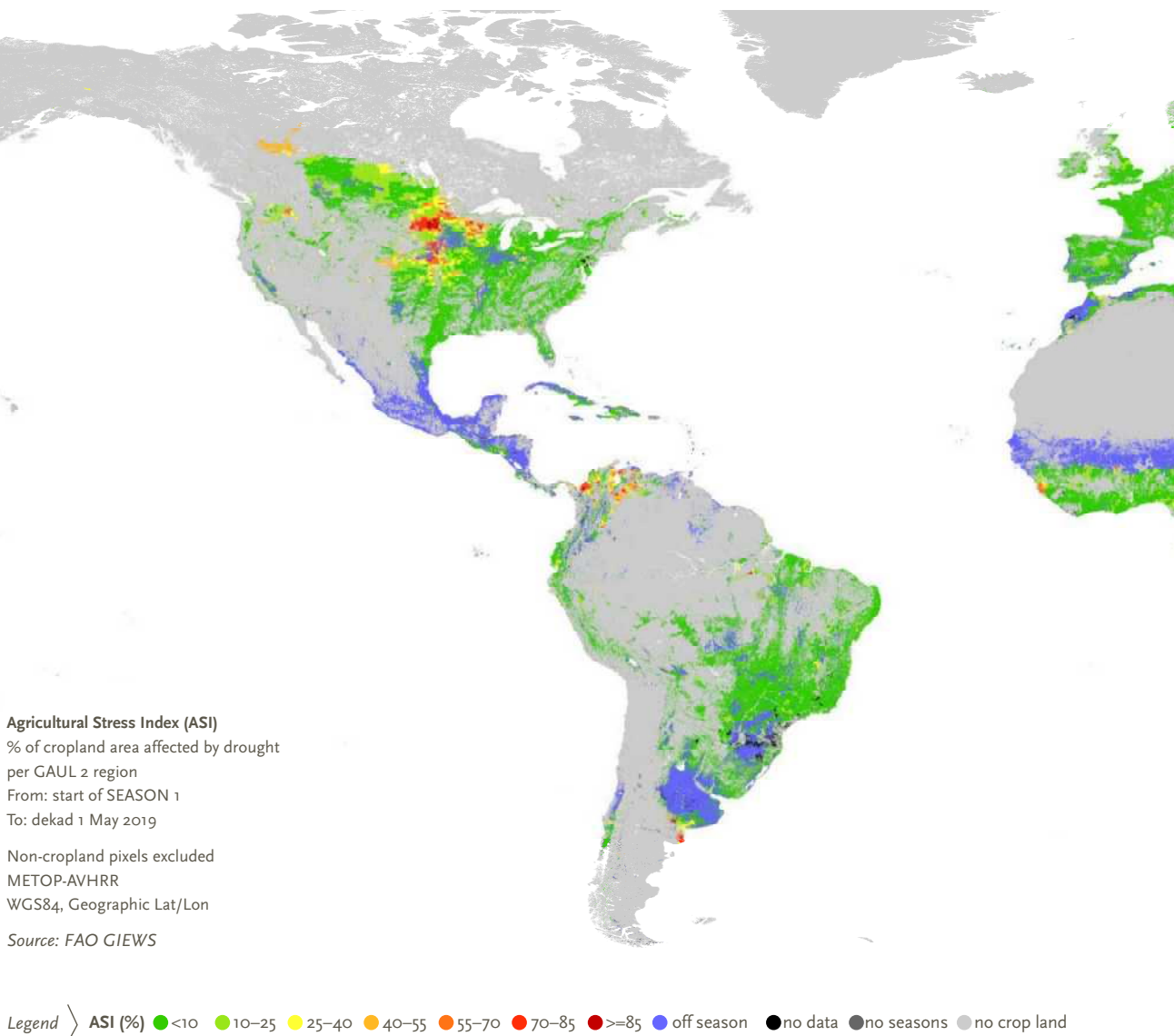
All these developments have the potential to significantly enhance not only post-disaster recovery but also the very DRM process itself. RS data, information, systems and tools can help identify and assess potential hotspots that may be linked to future disasters, which helps anticipate risks, prioritize actions and facilitate evidence-based programming to improve food security in a pre-emptive fashion.

This is especially useful in case of drought – the single greatest cause of agricultural production loss around the world, especially in the Horn of Africa (see Chapter 1) – and the hunger crises it can cause. Unlike many other quick-onset weather- and climate-related disasters, drought develops gradually over time. This rather long lead time means its arrival can be detected well in advance, allowing for early implementation of anticipatory and mitigatory action. Meanwhile, satellite observations of medium- and long-term climate forecasts can help build seasonal outlook scenarios on expected crop performance before or at the beginning of each crop growing season. Satellite data on rainfall during the season can help monitor growing conditions and predict soil moisture, and indices such as the normalized difference vegetation index (NDVI) and the vegetation health index (VHI) are used to analyse RS measurements and anticipate impacts on crop production and yield.



A drone maps farmland in the Pampanga province, Philippines 2018

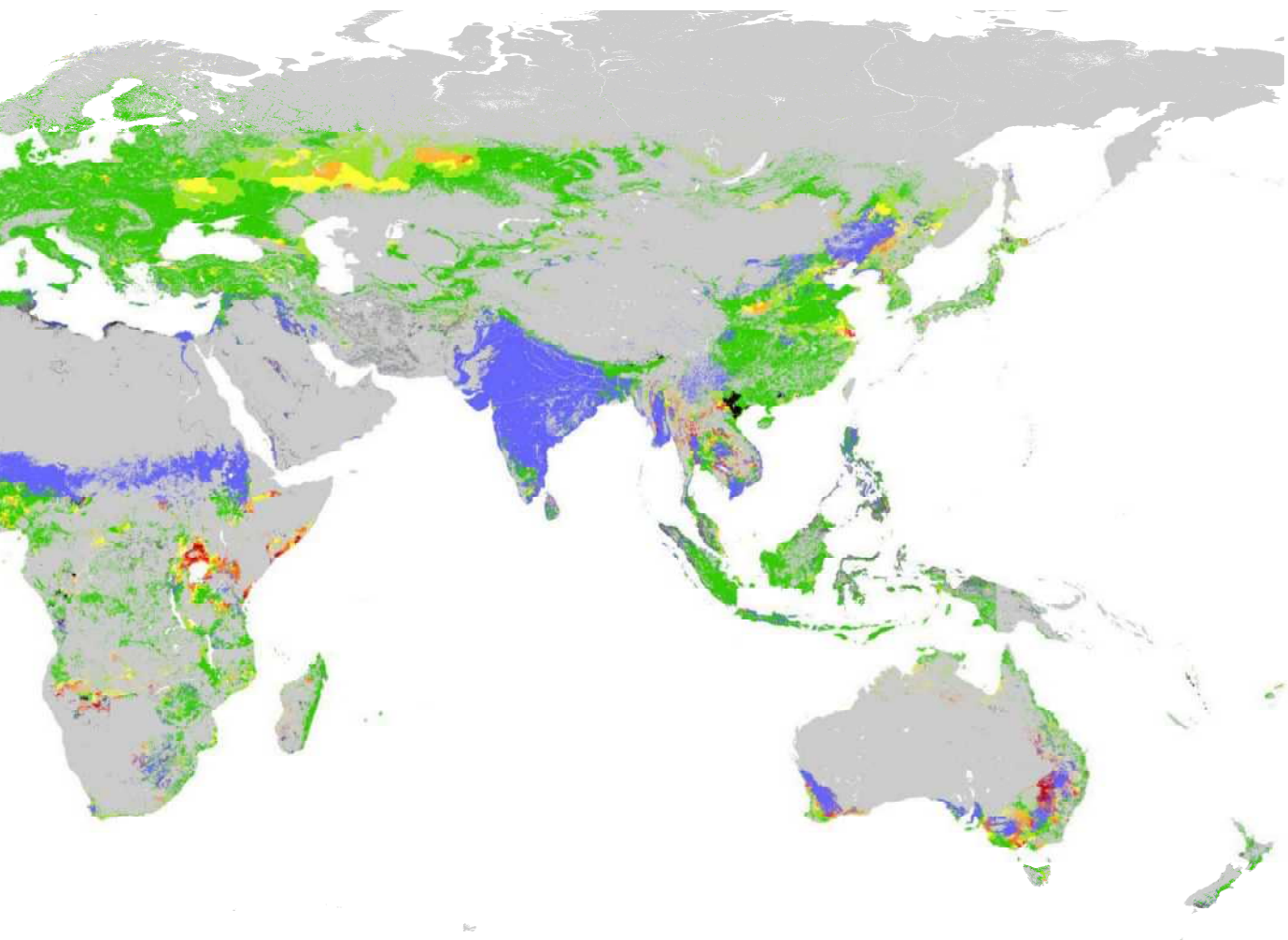
Figure 1. Agricultural Stress Index



Monitoring the onset of drought through the FAO Agricultural Stress Index

Because droughts develop gradually, they often fail to capture national or global attention until they trigger a famine or wildfire. Even though drought events are particularly problematic for agriculture – disrupting production systems, food markets, local economies and rural households around the world – crisis management response is usually reactive rather than proactive. This is why early detection systems that can enable proactive responses are both necessary and key for dealing with increased fire risk, managing crop losses, mitigating food insecurity and preventing food crises. Real-time georeferenced information can detect the early onset of drought conditions and inform timely and efficient policies and plans to minimize the immediate and longer-term socio-economic impacts of drought.

The Agricultural Stress Index (ASI) is a snapshot indicator for the early identification of croplands that are highly likely to be affected by drought. The index is based on 1-kilometre resolution remote sensing data of vegetation conditions and land surface temperatures incorporating information on agricultural seasons and crop cycles. It also employs a ‘crop mask’ or pixel filter that enable its analysis to hone in on farming areas and specific crop classes, mainly wheat, maize, rice, sorghum, millet and beans. The ASI uses nearly real-time satellite information received by FAO every ten days, which is an ideal timeframe because it allows the analysis to factor in the soil's water holding capacity, an important characteristic that determines how long moisture remains available to crops. The index uses the crop mask provided by the 2014 FAO Global Land Cover – SHARE (GLC-SHARE) database, in which the cropland layer includes all cultivated annual plants.



ASI's principal building block is the vegetation health index (VHI), which is derived from the normalized difference vegetation index (NDVI). NDVI provides an indirect measure of primary production through its relationship with active radiation during the photosynthesis process of plants. ASI integrates VHI values along time and space, two crucial dimensions for assessing the onset of drought impacts on agriculture. First, it calculates a temporal average of VHI values, assessing the intensity and duration of dry periods during the crop cycle at pixel level. This calculation also employs specific coefficients that consider the sensitivity of crops to water stress during the growing cycle, particularly at the critical flowering and grain filling stages. Second, ASI defines the drought's spatial extent by calculating the percentage of cropland area with a VHI value lower than 35 percent, a threshold identified in previous studies to determine the existence of severe drought conditions. ASI has been fine-tuned to differentiate areas according to the severity of the water stress (mild, moderate, severe or extreme), and to provide colour-coded maps that highlight anomalous vegetation conditions during the growing season in each Global Administrative Unit Layer (GAUL).

Data derived from ASI monitoring is extremely valuable for hazard and disaster impact assessments throughout the risk management cycle, because they establish baseline information, which in turn enables trend analysis and the identification of trigger points as conditions devolve into drought over time.

Table 1. Remote sensing contribution at each stage of disaster risk management

Disaster type	Remote sensing contribution			
	Disaster risk reduction	Emergency response	Recovery	DL assessment
Floods	Baseline shoreline position, elevation, permanent water extent, historical flood extent, land cover/use	Rapid observation & monitoring of flood extent on land cover/use & crops	→ Flood extent as input for planning → Monitoring rehabilitation & reconstruction	Estimates on size of area affected, calibrated with ground truthing of crop damage
Drought	Baseline of long-term temperature, precipitation, water extent, land cover/use	Observation & monitoring of climate anomalies from baseline, especially for crops & livestock	→ Water extent, climate data as input for planning	Assessment of crop health & growth by assessing the photosynthetic capacity of plants; estimates on the size of crop and rangeland area affected; identification of areas with land use change
Fires	Baseline of fire occurrence and intensity	Monitoring a fire's geographic location	→ Monitoring landscape restoration	Estimates on size of area burned, land cover & land use change
Landslides	Lithology, slope, land cover/use, lineament density, precipitation distribution, altitude, slope aspect, drainages & roads	Rapid observation of impact area	→ Monitoring land stabilization & prevention measures	Map of landslides' landcover; estimates on agricultural area affected
Land degradation	Historical vegetation, soil & water changes	Monitoring land degradation	→ Monitoring landscape restoration	Landcover map; estimates of agricultural area affected
Disease & pests	Baseline proxy variables such as vegetation health, land productivity	Monitoring proxy variables (land cover/use, VHI)	→ Monitoring prevention & response measures	RS microwave measurement to estimate occurrence of plant pests, locust breeding areas, and potential crop damage
Storms	Baseline sea wave height, wind speed, surface currents	Monitoring of storm impact & rapid observation of impact area	→ Monitoring rehabilitation & reconstruction	Estimates on size of crop, forest & coastal areas affected; crop & forest cover maps, calibrated with ground truthing of damage to agricultural areas, assets & infrastructure
Tidal surges, or storm tides	Near-shore bathymetry, land elevation, infrastructure & communities	Rapid observation of impact area	→ Change in nearshore bathymetry → Coastal zone & land use planning → Monitoring rehabilitation & reconstruction	Estimates on size of crop area affected and crop cover maps, calibrated with ground truthing of damage to agricultural areas crops, forest aquaculture, assets & infrastructure
Severe cold	Baseline of long-term water temperature; extent & duration of sea, lake, and river ice	Observation & monitoring of climate anomalies from baseline	→ Ice extent, climate data as input for planning	Estimates on levels and areas affected by frost damage in crops
Volcanic eruptions, earthquakes, tsunamis	Baseline mapping of agricultural infrastructure & communities	Rapid observation of impact area	→ Input data for recovery planning & monitoring → Monitoring rehabilitation & reconstruction	Estimates on agricultural area affected, calibrated with ground truthing of damage to crops, assets & infrastructure

The value added of spatial data for analyses of disaster-related impacts on agriculture

Geospatial data can help open a precious window of time during which life-saving help can be quickly mobilized and the impact on livelihoods can be minimized early on

Geospatial data play a fundamental role in DRM and disaster-related impact assessments of agriculture and food security, especially for natural hazards (floods, storms, drought, etc.). On the DRM front, geospatial instruments are key for real-time mapping of the magnitude and extent of any particular hazard, thereby allowing exposed areas, populations and agricultural livelihoods to be immediately identified and flagged so that the potential impact can be rapidly forecasted. This opens a precious window of time during which help to save lives can be promptly mobilized and directly guided to the most affected spots, potentially averting or mitigating livelihood impacts early on. Another advantage of geospatial instruments is their ability to establish, through regular monitoring, baselines that help estimate potential input supply gaps for agriculture immediately after a disaster event, thereby enabling and triggering tailor-made post-incident recovery.

Advantages of remote sensing for post-disaster assessments

- **Versatility** – covers disasters of all types and areas of all sizes, from only a few hundred meters to thousands of square kilometres.
- **Speed** – can be rapidly deployed before or immediately after disaster strikes.
- **Safety** – does not rely on physical access to remote or dangerous sites, and can provide data regardless of the site's infrastructure condition.
- **Ease-of-use** – can automatically update inventories and even prefill sections in questionnaires.
- **Timeliness** – provides up-to-date images of population distribution, unlike traditional maps.
- **Cost efficiency** – drones are more economical than on-site human inspections.
- **Window into the past** – can provide historic data to fill information gaps on past events.

Geospatially created baselines can be overlaid with elements of socio-economic risk exposure

Information produced by geospatial instruments is manifold and can support: database development; design of disaster management information systems; analysis of disastrous phenomena (location, frequency, magnitude, etc.); hazard zonation and mapping the environment in which calamitous events might occur (topography, geology, geomorphology, soils, hydrology, land use, vegetation); inventorying elements that might be impacted; cost benefit analyses; spatial decision support systems; conflict management; and the implementation of disaster management itself. Spatial baselines require data on land cover, geological and soil layers as well as digital elevation models (DEM) – three-dimensional representations of the terrain's surface – which are generated through geographic information systems (GIS) applications that make it possible to overlay various other elements of risk exposure (e.g. population, livelihoods zones, agricultural infrastructure).

Emerging methods of information acquisition and processing

The proliferation of earth-observing RS systems and the increase in computational capacity and speed has exponentially increased the volume of sensor data available for analysis. It also calls for rethinking and updating current assessment processes.

Ongoing evolution of disaster robotics technology offers great potential for DL assessment, which would in turn support advances in DRR and DRM planning

One area where the envelope is being pushed is the emerging field of disaster robotics, which use tactical, unmanned systems to collect data that complement RS-based observations. Remotely operating disaster robots allow for exploration of dangerous or inaccessible areas post-impact, reducing danger to ground assessment staff and speeding up immediate efforts to locate people in need of assistance. The technology offers ample scope for further development, and innovation, with great potential in assessing damage and loss caused by disasters on agricultural assets, which would in turn support subsequent advances in DRR and DRM (Szomiński *et al.*, 2015; Tadokoro, 2016; UN Economic and Social Commission for Asia and the Pacific, UNESCAP, 2016).

Another emerging technology helping responders and assessors cope with difficult field conditions involves the use of Wireless Sensor Networks (WSN). These networks employ a fleet of dispersed, dedicated and autonomous sensors to monitor different physical conditions and transmit data wirelessly to a central data collection point. They provide a valuable backstop to traditional wired information networks, which can fail during disasters. WSN technology is particularly relevant for early warning systems, as it is able to capture real-time changes in variables such as atmospheric humidity, temperature, water levels, etc., and can even be set to automatically transmit warnings when thresholds are surpassed (Benkhelifa *et al.*, 2014; Jha *et al.*, 2015). A similar example of the revolution in DRM information and communications technologies (ICTs) is the use of Sensor Web, an online network of sensors to monitor the environment and proxy indicators of climate change (e.g. tree rings, ice cores, corals, etc.). Processing data acquired by Sensor Web requires corresponding grid and cloud infrastructures.

Future developments in machine learning – which is already being deployed to create post-disaster crop type maps – could offer many more applications for DL assessment and DRM

Machine learning, a sub-category of artificial intelligence (AI), could play a central role in the analysis of disaster impact. Machine learning is based on algorithms that allow programs to ‘learn’ from previous data to produce outputs containing new information and insights that were not previously known. Future developments are bound to mine this rich vein for applications to disaster assessment and DRM. For example, disaster-related damage and loss data gathered via RS could be used as inputs into machine learning programmes with feature extraction and selection methods applied to the constructed dataset. This technology can be used for the classification or categorization of remotely sensed satellite, aerial, drone, and even farm-level imagery, capitalizing upon a large body of work on image recognition and classification. Some supervised machine learning algorithms already exist, such as ‘Support Vector Machine’ and ‘Random Forest,’ which are trained on field data and can be applied against datasets to generate crop type maps. Once verified, such maps yield detailed information on crop types affected by a disaster and the extent of the impacted area.

Ongoing progress in GIS and ICTs also creating further opportunities to enhance DRR and DRM in agriculture. Improved ICTs are integrated within geospatial information technology (GIT) to assess and monitor disasters before, during and after those events. In many DRM contexts, the availability and quality of geographic information remains poor.



© Veejey Villafrañca/NOOR for FAO



© REUTERS/Luc Gnago

TOP: Gathering data on recently damaged rice fields, Philippines 2018 | BOTTOM: Piloting a drone over a tomato farm, Ivory Coast 2019



© FAO/Nejry Vilagtranc



© REUTERS/Boz Ratner

TOP: Piloting drones to map agricultural areas, **Philippines 2018** | BOTTOM: Drone flies over a rice paddy, **United Republic of Tanzania 2019**

ICTs are advancing participative data collection via crowdsourcing of the kind being used for FRA 2020 RSS

With the expanded use of mobile devices and increased connectivity, ICT is taking GIT to a new dimension. Even as personal computing devices become lighter, smaller and more convenient, their processing systems become more powerful, increasing the amount of ground data that can be collected to complement and/or validate remotely sensed information on disaster-related impact to crop production, the presence of landslides, and land restoration. Use of information technologies is also helping to make DRM assessment more participative via crowdsourcing, which involves more people in ground data collection and mapping. One example is the Humanitarian OpenStreetMap Team (HOT), which couples satellite and aerial imagery with a huge network of volunteers to create free, up-to-date online maps for relief organizations responding to disasters. Another is the Global Forest Resources Assessment Remote Sensing Survey (FRA 2020 RSS) (FAO, 2020d), to which more than 700 people worldwide are contributing via Collect Earth Online, a new tool developed by FAO in collaboration with Google and SERVIR, a joint venture between the National Aeronautics and Space Administration (NASA) and the United States Agency for International Development (USAID). Analysis of the images gathered for FRA 2020 RSS – the results of which are to be reported in 2021 – will offer a good example of the straightforward way in which pixels relate directly to surface counts.

With so much available data, its management and analysis (e.g. via machine learning and big data analytics) is key. This will make modelling a more powerful and fundamental component of DRM, providing simulations, forecasts, and risk assessments, e.g. predicting cyclone strength and path, or the risk of drought under current and future climate conditions. FAO's "*Handbook on Remote Sensing and Agricultural Statistics*" (FAO, 2017c), which provides comprehensive guidelines on the use of RS in the wider domain of agricultural statistics, could also be a helpful reference on incorporating RS for disaster impact assessment in agriculture.

Moving forward, a hybrid approach for damage and loss assessments is needed

Understanding the scale and trends in disaster impact on agriculture at national level is an essential requirement for DRM and key to supporting national resilience policies, planning and action. However, new tools notwithstanding, surveying and quantifying agricultural damage and loss remains challenging in view of granular data requirements, complexity of national agricultural systems, ever changing meteorological conditions and statistical capacity gaps. While emerging technologies offer promising new tools, they by no means render obsolete the old, tried-and-true approaches. In fact, the former depends on the latter for validation and actionable data. They go together as hand in glove.

Geospatial technologies rely on conventional techniques for validation and calibration

While extremely helpful in assessing post-disaster damage and recovery needs, geospatial technologies cannot stand alone. They must be used in conjunction with conventional techniques that determine crop cycle stage and provide ground truthing both in terms of on-site or regular data collection, agricultural surveys, administrative data and stakeholder questionnaires. Obtaining this information requires detailed, routine and rapid inventorying of croplands, livestock systems, fisheries and aquaculture activities and forest resources with sufficiently high accuracy. To ensure data reliability and granularity, the use of national statistics, ground truthing and secondary (ancillary) data and information remain fundamental. Data gathered in this matter can in turn be used to inform and improve the use of RS approaches, allowing context-specific calibration of RS data using real data on production, water consumption, evapotranspiration, etc.

The success of remote sensing approaches requires their adaptation to local agricultural systems and environmental conditions, which further underscores RS' dependency on data collected via traditional methods, and the careful calibration between the two

Indeed, the success of remote sensing approaches requires their adaptation to local agricultural systems and environmental conditions, and is therefore critically dependent upon triangulation with core data collected from agricultural surveys and censuses. Assessing disaster impact in agriculture via on-site assessments is not an easy task. Cropping, livestock, forestry, fisheries and aquaculture systems are often diverse and complex; production systems vary from region to region, as do the management practices implemented. Shortcomings in the collection and sharing of core, field-based data remain and must be addressed, both to improve the quality of data gathered on the ground and to buoy the effectiveness of RS approaches.

Delivering an accurate catalogue of agricultural damage and loss data requires the selection of appropriate satellite data combined with the collection of quality ground information, calibrated for the application of suitable pre- and post-processing methods and the implementation of robust methodologies. FAO's DL methodology offers a suitable contribution for building a holistic information system on disaster impact in agriculture, i.e. one that has the potential to combine both traditional and innovative data sources to evaluate the nature, size and magnitude of disaster-related impacts on different agricultural systems across countries and regions. Such an understanding is crucial to inform adequate policy decisions and allow for effective monitoring of the agreed national and international resilience targets. FAO's DL methodology not only provides a suitable entry point to generate/contribute the statistical data necessary to make an integrated innovative information system functional, the data collected through the methodology can be used to validate geospatial data.

Operational damage and loss information systems at country level must be capable of providing timely, standardized and interchangeable production-related information with statistically valid precision and accuracy based on robust, consistent and continuously validated data and methodologies. The implementation of such systems requires confidence that the methods developed and data used at sub-national scales are strong enough to be geographically portable over much larger areas where access to data – by either RS or ground truthing – may not be as easy. Diverse countries will face diverse constraints in terms of limited technical, human and financial resources, which can hinder basic efforts to even collect the necessary data, let alone implement more advance solutions.

Establishing linkages between RS-generated data and data sourced through traditional methods is complicated and progress is hindered by a few stubborn barriers

Notwithstanding the above, the work of establishing linkages between RS-generated data and more traditional data sources is not trivial. The transition pathways to incorporating RS data into agricultural damage and loss assessments are still characterized by a variety of potential barriers. These include: (a) the lack of scientific understanding; (b) difficulties associated with extending scientific understanding or technological capability to operational utility; and (c) limitations to the observational technologies themselves, inadequate understanding of how those observations may be used effectively, and constraints on or deficiencies in the computational power required to use the observations in operational models. It is, therefore, imperative that information gathered via RS be triangulated with key ground-based damage and loss data to provide complete and accurate assessments.

Bridging the gaps between the various data systems remains a key issue. Making disaster assessment protocols and products more cost-effective and reliable, capable of generating unequivocal results that allow for cross-comparisons among countries requires harmonization and standardization across data platforms and domains, which should occur under routine conditions and not only during or after an emergency. This in turn demands greater commitment from stakeholders.

FAO's Hand-in-Hand Initiative (HIHI) geospatial platform

Launched in the summer of 2020, FAO's Hand-in-Hand Initiative geospatial platform aims to be a tool for a variety of actors operating in the realm of food and agriculture, including those working to create more resilient food systems with reduced hazard exposure and improved DRM.

It hosts more than one million geospatial layers and thousands of statistical series with over 4 000 metadata records, bringing together geographic information and statistical data on upwards of ten domains linked to food and agriculture, including food security; climate; soil, land and water resources; crops, livestock, forestry, fisheries and aquaculture. It also includes information on COVID-19's impact on food and agriculture.

FAO is adding new datasets along with country- and domain-specific case studies to the platform on an ongoing basis to improve targeting and tailoring of policy interventions, innovation, finance and investment, and institutional reform in food and agriculture. The data is sourced from FAO (including FAOSTAT data on food and agriculture for 194 member countries plus 51 territories) and other leading public data providers across the UN, NGOs, academia, the private sector and space agencies.

A tool for data-driven decision-making

Bringing together new tools, including advanced geospatial modelling and analytics, the HIHI platform allows users to create interactive data maps, analyse trends and identify real-time gaps in order to support data-driven and evidence-based decision-making in food and agriculture. It is available for use by all at fao.org/hand-in-hand/.

The geospatial platform is part of FAO's overarching Hand-in-Hand Initiative –an evidence-based, country-led and country-owned endeavour aimed at accelerating agricultural transformation and sustainable rural development to eradicate poverty (SDG 1) while ending hunger and all forms of malnutrition (SDG 2) and supporting achievement of the 2030 Agenda. FAO is using the HIHI geospatial platform to develop targeted agricultural interventions and investment plans using a territorial approach that identifies specific opportunities to raise the incomes of – and reduce the inequities and vulnerabilities experienced by – rural populations.

Applications in crises contexts

FAO has invited an initial set of 44 countries to join the Hand-in-Hand Initiative as beneficiaries. These are countries with limited capacities for achieving sustainable development or are in a condition of protracted crisis due to natural disaster or conflict.

The implementation of the Hand-in-Hand Initiative coincided with the onset of COVID-19 and the urgent need to cope with the combined impacts on agri-food systems of pandemic control measures and the concurrent major global economic recession. In most cases, the HIHI approach to analysis and partnership-building has proven to be a useful model for coordinating integrated rapid response to COVID-19 impacts on food systems, particularly at the local and territorial levels. It is also proving advantageous for enabling evidence-based anticipatory approaches to preventing broader food systems breakdown and for accelerating investment to address emerging threats to food system operations.

Using spatial data to assess the impact of disasters on agriculture – initial field experiences

Recent experiences from the field illustrate some of the different applications of spatial data for risk, impact and recovery and suggest areas for further work and exploration.

In one example, these technologies were used to plan land restoration activities in Bangladesh, following a massive influx of Rohingya refugees from Myanmar that made Cox's Bazar home to the largest refugee camp in the world. This put significant pressure on the regional landscape, resulting in the indiscriminate removal of trees, roots and cover grass to provide shelter and fuel energy for more than 860 000 people. The consequent land degradation has led to loss of top soil, making the area less productive for vegetation growth, increasing surface runoff, intensifying erosion and raising the risk of landslides.

Data collected via multiple satellites was combined with information gathered through traditional sources to plan land restoration activities in Cox's Bazar

Based on the national landcover map and forest inventory from the Bangladesh Forest Information System, FAO, in collaboration with IOM, has intensified field data collection for biophysical and socio-economic information to provide an assessment of the area's woodfuel gaps and needs (FAO, 2020e). This was later complemented with cadastral land digitalization and land suitability analysis to support landscape restoration analysis. Woodfuel supply and demand analysis was conducted by integrating different spatial information for both. The digitized cadastral maps were geo-referenced by available Differential Global Positioning Systems (DGPS)-corrected images from various satellites: Satellite pour l'observation de la terre (SPOT) (commercial), IKONOS (commercial), RapidEye (European Space Agency, ESA), and the Indian Remote-sensing Satellite equipped with a panchromatic camera (IRS PAN). The land suitability analysis was conducted using different spatial data such as: land cover, slope texture, altitude, road networks, river streams, distance to elephant path, risk for floods and protected areas. Impact of landscape restoration activities on vegetation was assessed using data gathered via the ESA's Sentinel-2 satellite: multispectral images at 10-meter resolution and the geographic delineation of landscape restoration activities.

RS proved essential for monitoring and assessing the impact of Cyclone Idai, the second deadliest storm in the Southern Hemisphere

Using RS tools to track the formation and path of Cyclone Idai provided another opportunity to explore the use of these technologies in disaster responses and DRR planning. The 2019 storm hit Mozambique twice, first as Tropical Depression 11 and then again as a named cyclone. The system is notable not only as the second-deadliest storm in the Southern Hemisphere, but also for its longevity (4–21 March), zig-zagging course and the manner of destruction it wrought. It produced a storm surge of 4.4 meters, strong winds of 160–180 km/h and – coupled with preceding rainfall – caused disastrous flooding in the affected low-lying coastal regions. Remote sensing constituted a valuable tool for monitoring and assessing the impact by enabling easy-access and providing timely information about land use in affected areas, sea surface temperatures, level of flooding, etc.

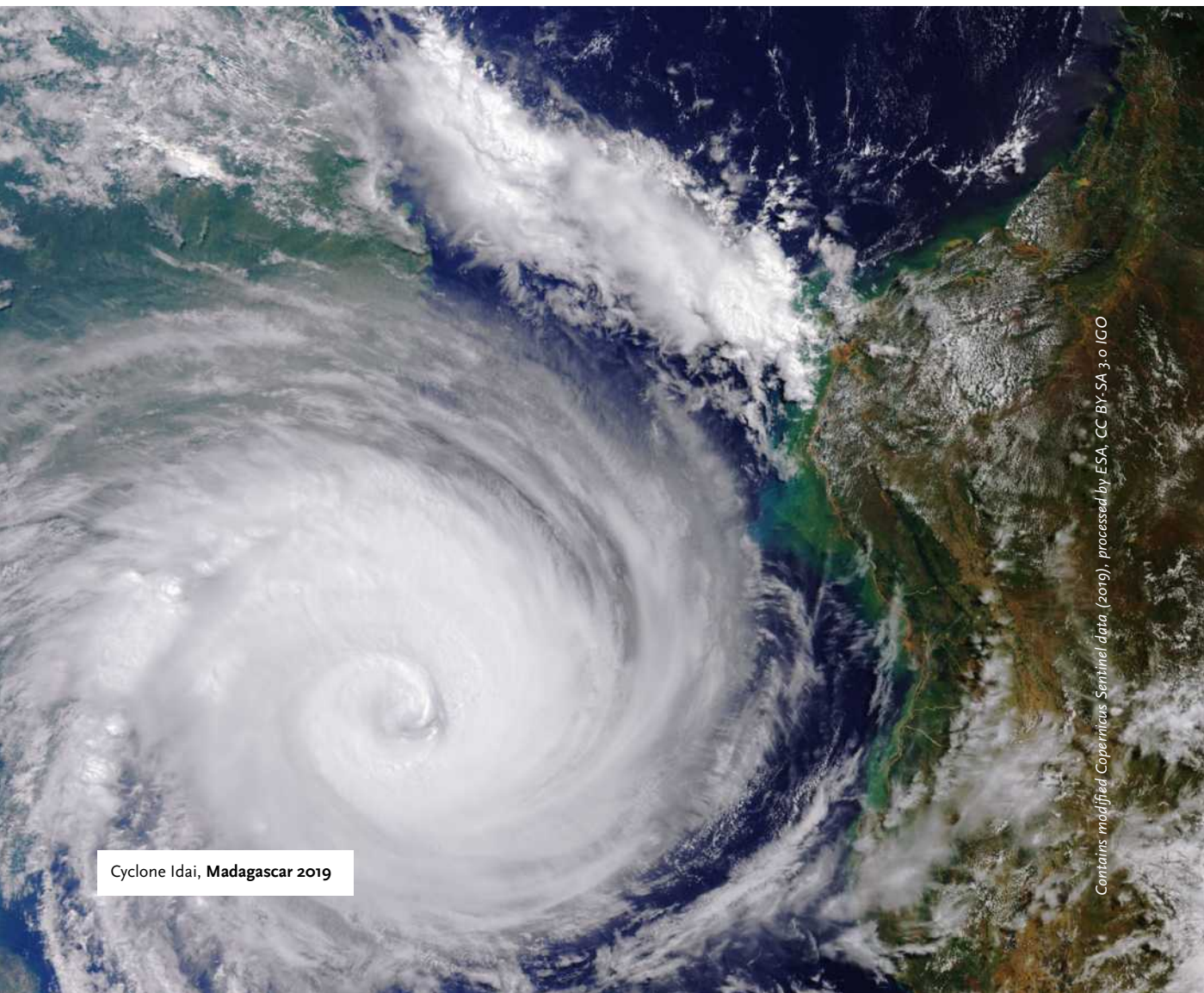
In the months prior to Cyclone Idai, the area had experienced extreme sea surface and land temperatures, which caused drought and drove formation of the tropical depression just off shore of Quelimane, over the Sofala Bank. Initially moving inland towards the border of Malawi over Lake Chilwa, the system reversed course and headed back out to sea, increasing in magnitude over the Mozambique Channel, where it made a hairpin turn just off the coast of Madagascar.

Hitting first as a tropical storm, Idai intensified over the channel before making a hairpin turn to slam Mozambique a second time as a category 2 cyclone

As it headed back to Mozambique's Sofala Bank, it developed significant convection and rapid intensification, briefly reaching the equivalent of a category 3 hurricane (Saffir-Simpson scale) before making landfall 60 to 80 km north of Beira with sustained winds of 177 km/h (category 2). Cyclone Idai thus presents an uncommon scenario in which a cyclone is both born and makes landfall in the same region, rather than a typical system, which forms over a large ocean basin and strikes adjacent coastal areas.

On 15 March, the Copernicus Emergency Management Service Rapid Mapping module was activated to produce delineation monitoring maps over ten areas of interest (Aoi). The set of maps produced from imagery acquired between 16 and 19 March showed a total flooded area of approximately 52 000 ha (518 square kilometres) – including 7 254 ha (72.5 square kilometres) in Beira alone (Figure 3) – affecting more than 24 290 inhabitants within the Aoi.

Another example of Cyclone Idai impact assessment is drone imagery of a remote community 8 km from Idai's point of landfall (Figure 2). Features such as the water hole (centre), waste, and mangroves cut for charcoal were used as key indicators for training machine learning algorithms to search satellite images for other impacted communities.



Cyclone Idai, Madagascar 2019

Quantifying damage from this imagery was also achieved by comparing ground truthing and non-aerial geotagged images with anecdotal evidence. Traits such as the remaining ‘footprints’ of houses and other structures such as fish drying racks were used to detect the extent of the damage.

RS enables a clearer and more accurate understanding of an emergency’s scale and magnitude of impact

RS approaches can combine multiple layers of information on a single map, thus allowing for a more clear and accurate understanding of the emergency’s scale, the magnitude of impact and the logistics involved. This provides a firm basis upon which to improve surveillance and coordinate response action. As global average temperatures continue to rise, and extreme weather events become more frequent, RS can therefore play a significant role in anticipating similar scenarios in the future, as well as in developing resilience strategies relating to land use and flood management, while also providing baseline data prior to such events.

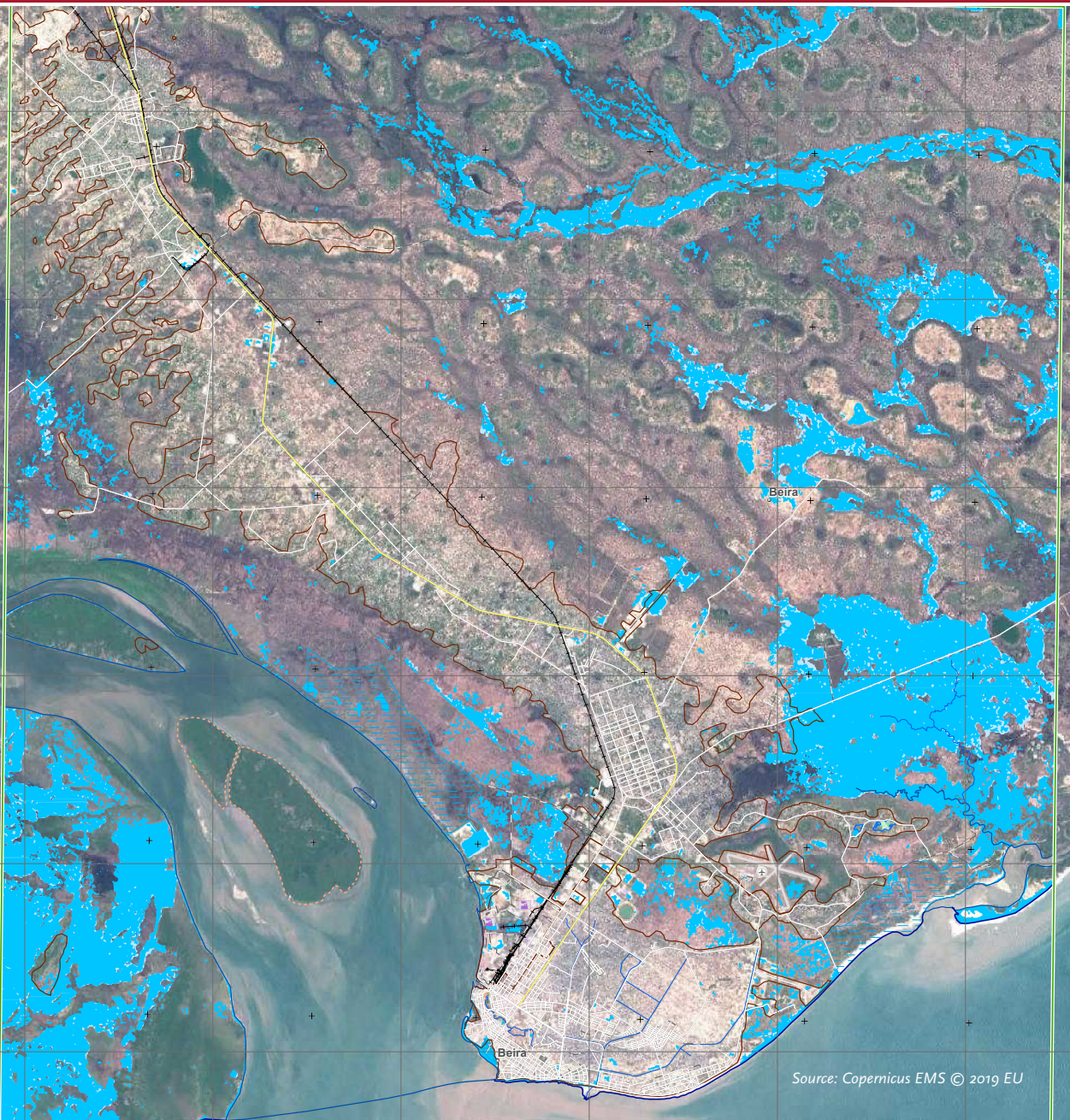
Figure 2. Drone image of a remote community in Mozambique used to train machine learning and quantify damage following Cyclone Idai



©/ @ Reefscan / Matt Bjertsgaard Walsh

The Copernicus Emergency Management Service (EMS) is based on continuous monitoring via a constellation of satellites (dubbed Sentinel-1 through Sentinel-6) operated by the European Space Agency (ESA). Copernicus EMS provides maps, forecasts, and analyses of risk-relevant data (i.e. before, during and after a crisis) for drought, floods, and forest fires as well as near real-time assessment of their impacts. Rapid mapping provides geospatial information (maps and brief analyses) within hours or days after a hazardous event occurs and includes: reference maps that are based on satellite imagery acquired before the disaster happened, thereby supplying a baseline for comparison; delineation maps illustrating the extent of the area affected; and grading maps showing the impact caused by the disaster. Separately, risk and recovery mapping provides data within weeks or months. It offers information on pre-disaster situations, such as the exposure of a given location to a hazard and the vulnerability and/or resilience of buildings, people and assets within that area. It also provides information beyond the immediate response phase, such as data on recovery needs, long-term impact and reconstruction/rehabilitation monitoring. Governments and agencies are then able to use this data as an objective basis for policy planning, risk and vulnerability assessments and emergency response.

Figure 3. Delineation monitoring map of Beira, Mozambique, after Cyclone Idai



In the context of more frequent and more intensified weather events, enhancing use of RS is especially important for coastal communities and small-scale fisheries, which are on the front lines of climate change impacts

Building on experiences like this to improve and enhance the use of RS in managing disaster risk in coastal areas will be important in the coming years and decades, given the context of a changing climate with altered and intensified weather events. Coastal areas are particularly exposed to the effects of cyclones, tsunamis and flooding as well as to the adverse effects of climate change, which include sea level rise, changes in the frequency and intensity of storms, warmer ocean temperatures, and increased seawater acidity. Coastal waters represent only 15 percent of the global ocean but account for 90 percent of commercial fisheries, contribute 25 percent of global biological productivity, and represent 80 percent of all marine biodiversity. Coastal communities and small-scale fisheries are on the front lines of extreme weather and climate change impacts. While rural coastal populations may not have a particularly high population density, they are situated where the impact of cyclonic systems are at their highest level of magnitude in terms of wind speed and area coverage.

The monitoring and management of coastal zones following a disaster requires past, present, and future observations adapted to quite diverse and dynamic environments. To complement field measurements, the use of remote sensing data provides useful information to map the hydromorphological (freshwater discharge, currents, shoreline evolution), physio-chemical (water transparency, temperature, salinity, oxygen, nutrients, and pollutants), and biological (habitats, phytoplankton blooms) properties of the coastal zones. Taking a livelihoods approach across key sectors such as capture fisheries is therefore vital to understand the context of the disaster and immediate needs in coastal contexts. Remote sensing from on-site, aerial, and space-borne platforms satisfies these criteria and offers large-scale data acquisition at regular temporal frequencies for monitoring of coastal environments.

Challenges to RS-based disaster assessments in agriculture

Evidence-driven disaster risk management relies upon many different data types, information sources, and types of models to be effective. Enhancing efforts to integrate data and information, field and remote sensing, machine learning, biophysical and socio-economic knowledge will be essential to providing timely and enhanced support for decision-making on DRM, emergencies and recovery.

Agriculture may require higher resolution imagery compared to other sectors

However, the application of remote sensing technologies in the context of DL assessments is not without hurdles. When confronting sudden-onset disasters (e.g. cyclones), the need for RS images is critical and urgent, but it takes time to acquire them and cloud cover and other weather conditions can delay or restrict use of optical imagery equipment. Partnerships with commercial companies and space agencies can help overcome these obstacles to deliver timely analysis.

Moreover – and this is fundamental – agriculture may require higher resolution imagery compared to other sectors, especially when smallholder-farming systems are affected, and when assessing the localized impacts of hazards such as cyclones. In such cases, RS-equipped drones are especially key.

Combining emerging technologies with traditional methods is the best way to validate hypotheses, calibrate tools and address the challenges that frequently arise when assessing disaster impacts

Ultimately, ground truthing is essential and necessary at different stages to assess the immediate and longer-term impacts (e.g. vegetation recovery) of a disaster as well as the effects of recovery activities. This is especially so for those interventions aimed at restoring natural resources and crop production, where remote sensing analysis proves ineffective if not validated by field measurements, agricultural surveys, and geographic coordinates. Therefore, using a combination of instruments (e.g. high-resolution imagery, medium- and low-resolution optical and radar imagery, ICTs, ground truthing) is the most effective approach to validating hypotheses, calibrating tools and addressing challenges that are frequently encountered when assessing disaster impacts. The later include, among other things, the unavailability of imagery or prohibitive cost of satellite imagery, difficulties in physically accessing affected rural areas, and gaps in mobile data networks that impede information acquisition and transfer. RS tools can be used to generate and overlap multiple (and cross-sectoral and transboundary) risk maps, thereby facilitating the formulation of DRM strategies at both the national and supra-national levels. Field assessments complement the analysis provided by remote sensing while enabling the people-centred approach that is necessary to capture the impacts of disasters on the food security, livelihoods and lifestyle of affected populations.

Overall, combining traditional assessment techniques with RS pre- and post-event data requires close planning, collaboration, training and guiding strategies implemented at country level. Ongoing efforts to explore, implement, innovate, and adapt these new approaches to DRR and DRM in agriculture, as well as to post-disaster rehabilitation efforts are sparking innovation in the field today, and will continue to do so for some time to come.



© FAO/Kwangji Yoon

Women sifting for broken rice, Nigeria 2017



Conclusion

The road to 2030: risk-resilient development pathways for agriculture

Disaster risk is systemic and requires systemic solutions. Recognizing the links between natural and biological hazards, climate change and socio-economic shocks such as conflict, hunger and malnutrition, global, regional and national policy dialogues must be risk-informed and geared towards system-wide solutions across sectors and actors. Attaining disaster and climate resilience as well as food security and nutrition for all requires scaled-up action, integrated approaches to disaster, climate and crisis risk reduction and management at all levels. This can be achieved through a solid disaster impact evidence base, good risk governance architecture and coherent implementation of global agendas.

New decade, new hurdles

Offsetting the increased frequency and severity of disasters, extreme weather events, and biological hazards in the context of Earth's changing climate requires an integrated approach grounded in an evidence-based understanding of how these risk factors impact agriculture and food security

An intensified pattern of increasingly frequent and severe disasters and extreme weather events is posing unprecedented challenges for agriculture and food systems on every level: local, national, regional and global. Heavily reliant on weather, climate and water for its ability to feed the planet, agriculture is particularly vulnerable to disasters. Their impacts can be multipronged and enduring, including loss of harvests or livestock, compromised food security and nutrition, and destruction of irrigation systems and other infrastructure. From the start, the 2020s have demonstrated the potential of biological hazards such as the SARS-CoV-2 virus and desert locusts to disrupt rural livelihoods, with cascading consequences for value chains, agricultural markets, trade and the entire food system. The earth's changing climate will further aggravate these impacts in the new decade. Offsetting them demands risk-informed policy and action. To be effective, national strategies on disaster risk reduction, resilience and climate change adaptation must be incorporated into sectoral development strategies and grounded in a comprehensive understanding of the particular impacts extreme weather events and disasters have on food security, agriculture and each of its sectors: crops, livestock, forestry, fisheries and aquaculture.

This report offers a first-ever look at the alarming implications of disaster loss for human nutrition and food security

At the forefront of bridging persistent knowledge and data gaps, the present report strides towards building a comprehensive and panoramic view. It deepens the focus on estimating crop and livestock production loss, taking all commodities into account, and considers impacts in UMIC and HIC countries alongside LDCs and LMICs. A first-ever nutrition perspective reveals the nutrient deficits associated with foregone production, highlighting the alarming implications of disaster loss for human nutrition and food security. The current edition's expanded scope paints an evidence-based picture of how agriculture is affected not only by traditional disaster events, but also by emerging biological hazards such as the COVID-19 pandemic, desert locusts and animal disease outbreaks that have already marked the turn of the decade. This report tells us that:

- Cumulatively between 2008 and 2018, approximately USD 108.5 billion was lost as a result of declines in crop and livestock production in LDCs and LMICs following disasters. At a global level – including UMICs and HICs – disaster-related loss amounted to USD 280 billion. Up to 4 percent of potential agricultural production was lost to disasters worldwide.
- Drought poses a major threat to both crop and livestock production and is responsible for 34 percent of overall loss in LDCs and LMICs.
- The impact of disasters on agriculture extends beyond production alone. Crop and livestock production loss in LDCs and LMICs between 2008 and 2018 is equivalent to the annual calorie intake of 7 million adult persons. On average, 22 percent of daily calorie intake is lost to disasters. In a world with already rampant food insecurity, forfeits in nutrition potential of this magnitude can have far-reaching detrimental consequences.

- Given the complex disaster risk profile of the forestry sector – in terms of its exposure and vulnerability to specific types of disasters as well as the ability of forest systems to partake in disaster prevention, mitigation and recovery – it is important to adopt a universal methodological basis for detailed analysis. FAO's updated methodology provides a tailored approach for estimating sector-specific damage and loss in forestry.
- Usually on the low rung of the socio-economic ladder, fisheries and aquaculture livelihoods are particularly vulnerable to climate- and weather-related disasters. Effective disaster risk reduction requires a thorough understanding of the status and management of aquatic resources. Trials of FAO's DL methodology have highlighted how a solid information system and data-based analyses can guide a streamlined damage and loss assessment in fisheries and aquaculture leading to sustainable technical solutions to disaster impact.
- Spread of infectious disease cuts across wildlife, livestock and human populations, and over 70 percent of new diseases in humans are of animal origin. Biological hazards have strong negative impacts on production, disturb farming systems and disrupt markets and trade. The impacts of these dynamics are clearly evident in the COVID-19 global pandemic, the impacts of which are spiralling across our entire system.
- Alongside the concurrent pandemic, sustained efforts to contain East Africa's worst invasion of desert locusts in decades forged ahead throughout 2020 and into 2021. Drawing on experience from past locust crises, the case for investing in national capacity for continuous surveillance and monitoring, and not just during outbreaks, is incontrovertible.
- We have reached a climate crossroads: global average temperatures have already warmed by 1.1 °C above the pre-industrial period. Around the 2 °C mark lies the tipping point, where the effects of climate change accelerate dramatically and can reshape the planet. The most tangible effects on agriculture are already being felt through the increased incidence and intensity of extreme weather events, such as drought and all kinds of violent storms, and may result in long-term productivity loss, ecosystem degradation, fragility and food insecurity. As the agriculture and climate science communities are learning how to best attribute loss and damage from extreme and slow-onset events, FAO's DL methodology can contribute to establishing a standardized and coherent information system that would add a quantitative dimension to WIM discussions.

Greater challenges call for better governance

The COVID-19 crisis demonstrates how the nature and scale of risk has changed against the backdrop of an increasingly complex and globalized world

The ravaging effects of climate change, exacerbated by the profound repercussions of the unyielding pandemic, threaten global progress towards the achievement of zero hunger, food security, improved nutrition and sustainable agriculture. As COVID-19 continues to spread and wreak havoc around the world, recovery and rehabilitation efforts provide an opportunity to change its destructive course and inject novel resilience strategies into agricultural, socio-economic and environmental policies. The COVID-19 crisis demonstrates how the nature and scale of risk has changed against the backdrop of an increasingly complex and globalized world. Risk has become systemic, challenging established national governance mechanisms and traditional single-hazard and sector-based approaches. In agriculture, both risk drivers and disaster impacts ripple through national, regional and global supply chains and spill over from one country to another.

This calls for a reconfiguring of disaster risk governance from a sectoral perspective. Countries must adopt a multi-hazard and multi-sectoral systemic risk management approach to anticipate, prevent, and prepare for and respond to disaster risk in a holistic manner. Disaster risk reduction strategies need to integrate not only natural hazards but also anthropogenic and biological hazards and they must be based on a comprehensive understanding of the systemic nature and interdependencies of risks. Under the impetus of the UN General Assembly (resolution A/74/L.92), Member States have vouched to put the Sendai Framework for Disaster Risk Reduction at the centre of COVID-19 response and rehabilitation to ensure a prevention-oriented and risk-informed approach to socio-economic recovery.

Addressing the complexity and non-linear nature of systemic risks requires a holistic approach to hazard identification, risk assessment and risk management. For agriculture, this can be achieved by building a shared understanding and synergies among diverse government entities and stakeholders at different levels. Changing the *modus operandi*, however, implies not only considerable shifts in national and local governance, legislation, policies and financial mechanisms, but also a new thinking about DRR and climate change interventions. Active engagement by actors whose agendas directly influence individuals' and local communities' vulnerabilities is required for shaping sub-national, national, regional and global economic development. The current pandemic can therefore be a watershed moment to transform disaster risk reduction in all sectors and all countries. Lessons from the COVID-19 pandemic must be integrated into responses to other challenges confronting agriculture, such as climate change, natural disasters and locusts to build resiliency and ensure food security.

The pandemic could become a watershed moment to transform DRR in all sectors and countries

To be successful across livelihoods and food systems and to address food insecurity and all forms of malnutrition, disaster risk reduction policies and programmes must be built around systemic risk assessments, scientific and interdisciplinary cross-sectoral knowledge, as well as participatory and inclusive humanitarian and development approaches driven by the needs of the most vulnerable groups.



© FAO/Michael Tewelde



© FAO/Luis Tato

TOP: Rebuilding in flood aftermath, Ethiopia 2020 | BOTTOM: Mechanizing farmers engaged in conservation agriculture, Kenya 2017

Common ground for resilience action

The Sendai Framework is the principal global instrument for DRR, while the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement steer action on climate change adaptation. Together with the Sustainable Development Goals, these landmark UN agreements have set the agenda for reducing risks associated with all hazards and unsafe conditions. Resilience is a cross-cutting theme. Fully and intrinsically incorporated into the SDGs, both the SFDRR and the Paris Agreement provide strategic guidance towards building disaster and climate resilience, respectively. However, they have not yet firmly established the common ground upon which their joint objectives could be aligned and operationalized.

Nevertheless, DRR and climate change adaptation are profoundly interconnected and complementary, making a marriage between the two approaches more than feasible. Both concepts are concerned with reducing vulnerability and strengthening structural capacities to reduce and manage risk from extreme events.

On both the conceptual and practical levels, DRR and climate change adaptation blend together well

On a conceptual level, they share a common definition of risk and understanding of resilience. On a practical level, climate change adaptation and disaster risk reduction strategies and actions are also consistent with one another and blend together well: both use similar tools to monitor, analyse and address the adverse consequences of disasters and extreme events. In the toolbox of both concepts are actions addressing vulnerability, strengthening coping capacity, reducing direct exposure, and similar measures to ensure risk reduction, adaptation preparedness and capacity to recover. For agriculture, concrete measures prescribed by both camps are the adoption of resistant crop varieties, diversification practices, agricultural insurance, livestock vaccination, improved irrigation, rural infrastructure and storage facilities, etc.

A further convergence between the two agendas is therefore imperative and would involve considering concrete opportunities for joint action while managing the strategic challenges related to the existence of their separate institutional structures, as well as the particular interests of their respective constituent communities.

The inclusion of a stand-alone text setting out the need to address *loss and damage* in both article 8 of the Paris Agreement as well as in the declaration through which COP21 adopted that accord (FCCC/CP/2015/L.9.Rev.1, paragraphs 48-52) represents a significant progress in terms of agenda convergence. This important breakthrough, however, may have come at the cost of a very narrowly framed concept of *loss and damage* that creates future difficulties in measurement and monitoring.

Existing DRR methodologies and indicators, including FAO's own DL approach, can chaperone climate adaption strategies at national and regional levels

The Warsaw International Mechanism for Loss and Damage can draw upon a rich knowledge base of agricultural DRR expertise, including existing methodologies and indicators, to chaperone climate adaptation management strategies at national and regional level. One major tool at hand is FAO's methodology for assessing damage and loss from disasters in agriculture (Technical annex). FAO's DL approach aims to improve agricultural resilience monitoring within the UN-wide system by providing a standardized set of procedural and methodological steps that can be used at subnational, national, regional and global levels. It allows for thorough damage and loss assessments in each sector, ensuring consistency across countries and disasters, and it constitutes a useful vehicle for assembling and interpreting existing information to inform risk-related policy decision-making and planning.

It is already being used in tracking Sendai Framework Indicator C-2 on assessing direct agricultural loss attributed to disasters, and the Sustainable Development Goals Target 1.5, which aims to build resilience and reduce exposure and vulnerability to climate-related extreme events and other shocks and disasters. Because those instruments in turn support the Paris Agreement and advance the Warsaw goals, FAO's methodology has a constitutive part to play in informing and enriching the climate change adaptation agenda, to which it could contribute a quantitative dimension.

Measuring for success

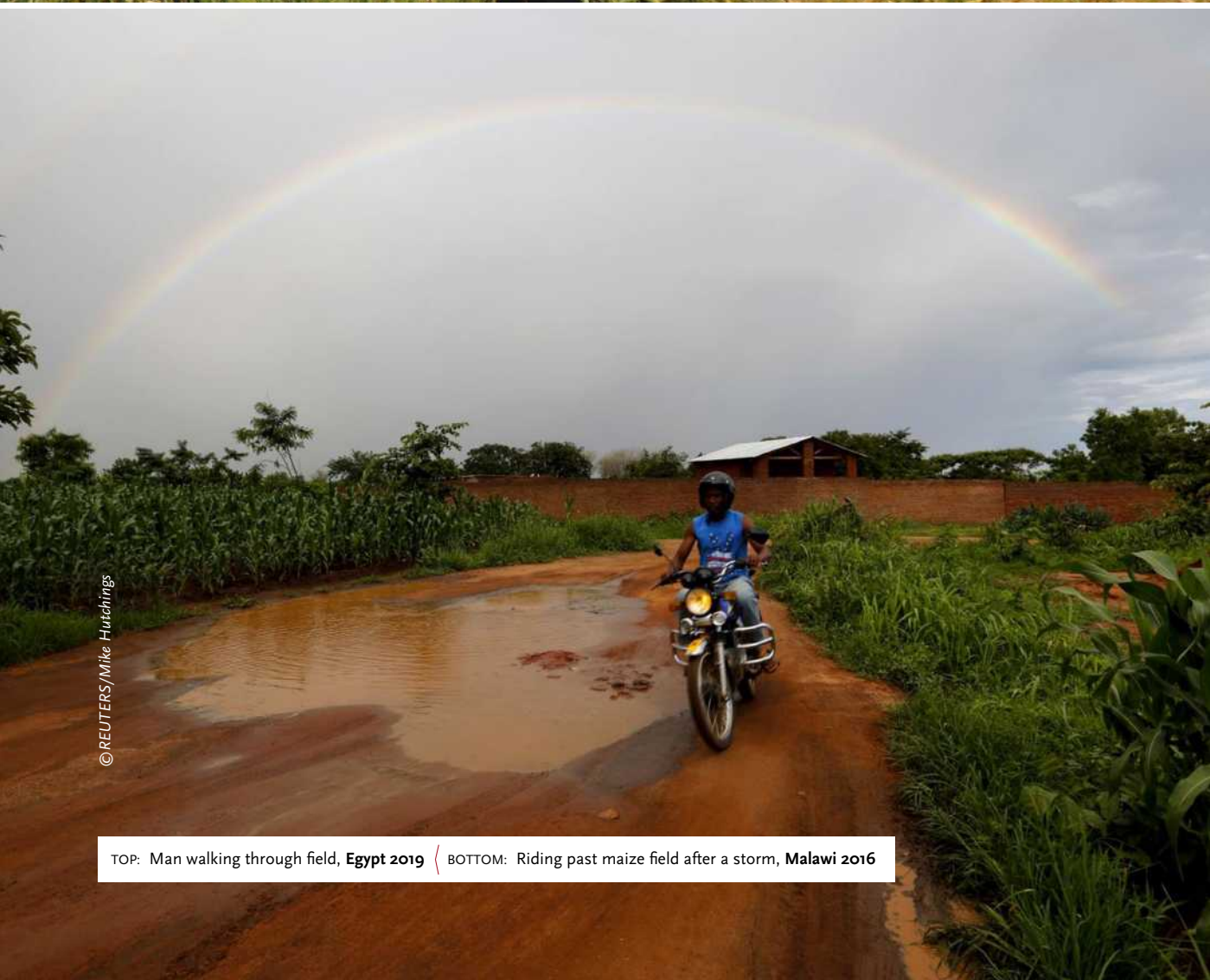
For FAO's DL methodology to achieve its potential within the SFM context, countries must step up their data collection efforts, which – at present – still do not document disaster-related effects on the sector in a structured and systematic way

As signalled throughout this report, the evidence base for disaster impact needs more attention. While FAO's DL methodology lays the foundation for improved monitoring of disaster impact, its usefulness hinges on the capacity of national disaster loss databases and information systems. Without the latter, assessments fail to capture the full extent of disasters' toll on agriculture. At present, damage and loss estimates are based on crucial, yet highly incomplete data because disaster-related effects on the sector are still not documented in a structured and systematic way. To establish holistic information systems for agricultural damage and loss and obtain reliable assessment results, countries need to step up their data collection efforts. Targeted survey methodologies and the incorporation of innovative tools, such as remote sensing, are key for improving assessment precision.

National and subnational are the most important levels of reporting and rely heavily on the work of national statistical offices, national DRM agencies and ministries of agriculture. Reinforcing their capacities, mechanisms and resources for data collection, management and analysis will enable a coordinated and coherent application of FAO's assessment methodology. This will, in turn, build and strengthen cross-institutional partnerships, foster shared responsibility, and improve information flow among all relevant national institutions. Initiatives such as the 50x2030 Data to End Hunger and the Agricultural Integrated Survey Programme (AGRISurvey) – which constitute large-scale efforts to strengthen national agricultural survey systems and promote access to agricultural statistics – offer key opportunities to make disaster damage and loss statistics an integral component of national data catalogues. Enhanced data availability allows for improved precision in damage and loss assessments, ultimately leading to better-informed policy, action and investment for disaster risk reduction, preparedness and resilience in agriculture.



© FAO/Jordi Vaque



© REUTERS/Mike Hutchings

TOP: Man walking through field, **Egypt 2019** | BOTTOM: Riding past maize field after a storm, **Malawi 2016**

Way forward into the Decade of Action

Improving agriculture's resilience requires increased partnerships, enhanced risk management capacities and multi-year, predictable large-scale funding of DRR and climate change adaptation policies, programmes and practices

Quantifying loss is not solely an assessment of the harm done by a disaster. It is also an evaluation of disaster risk reduction and resilience strategies and their effectiveness: how much loss is acceptable in agriculture? When does crop and livestock loss translate into food insecurity? How much investment is needed to reduce damage and loss? The increase in primary and secondary impacts observable in agriculture is a sign of our still insufficient disaster risk reduction actions – and of our climate maladaptation – while COVID-19 demonstrates how the sector is also susceptible to biological hazards primarily affecting humans. Both underscore the need for a deeper understanding of the systemic and structural underpinnings of – and complex interplay among – different disaster types, including human crises that have a direct impact in agriculture, like COVID-19. To address these issues, concerted planning, implementation, and monitoring and evaluation efforts at the national, regional and global levels will be of crucial importance. This would require increased partnerships, enhanced risk management capacities and multi-year, predictable large-scale funding of DRR and climate change adaptation policies, programmes and practices. Dedicated resources must be used in an evidence-based, 'build-to-transform' manner. Furthermore, adopting a systemic, multi-hazard and cross-sectoral approach would substantially increase resilience of agricultural livelihoods in the face of disasters, threats and crises.

Disaster risk can be reduced and managed. Decades of experience in the implementation of disaster and climate resilience policies and programmes have produced a wealth of knowledge and good practices. Interventions such as risk monitoring and early warning systems, emergency preparedness, vulnerability reduction, shock-responsive social protection, risk transfers and forecast-based financing should be tailored to the systemic risk landscape of the new decade. Local and national governments, financial institutions and the international development community should adopt these measures as a 'new normal' and embed them in an improved risk governance in the environment–food–health system nexus. As a recent study of 900 farms in ten countries proves, there is ample scope at farm level for broader use of often easy-to-implement DRR practices, with the potential to yield substantial benefits (FAO, 2019a).

A consistent evidence base for disaster impact on crops, livestock, forestry, fisheries and aquaculture is the cornerstone of well-tailored resilience policies and investments, and for tracking progress towards global targets

Under any scenario, establishing an improved system for the assessment of disaster-related damage and loss in agriculture is a step in the right direction; this is even more evident in light of the disruption brought about by the COVID-19 pandemic. As data producers are themselves limited by measures to contain the virus, innovative methods such as phone- and web-based interviewing as well as remote sensing are helping ensure timely and responsive data, despite new constraints. Through strengthening local capacities for disaster impact assessment, integrated risk information systems can be further fortified to inform effective DRR and climate change adaptation policy and practice in agriculture. Having a consistent evidence base on disaster impact on crops, livestock, forestry, fisheries and aquaculture is the cornerstone of well-tailored resilience policies and investments in the sector, and for tracking progress toward global targets. This will help direct key investment and development assistance, consistent with agriculture's crucial role in achieving food security, promoting sustainable development and economic growth, and building the future we want.

Appendices

Technical annex
FAO's damage and loss
assessment methodology

Glossary
References

Technical annex

FAO's damage and loss assessment methodology

FAO has developed an agriculture-specific methodology for identifying, analyzing and evaluating disaster-related damage and loss. This methodology is both sufficiently holistic to be applied in different country/regional contexts, and precise enough to consider all agricultural subsectors (crops, livestock, apiculture, forestry, fisheries and aquaculture) and their specificities. It measures the effects of a broad range of disasters of different type, duration or severity – from large-scale shocks to small- and medium-scale events, from sudden-onset to slowly evolving disasters with a cumulative impact. It constitutes a strategic tool for assembling and interpreting new or existing information to inform risk-related policy decision-making and planning.

In partnership with UNDRR, FAO's methodology has been adopted into the two main 2015 international agendas that recognize resilience as fundamental to their achievement, namely the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction. As such, it contributes to monitoring the achievement of specific targets on reducing direct economic loss from disasters. Specifically, the FAO methodology is used to track progress of Sendai Indicator C-2 on reducing direct agricultural loss attributed to disasters, and the corresponding SDG Indicator 1.5.2.

Following its first publication in 2017, certain formulas of the methodology have been revised to reflect refinements in notation and computation principles. Most notably, those for production loss in the forestry sector have been updated according to new standards for the valuation of timber according to its discounted net present value.

Structure

The DL methodology uses a standardized computation for each of agriculture's five sectors:

- **DL (C):** Direct damage and loss to crops
- **DL (L):** Direct damage and loss to livestock³
- **DL (FO):** Direct damage and loss to forestry
- **DL (FI):** Direct damage and loss to fisheries
- **DL (AQ):** Direct damage and loss to aquaculture

Together, they aim to capture the total effect of disasters on agriculture:

$$\text{Impact to agriculture} = \text{DL (C)} + \text{DL (L)} + \text{DL (FO)} + \text{DL (FI)} + \text{DL (AQ)}$$

In order to capture the full impact of disasters on each subsector, FAO's DL methodology distinguishes between **damage**, i.e. total or partial destruction of physical assets, and **loss**, i.e. changes in economic flows arising from a disaster. Each subsector is further divided into two main components: **production** and **assets**. To capture the direct impact of disasters on agriculture, it is important to consider both the damage and the loss accrued in agricultural production and assets.

The production component measures disaster impact on agricultural inputs and outputs. Damage here includes the value of stored inputs (e.g. seeds) and outputs (e.g. crops) that were fully or partially destroyed by the disaster. Production loss, on the other hand, refers to declines in the value of agricultural production resulting from the disaster. The assets component measures damage inflicted upon facilities, machinery, tools, and key infrastructure related to agricultural production. The monetary value of (fully or partially) damaged assets is calculated using the replacement or repair/rehabilitation cost, and is accounted for under damage.

Table 1 illustrates FAO's DL methodology while indicating some of the items and economic flows that should be considered in post-disaster assessments. In line with the main methodological concepts (Table 1), each subsector is divided into production damage, production loss and assets damage.

Table 1. FAO's damage and loss assessment methodology

Crops, Livestock, Forestry, Fisheries and Aquaculture	
Production	
Damage	Loss
Pre-disaster value of destroyed stored production and inputs	Difference between expected and actual value of production and short-run disaster expense
Items: seeds, fertilizer, pesticides, fodder, fish feed, stored crops, stored meat, dead animals, etc.	Items: crop yield reduction, animal production reduction, destroyed timber, lost fish capture, cost of re-planting, etc.
Assets	
Replacement or repair value of destroyed machinery, equipment, tools	
Items: tractors, harvesters, silos, barns, milking machines, boats, fishing gear, pumps, aerators, etc.	

The computation in detail

Box 2. Notation used in the methodological formulas

i	output
j	geographical units affected by the disaster
k	asset (equipment, machinery, tools, facilities) used to produce an agricultural output
x	input used for agricultural production
h	perennial crops and trees
t	the first time unit when post-disaster data are available
t-1	the first time unit when pre-disaster data are available
$y_{i,j,t}$	yield of item i in zone j at time t
$P_{x(\text{or } i \text{ or } h),j,t-1}$	price of input x (or product i or tree h) in zone j at time t-1
$P_{k,j,t}$	price (or repair cost) of one unit of asset k in zone j at time t
$q_{i,j}$	quantity of item i in zone j
$q_{i(\text{or } x)(\text{stored}),j,t}$	stored quantity of item i (or input x) in zone j at time t
$q_{k,j,t}$	number of assets used for item i in zone j at time t
$ha_{i,j,t}$	number of hectares devoted to item i in zone j at time t
$\Delta ha_{i,j,t}$	unexpected change in the number of hectares where i is produced
w_i	average weight (in tonnes) of item i
$P_{\text{short-run}}$	lump sum of expenses used to temporarily sustain production activities after a disaster
α	share of the value of dead animals that can be sold
$area_{j,t}$	size of aquaculture area (cages, tanks, pens, etc.) in zone j at time t
T	number of days devoted to fishing activities
r	real interest rate
$R_{\text{non-timber}}$	revenue from non-timber forest activities

Damage and loss in crops

DL (C) = Crop production damage + Crop production loss + Crop assets damage (complete and partial)

→ **Crop Production Damage PD (PC)** for both annual and perennial crops is composed of the:

- 1) Pre-disaster value of destroyed stored inputs: $\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}$
- 2) Pre-disaster value of destroyed stored perennial crops: $\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$
- 3) Replacement value of fully damaged trees: $\Delta ha_{i,j,t} * h_{i,j} * p_{h,j,t-1}$

- The term $(\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1})$ represents the quantity of inputs (q) for annual and perennial crop production by input type (such as fertilizer, pest control, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level (t-1). Calculations are done by input type for all affected inputs.

- The term $(\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1})$ represents the quantity of stored annual and perennial crops by commodity (rice, maize, wheat, avocado, bananas, coconuts, coffee beans, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level (t-1). Calculations are done for every affected stored crop commodity.

- The term $(\Delta ha_{i,j,t} * h_{i,j} * p_{h,j,t-1})$ represents the replacement value of destroyed perennial crops/trees expressed as the number of crops/trees (h) per hectare in the disaster-affected area (Δha = number of hectares of affected perennial crops/trees), valued at pre-disaster-level plantation/re-forestation price (p) at level (t-1).

The overall Production Damage for annual and perennial crops is the summary of all three terms.

$$PD (PC)_{i,j} = (\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}) + (\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}) + (\Delta ha_{i,j,t} * h_{i,j} * p_{h,j,t-1})$$

→ **Crop Production Loss PL (AC)** for both annual and perennial crops is composed of the:

- 1) Difference between expected and actual value of crop production in non-fully damaged harvested areas: $p_{i,j,t-1} * \Delta y_{i,j,t} * ha_{i,j,t}$
- 2) Pre-disaster value of destroyed standing crops in fully damaged (not harvested) areas: $p_{i,j,t-1} * y_{i,j,t-1} * \Delta ha_{i,j,t}$
- 3) Short-run post-disaster maintenance costs (expenses used to temporarily sustain production activities immediately post-disaster): $P_{\text{short-run}}$

- The term $(p_{i,j,t-1} * \Delta y_{i,j,t} * ha_{i,j,t})$ represents the crop production that has been reduced as a consequence of the disaster. This formula is applied when a disaster impacted the crop land only partially and harvest took place after the event, however the crop yield was reduced due to the impact of the event. The calculation consists of multiplying the reduced yield per hectare (Δy) by the number of hectares of the fully-affected area ha. The overall reduction in harvest is then valued at pre-disaster price (p) at level (t-1). This calculation is done by crop for each crop affected.

- The $(p_{i,j,t-1} * y_{i,j,t-1} * \Delta ha_{i,j,t})$ represents the crop production that has been fully lost as a consequence of the disaster. This formula is applied when a disaster completely devastated the crop land and no harvest took place as a result. The calculation consists of multiplying the number of fully destroyed hectares (Δha) by an estimate of the average expected yield of the destroyed crop in normal conditions (y), and value of the overall amount of lost harvest at pre-disaster price (p) at level (t-1). The average (expected) yield estimates could be based on a five- (or more) year trend of the reported crop yield data.

- The term ($P_{\text{short-run}}$) captures any short-run disaster-related expenses incurred by farmers in the short aftermath of a disaster in order to maintain production activities or to restore activities to pre-disaster level. This could entail hiring generators, expenses for clearing up after earthquakes or landslides, short-run hire of machinery, hire of irrigation services, etc.

The overall Production Loss for Annual Crops is the summary of all three terms.

$$PL(AC)_{i,j} = (p_{i,j,t-1} * \Delta y_{i,j,t} * ha_{i,j,t}) + (p_{i,j,t-1} * y_{i,j,t-1} * \Delta ha_{i,j,t}) + P_{\text{short-run}}$$

Assets Damage in Crops AD (C) is composed of the:

1) Repair/replacement cost of partially/fully destroyed assets at pre-disaster price:

$$p_{k,j,t-1} * \Delta q_{k,j,t}$$

- The term ($p_{k,j,t-1} * \Delta q_{k,j,t}$) represents the total assets damage, where the quantity of damaged or destroyed items (Δq) is valued by their respective repair or replacement cost (p) at pre-disaster level ($t-1$). This Assets category includes crop-specific infrastructure, machinery and equipment, for example: tractors, balers, harvesters, storage facilities, etc.

$$AD(C)_{i,j} = p_{k,j,t-1} * \Delta q_{k,j,t}$$

Damage and loss in livestock

DL (L) (Livestock damage and loss) = Livestock production damage + Livestock production loss + Livestock assets damage (complete and partial)

→ Livestock Production Damage PD (L) is composed of the:

1) Pre-disaster value of stored inputs (fodder and forage):

$$\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}$$

2) Pre-disaster value of destroyed stored animal products:

$$\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$$

3) Pre-disaster net value of dead animals:

$$(\Delta q_{i,j,t} * w_i) * (p_{i,j,t-1} - \alpha * p_{i,j,t})$$

- The term ($\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}$) represents the quantity of inputs (q) for livestock production by input type (such as animal feed, vaccines, medicine, pest control, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level ($t-1$). Calculations are done by input type for all affected inputs.

- The term ($\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$) represents the quantity of stored primary livestock products by commodity (frozen meat from previous slaughters, milk, eggs, skins and hides, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level ($t-1$). Calculations are done for every affected stored livestock commodity.

- The term $[(\Delta q_{i,j,t} * w_i) * (p_{i,j,t-1} - \alpha * p_{i,j,t})]$ represents the value of dead animals expressed as the number of dead animals by type (Δq), multiplied by carcass weight (w),¹ and valued at pre-disaster level ($t-1$) meat prices (p), and subtracting the share of sold meat from dead animals (α) at post-disaster price (p) of time (t).

The overall Production Damage for the Livestock Sector is the summary of all three terms.

$$PD(L)_{i,j} = (\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}) + (\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}) + [(\Delta q_{i,j,t} * w_i) * (p_{i,j,t-1} - \alpha * p_{i,j,t})]$$

1 Carcass weight data should be given in terms of dressed carcass weight, excluding offal and slaughter fats. Production of beef and buffalo meat includes veal; mutton and goat meat includes meat from lambs and kids; pig meat includes bacon and ham in fresh equivalent. Poultry meat includes meat from all domestic birds and refers, wherever possible, to ready-to-cook weight.

→ **Livestock Production Loss PL (L) is composed of the:**

1) Difference between expected and actual value of production (of livestock products):

$$q_{i,j,t} * p_{i,j,t-1} * \Delta y_{i,j,t}$$

2) Short-run post-disaster maintenance costs:

$$P_{\text{short-run}}$$

- The term $(q_{i,j,t} * p_{i,j,t-1} * \Delta y_{i,j,t})$ represents the livestock production directly lost as a consequence of the disaster; this refers to either reduced production or completely ceased production of milk, eggs, etc., due to injured or killed animals. This term does not include meat production from dead animals if this has already been fully counted towards estimating the value of dead animals as part of the Livestock Production Damage. The calculation consists of multiplying the number of animals dead/injured (q) by the reduced output per animal (Δy) and times the price per output at pre-disaster price (p) at level (t-1).

- The term $(P_{\text{short-run}})$ captures any short-run disaster-related expenses incurred by farmers in the short aftermath of a disaster in order to maintain production activities or to restore activities to pre-disaster level. This could entail hiring generators, expenses for clearing up after earthquakes or landslides, short-run hire of machinery, veterinary expenses, etc.

The overall Production Loss for the Livestock Sector is the summary of both terms.

$$PL (L)_{i,j} = (q_{i,j,t} * p_{i,j,t-1} * \Delta y_{i,j,t}) + P_{\text{short-run}}$$

→ **Livestock Assets Damage AD (L) is composed of the:**

1) Repair/replacement cost of partially/fully destroyed assets at pre-disaster price:

$$p_{k,j,t-1} * \Delta q_{k,j,t}$$

- The term $(p_{k,j,t-1} * \Delta q_{k,j,t})$ represents the total assets damage, where the quantity of damaged or destroyed items (Δq) is valued by their respective repair or replacement cost (p) at pre-disaster level (t-1). This Assets category includes livestock-specific infrastructure, machinery and equipment, for example: milking machines, dairy machines, feeding machines, barns and stables, etc.

$$AD (AL)_{i,j} = p_{k,j,t-1} * \Delta q_{k,j,t}$$

Damage and loss in forestry

DL (FO) (Forestry damage and loss) = Forestry production damage + Forestry production loss + Forestry assets damage (complete and partial)

A forest typically consists of individual timber stands, each having distinct characteristics. A timber stand is a contiguous group of trees sufficiently uniform – age-class distribution, composition, structure, and growing on a site of sufficiently uniform quality – as to be a distinguishable unit. Merchantable timber stands consist of trees that have the size, quality, and condition to be salable under a given economic condition by a given time. Pre-merchantable timber stands are stands composed of trees that are too immature to be profitably harvested and sold for manufacturing forest products at the time of disaster occurrence (Zhang & Pearse, 2012). The time when a disaster occurs (t) is therefore the reference point for determining stand maturity.

The value of merchantable timber stands is called stumpage value or simply stumpage. Stumpage value equals the market-determined (unit) stumpage price times the standing timber volume in a stand.

→ **Forestry Production Damage PD (FO)** is composed of the:

1) Pre-disaster value of stored inputs:

$$\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}$$

2) Pre-disaster value of destroyed stored products:

$$\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$$

- The term $(\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1})$ represents the quantity of inputs (q) for forestry production by input type (such as fertilizer, pest control, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level (t-1). Calculations are specified by input type for all affected inputs.

- The term $(\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1})$ represents the quantity of stored timber that has been destroyed by a disaster, valued at pre-disaster price (p) at level (t-1).

The overall Production Damage for Forestry is the summary of both terms.

$$PD(FO)_{i,j} = (\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}) + (\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1})$$

→ **Forestry Production Loss PL (FO)** is composed of the:

1) (Discounted) present value of timber production from both merchantable and pre-merchantable stands:

$$(p_{t-1}/m^3 * y m^3/ha * ha) / (1+r)^{60 - \text{age}}$$

2) (Discounted) present value of non-timber forest products:

$$R_{\text{non-timber}} / (1+r)^n$$

3) Minus the value of timber salvaged and marketed post-disaster:

$$- p_{t-1}/m^3 * y m^3_{(\text{salvaged})}$$

- The production loss value for a forest is the summation of the production loss values for all stands.

The **production loss for a merchantable timber stand** equals the market-determined (unit) timber price times the standing timber volume in a stand. Therefore, the term $(p_{t-1}/m^3 * y m^3/ha * ha)$ represents the production loss value of the forest stand affected expressed as the volume of timber by stand, valued by the current price of timber (p_{t-1}) and multiplied by size of the stand in hectares.

- **The production loss for a pre-merchantable timber stand** is calculated as an estimate of the value of the stand's projected future income at the time of the disaster. The value of a pre-merchantable timber stand is equal to the timber stand's projected (potential) revenues discounted to the stand's age at the time of damage. This is achieved by adding the discount factor $(1+r)^{60 - \text{age}}$.

- Other than timber value, a forest (which consist of many merchantable and pre-merchantable timber stands) often generates income from non-timber forest products such as fuelwood, fruit, mushrooms, flowers, and recreational activities. Unlike timber production loss, income from non-forest products is not associated with a specific stand, but attributed to the whole forest. Thus, the present value of all income from non-timber products is usually calculated for the whole forest (or adjusted to the size of the damaged portion of the forest). The term $R_{\text{non-timber}} / (1+r)^n$ represents the income obtained from non-timber forest activities (R), which will be lost as a consequence of the disaster, divided by the discount factor in order to obtain the net present value of future income lost until full recovery of normal forest (non-timber) income-generating activities $(1+r)^n$, where (r) is the interest rate and (n) is the number of years until full recovery of activities.

- The value of the timber which was salvaged and marketed following a disaster should be taken into consideration. The term $(- p_{t-1}/m^3 * y m^3_{(\text{salvaged})})$ represents the overall volume of re-sold timber ($y m^3$), valued at the pre-disaster level price (p_{t-1}) per cubic meter.

The overall Production Loss for Forestry is the summary of the three terms.

$$PL(FO)_{i,j} = [(p_{t-1}/m^3 * y m^3/ha * ha) / (1+r)^{60 - \text{age}}] + (R_{\text{non-timber}} / (1+r)^n) + (- p_{t-1}/m^3 * y m^3_{(\text{salvaged})})$$

→ **Forestry Assets Damage** is composed of the:

- 1) Repair/replacement cost of partially/fully destroyed assets at pre-disaster price:

$$p_{k,j,t-1} * \Delta q_{k,j,t}$$

- The term ($p_{k,j,t-1} * \Delta q_{k,j,t}$) represents the total assets damage, where the quantity of damaged or destroyed items (Δq) is valued by their respective repair or replacement cost (p) at pre-disaster level ($t-1$). This category includes forestry-specific infrastructure, machinery and equipment, for example: skidders, forwarders, tractors, feller bunchers, etc.

$$AD (FO)_{i,j} = p_{k,j,t-1} * \Delta q_{k,j,t}$$

Damage and loss in fisheries

DL (FI) (Fisheries damage and loss) = Fisheries production damage + Fisheries production loss + Fisheries assets damage (complete and partial)

→ **Fisheries Production Damage PD (FI)** is composed of the:

- 1) Pre-disaster value of stored inputs:
2) Pre-disaster value of destroyed stored capture:

$$\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}$$

$$\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$$

- The term ($\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}$) represents the quantity of fishing inputs (q) by input type (bait, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level ($t-1$). Calculations are done by input type for all affected inputs.

- The term ($\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$) represents the quantity of stored fisheries capture that has been destroyed by a disaster, valued at pre-disaster price (p) at level ($t-1$).

$$PD (FI)_{i,j} = \Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1} + \Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$$

→ **Fisheries Production Loss PL (FI)** is composed of the:

- 1) Difference between expected and actual value of fisheries capture in disaster year:

$$\Delta T_{j,t} * y_{i,j,t} * p_{i,j,t-1}$$

- The term ($\Delta T_{j,t} * y_{i,j,t} * p_{i,j,t-1}$) represents the fisheries capture that has been lost due to disasters, expressed as the time when fishermen will be prevented from conducting normal fishing activities (T) (in number of days) multiplied by the average capture per day in normal conditions (y) and valued at pre-disaster level prices (p) at level ($t-1$).

$$PL (FI)_{i,j} = \Delta T_{j,t} * y_{i,j,t} * p_{i,j,t-1}$$

→ **Fisheries Assets Damage AD (FI)** is composed of the:

- 1) Repair/replacement cost of partially/fully destroyed assets at pre-disaster price:

$$p_{k,j,t-1} * \Delta q_{k,j,t}$$

- The term ($p_{k,j,t-1} * \Delta q_{k,j,t}$) represents the total assets damage, where the quantity of damaged or destroyed items (Δq) is valued by their respective repair or replacement cost (p) at pre-disaster level ($t-1$). This Assets category includes fisheries-specific infrastructure and equipment, for example: boats, fishing vessels, engines, fishing gear, cold storage, etc.

$$AD (FI)_{i,j} = p_{k,j,t-1} * \Delta q_{k,j,t}$$

Damage and loss in aquaculture

DL (AQ) (Aquaculture damage and loss) = Aquaculture production damage + Aquaculture production loss + Aquaculture assets damage (complete and partial)

→ **Aquaculture Production Damage PD (AQ)** is composed of the:

- 1) Pre-disaster value of stored inputs: $\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}$
- 2) Pre-disaster value of destroyed stored aquaculture products: $\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}$
- 3) Pre-disaster net value of broodstock² loss: $(\Delta q_{\text{broodstock},i,j,t} * p_{t-1})$

- The term $(\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1})$ represents the quantity of inputs (q) for aquaculture production by input type (such as fingerlings, fish feed, fertilizer, medicine, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level (t-1). Calculations are done by input type for all affected inputs.

- The term $(\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1})$ represents the quantity of stored primary aquaculture products by commodity (frozen fish, caviar, etc.) that have been destroyed by a disaster, valued at their respective price (p) at pre-disaster level (t-1). Calculations are specified for every affected stored aquaculture commodity.

- The term $(\Delta q_{\text{broodstock},i,j,t} * p_{t-1})$ represents the value of broodstock fish expressed as the number of broodstock fish (Δq) lost, multiplied by their pre-disaster-level (t-1) prices (p).

The overall Production Damage for the Aquaculture sector is the summary of all three terms.

$$PD(AQ)_{i,j} = (\Delta q_{x(\text{stored}),j,t} * p_{x(\text{stored}),j,t-1}) + (\Delta q_{i(\text{stored}),j,t} * p_{i(\text{stored}),j,t-1}) + (\Delta q_{\text{broodstock},i,j,t} * p_{t-1})$$

→ **Aquaculture Production Loss PL (AQ)** is composed of the:

- 1) Difference between expected and actual value of aquaculture production in non-fully damaged aquaculture areas: $area_{i,j,t} * p_{i,j,t-1} * \Delta y_{i,j,t-1}$
- 2) Pre-disaster value of aquaculture production lost in fully damaged aquaculture areas: $\Delta area_{i,j,t} * p_{i,j,t-1} * y_{i,j,t-1}$
- 3) Short-run post-disaster maintenance costs: $P_{\text{short-run}}$

- The term $(area_{i,j,t} * p_{i,j,t-1} * \Delta y_{i,j,t-1})$ represents aquaculture production that has been reduced as a consequence of the disaster. This formula is applied when a disaster impacted the area of aquaculture cages and pens only partially and harvest took place after the event, however the fish yield was reduced due to the impact of the event. The calculation consists of multiplying the amount of reduced yield per hectare (or square meter) of aquaculture facilities (Δy) by the number of hectares (square meters) of the fully-affected area ($area_{i,j,t}$). The overall reduction in harvest is then valued at pre-disaster price (p) at level (t-1). This calculation is done by area affected.

- The term $(\Delta area_{i,j,t} * p_{i,j,t-1} * y_{i,j,t-1})$ represents aquaculture production that has been fully lost as a consequence of the disaster. This formula is applied when a disaster completely devastated the area of aquaculture cages and pens and no fish harvest took place as a result. The calculation consists of multiplying the number of fully destroyed hectares (or square meters) ($\Delta area$) by an estimate of the average expected fish yield in normal conditions (y) and value of the overall amount of lost harvest at pre-disaster price (p) at level (t-1). The average (expected) yield estimates could be based on a five- (or more) year trend.

2 Broodstock, or broodfish, is a group of mature individuals used in aquaculture for breeding purposes. Broodstock can be a population of animals maintained in captivity as a source of replacement for, or enhancement of, seed and fry numbers.

- The term ($P_{\text{short-run}}$) captures any short-run disaster-related expenses incurred by farmers in the short aftermath of a disaster in order to maintain production activities or to restore activities to pre-disaster level. This could entail hiring generators, expenses for clearing up, short-run hire of machinery, hire of irrigation services, etc.

The overall Production Loss for Aquaculture is the summary of all three terms.

$$PL(AQ)_{i,j} = (\text{area}_{i,j,t} * p_{i,j,t-1} * \Delta y_{i,j,t-1}) + (\Delta \text{area}_{i,j,t} * p_{i,j,t-1} * y_{i,j,t-1}) + P_{\text{short-run}}$$

→ **Aquaculture Assets Damage AD (AQ)** is composed of the:

1) Repair/replacement cost of partially/fully destroyed assets at pre-disaster price:

$$p_{k,j,t-1} * \Delta q_{k,j,t}$$

- The term ($p_{k,j,t-1} * \Delta q_{k,j,t}$) represents the total assets damage, where the quantity of damaged or destroyed items (Δq) is valued by their respective repair or replacement cost (p) at pre-disaster level ($t-1$). This Assets category includes aquaculture-specific infrastructure, machinery and equipment, for example: aquaculture feeders, pumps and aerators, feeding machines, cold storage, aquaculture support vessels, etc.

$$AD(AQ)_{i,j} = p_{k,j,t-1} * \Delta q_{k,j,t}$$

Optimal and minimal data requirements

FAO's damage and loss assessment methodology provides flexibility because it can function with varying degrees of data availability. Below are the optimal and minimal data requirements necessary for a functional damage and loss assessment in each subsector. Indications of the necessary baseline data are also provided.

1. Data requirements for damage and loss assessment in crops:

- Number of hectares of crops damaged and/or destroyed, by disasters, disaggregated by type of crop (minimal requirement)
- Expected yield reduction in partially affected plot areas (t/ha) by crop (minimal requirement)
- Number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement)
- Volume of destroyed stored crops by crop type (optimal requirement)
- Volume of destroyed stored inputs by input type (optimal requirement)
- Average yield (t/ha) by crop (minimal requirement)
- Types of cultivated crops per area (minimal requirement)
- Hectares of planted crops by crop type (minimal requirement)

2. Data requirements for damage and loss assessment in livestock:

- Number of livestock deaths, by animal type (minimal requirement)
- Number of livestock injured, sick or affected by disaster, by animal type (minimal requirement)
- Expected reduction in milk, egg, etc., production per affected animal by product type (minimal requirement)
- Volume of destroyed stored animal products from previous slaughters by type (optimal requirement)
- Volume of destroyed stored inputs by input type (optimal requirement)
- Number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement)
- Average volume of meat production per animal by animal type (minimal requirement)
- Number of livestock herd size by animal type (minimal requirement)

3. Data requirements for damage and loss assessment in forestry:

- Size in hectares of destroyed merchantable forest stands by stand type (minimal requirement)
- Size in hectares of destroyed pre-merchantable forest stands by stand type (minimal requirement)
- Standing timber volume per hectare in merchantable stands by stand (minimal requirement)
- Average timber volume per hectare in pre-merchantable stands by stand (minimal requirement)
- Age of destroyed pre-merchantable stands (minimal requirement)
- Stored timber volume destroyed by disaster (minimal requirement)
- Salvaged and re-sold timber volume (minimal requirement)
- Real interest rate (minimal requirement)
- Number of stands per forest (minimal requirement)
- Number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement)
- Average annual value of non-timber forest activities (optimal requirement)

4. Data Requirements for damage and loss assessment in aquaculture:

- Types of aquaculture activity in affected areas (land-based pens, water-based tanks, etc.)
- Size in hectares of fully-affected aquaculture areas by type (minimal requirement)
- Size in hectares of partially-affected aquaculture areas by type (minimal requirement)
- Average production per hectare by aquaculture activity type (minimal requirement and baseline)
- Expected yield reduction per hectare in partially-affected aquaculture areas (optimal requirement)
- Volume of destroyed stored production by aquaculture type (optimal requirement)
- Volume of destroyed inputs by input type (optimal requirement)
- Number of damaged/destroyed machinery, equipment and facilities by type (optimal requirement)

5. Data requirements for damage and loss assessment in fisheries:

- Types of fishing activities in the affected areas (small-scale, industrial, etc.) (minimal requirement)
- Average volume of daily/weekly/monthly capture by fishing activity (minimal requirement)
- Number of days fishing activities are suspended due to disaster, by fishing activity (minimal requirement)
- Number of fully and/or partially damaged vessels, equipment, infrastructure and other assets by asset type (minimal requirement)
- Volume of inputs and stored capture destroyed by disaster (optimal requirement)

To know more about the FAO damage and loss assessment methodology, its data requirements, computational steps and Sendai framework reporting for Indicator C-2, visit FAO's e-learning academy and the dedicated e-learning course series at <https://elearning.fao.org/course/view.php?id=608>.

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, aquaculture and fisheries (includes, but is 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, wheeled special machines, portable chain-saws, fishing vessels, fishing gear, aquaculture feeders, pumps and aerators, aquaculture support vessels).

Agricultural production loss: Declines in the volume of crop, livestock (and also forestry, aquaculture and fisheries) production resulting from a disaster, as compared to pre-disaster expectations.

Attribution: the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence (IPCC, AR5).

Biological hazards: Are of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins and bioactive substances. Examples are bacteria, viruses or parasites, as well as venomous wildlife and insects, poisonous plants and mosquitoes carrying disease-causing agents (UNDRR Terminology).

Climate: In a simple sense, climate is usually defined as the average weather, but more rigorously 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 (IPCC, AR5).

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 which 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 (IPCC, AR5). In its Article 1, the UNFCCC 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: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, AR5).

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 (IPCC, AR5).

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 intra-seasonal to multi-decadal climate variability (EM-DAT CRED, 2017).

Conflicts: Situations of civil unrest, regime change, interstate conflicts, civil wars, etc.

Damage: The monetary value of total or partial destruction of physical assets and infrastructure in disaster-affected areas, expressed as replacement and/or repair costs. In the agriculture sector, damage is considered in relation to standing crops, farm machinery, irrigation systems, livestock shelters, fishing vessels, pens and ponds, etc. (European Union, UNDG & World Bank, 2013; UNDRR Terminology; FAO, 2017b).

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 (UNDRR Terminology).

Dietary energy intake: The energy content of food consumed (FAO *et al.*, *SOFI* 2020).

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 (UNDRR Terminology).

Disaster risk reduction: The policy objective of disaster risk management. DRR strategies and plans aim at preventing new and reducing existing disaster risk and managing residual risk, all of which contributes to strengthening resilience and advancing achievement of sustainable development (UNDRR Terminology).

Early-warning system: An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events (UNDRR Terminology).

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 an extreme weather event would normally be as rare as, or rarer, than the 10th or 90th percentile of a probability density function estimated from observations. 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 classed 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) (IPCC, AR5).

Food chain: The series of processes by which food is grown or produced, sold, and eventually consumed.

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 (FAO, 2017d).

Food insecurity: A situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by 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 (FAO *et al.*, *SOFI* 2018).

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 (FAO *et al.*, *SOFI* 2020).

Food systems: The entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products. Food systems comprise all food products that originate from crop and livestock production, forestry, fisheries and aquaculture, as well as the broader economic, societal and natural environments in which these diverse production systems are embedded (FAO *et al.*, *SOFI* 2020).

Geophysical disasters: Originate from the Earth's internal processes. Examples are earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses and debris or mud flows. Hydro- and meteorological factors are important contributors to some of these processes. Tsunamis are difficult to categorize: although they are triggered by undersea earthquakes and other geological events, they essentially become an oceanic process that is manifested as a coastal water-related hazard (UNDRR Terminology).

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 socio-natural in origin. Natural hazards are predominantly associated with natural processes and phenomena (UNDRR, Terminology).

Hunger: An uncomfortable or painful physical sensation caused by insufficient consumption of dietary energy (FAO *et al.*, *SOFI* 2020).

Hydrological disasters: Those caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater (EM-DAT CRED, 2017).

Loss: The change in economic flows occurring as a result of 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 expenditure to meet immediate needs in the aftermath of a disaster (European Union, UNDG & World Bank, 2013; UNDRR Terminology; FAO, 2017b).

Malnutrition: An abnormal physiological condition caused by inadequate, unbalanced or excessive consumption of macronutrients and/or micronutrients. Malnutrition includes undernutrition (child stunting, wasting, vitamin and mineral deficiencies) as well as overweight and obesity (FAO *et al.*, *SOFI* 2020).

Meteorological disasters: Events caused by short-lived/small- to mesoscale atmospheric processes (in the spectrum from minutes to days) (EM-DAT CRED, 2017).

Micronutrients: Vitamins, minerals and other substances that are required by the body in very small but specific amounts; measured in milligrams or micrograms (FAO *et al.*, *SOFI* 2020).

Migration: The movement of a person or a group of persons, 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 (IOM, 2017).

Mitigation (of climate change): A human intervention to reduce the sources or enhance the sinks of greenhouse gases that lead to climate change (IPCC, AR5).

Mitigation (of disaster risk and disaster): The lessening of the potential adverse impacts of a hazardous event (including those that are human-induced) through actions that reduce hazard, exposure and vulnerability (UNDRR Terminology).

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 (UNDRR Terminology).

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 (UNDRR Terminology).

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 socio-economic and technological developments that may or may not be realized (IPCC, AR5).

Protracted crisis: Environment in which a significant proportion of the population is acutely vulnerable to death, disease and disruption of livelihoods over a prolonged period of time. The governance of such an environment is usually very weak, with the state having a limited capacity to respond to, or mitigate, threats to the population, or to provide adequate levels of protection (FAO *et al.*, *SOFI* 2010).

Reconstruction: The medium- and long-term rebuilding and sustainable restoration of resilient critical infrastructures, services, housing, facilities and livelihoods required for the full functioning of a community or a society affected by a disaster, aligning with the principles of sustainable development and ‘building back better,’ to avoid or reduce future disaster risk (UNDRR Terminology).

Recovery: The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and ‘build back better,’ to avoid or reduce future disaster risk (UNDRR Terminology).

Rehabilitation: The restoration of basic services and facilities for the functioning of a community or a society affected by a disaster (UNDRR Terminology).

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 (UNDRR Terminology).

Response: Actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected (UNDRR Terminology).

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 of time, 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 (UNDRR Terminology).

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 well-being at grave risk, based on the Food Insecurity Experience Scale (FAO *et al.*, *SOFI* 2020).

Vulnerability: The 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 (UNDRR Terminology).

References

Databases and online resources

- BFD. 2021.** Bangladesh Forest Information System. In: *Bangladesh Forest Department* [online]. Updated as at 18 January 2021. <http://bfis.bforest.gov.bd/bfis/>
- CRED. 2021.** International Disaster Database - EM-DAT CRED. In: *EM-DAT* [online]. Brussels. Updated as at 18 January 2021. <http://www.emdat.be/database>
- ESA. 2021.** European Space Agency Climate Change Initiative: Land Cover. In: *ESA Landcover* [online]. Paris. Updated as at 18 January 2021. <https://www.esa-landcover-cci.org/>
- ESRI. 2021.** ArcGIS Solutions for Emergency Management. In: *ArcGIS Solutions* [online]. Redlands, USA. Updated as at 18 January 2021. <http://solutions.arcgis.com/emergency-management/response>
- European Commission. 2021.** Copernicus Emergency Management Service – CEMS. In: *Copernicus CEMS* [online]. Brussels. Updated as at 18 January 2021. <https://emergency.copernicus.eu/>
- FAO. 2021.** Agricultural Integrated Survey Programme - AGRISurvey. In: *FAO* [online]. Rome. Updated as at 18 January 2021. <http://www.fao.org/in-action/agrisurvey/en/>
- FAO. 2021.** CountrySTAT. In: *FAO* [online]. Rome. Updated as at 18 January 2021. <http://www.fao.org/in-action/countrystat/en/>
- FAO. 2021.** Collect Earth Online. In: *Open Foris* [online]. Rome. Updated as at 18 January 2021. <http://www.openforis.org/tools/collect-earth-online.html>
- FAO. 2021.** Global Information and Early Warning System – GIEWS. In: *FAO* [online]. Rome. Updated as at 18 January 2021. www.fao.org/giews/english/index.htm
- FAO. 2021.** FAO Locust Hub. In: *FAO* [online]. Rome. Updated as at 18 January 2021. <https://locust-hub-hqfao.hub.arcgis.com/>
- FAO. 2021.** FAO Hand-in-Hand Geospatial Platform. In: *FAO* [online]. Rome. Updated as at 18 January 2021. <http://www.fao.org/hand-in-hand>
- FAO. 2021.** FAOSTAT. In: *FAO* [online]. Rome. Updated as at 18 January 2021. <http://www.fao.org/faostat/en/>
- GDIN. 2021.** Global Disaster Information Network – GDIN. In: *GDIN* [online]. Washington, DC. Updated as at 18 January 2021. www.gdin.org
- GFDRR. 2021.** Global Facility for Disaster Reduction and Recover – Online Utilities. In: *GFDRR* [online]. Washington, DC. Updated as at 18 January 2021. <https://www.gfdr.org/en/onlineutilities>
- GFDRR. 2021.** GFDRR Post Disaster Needs Assessments. In: *GFDRR* [online]. Washington, DC. Updated as at 18 January 2021. <https://www.gfdr.org/en/post-disaster-needs-assessments>
- GFDRR. 2021.** GFDRR Post Disaster Needs Assessments (PDNAs) and Rapid Assessments. In: *GFDRR* [online]. Washington, DC. Updated as at 18 January 2021. <https://www.gfdr.org/en/publication/pdnas-and-rapid-assessments>
- HOT. 2021.** Humanitarian OpenStreetMap Team – Tools and Data. In: *Hot* [online]. Washington, DC. Updated as at 18 January 2021. <https://www.hotosm.org/>
- ILO. 2021.** ILOSTAT. In: *ILO* [online]. Geneva. Updated as at 18 January 2021. <https://ilostat.ilo.org/data/>
- NBS. 2021.** National Bureau of Statistics of China – Data. In: *stats.gov.cn* [online]. Beijing. Updated as at 18 January 2021. <http://www.stats.gov.cn/english/>
- OIE. 2021.** OIE WAHIS Portal: Animal Health Data. In: *OIE* [online]. Paris. Updated as at 18 January 2021. <https://www.oie.int/en/animal-health-in-the-world/wahis-portal-animal-health-data/>
- OCHA. 2021.** UN OCHA Services: Humanitarian Response. In: *OCHA* [online]. New York, USA. Updated as at 18 January 2021. <https://www.humanitarianresponse.info>
- Pig333. 2021.** Professional Pig Community. In: *Pig333* [online]. Barcelona, Spain. Updated as at 18 January 2021. <https://pig333.com/>

- UNDRR. 2021.** Sendai Framework Monitor. In: *UNDRR* [online]. Geneva, Switzerland. Updated as at 18 January 2021. <https://sendaimonitor.undrr.org/>
- UNDP. 2021.** UNDP Human Development Reports. In: *UNDP* [online]. New York, USA Updated as at 18 January 2021. <http://hdr.undp.org/en/countries/profiles/MDG>
- UNDRR. 2021.** UNDRR Terminology. In: *UNDRR* [online]. Geneva, Switzerland. Updated as at 18 January 2021. <https://www.undrr.org/terminology#V>
- USDA. 2021.** USDA National Nutrient Database for Standard Reference. In: *USDA* [online]. Updated as at 18 January 2021. <https://data.nal.usda.gov/dataset/usda-national-nutrient-database-standard-reference-legacy-release>
- USGS. 2021.** U.S. Geological Survey (USGS) Emergency Operations Portal. In: *USGSG* [online]. Updated as at 18 January 2021. <https://hdds.usgs.gov>
- WHO. 2021.** WHO Global Health Observatory. In: *WHO* [online]. Geneva, Switzerland. Updated as at 18 January 2021. <https://www.who.int/data/gho/>
- World Bank. 2021.** World Bank World Development Indicators. In: *World Bank* [online]. Washington, DC. Updated as at 18 January 2021. <https://datacatalog.worldbank.org/dataset/world-development-indicators>

Framework agreements

- COP19. 2013.** *Warsaw International Mechanism for Loss and Damage (Decision 2/CP.19)*. 3 pp. (available at <https://unfccc.int/sites/default/files/resource/docs/2013/cop19/eng/10a01.pdf>).
- COP21. 2015.** *Adoption of the Paris Agreement, FCCC/CP/2015/L.9.Rev.1*. 32 pp. (available at <https://undocs.org/en/FCCC/CP/2015/L.9/Rev.1>).
- CRED & UNDRR. 2020.** *The human cost of disasters: an overview of the last 20 years (2000–2019)*. Geneva, Switzerland. 30 pp. [Cited 30 December 2020]. (available at <https://reliefweb.int/report/world/human-cost-disasters-overview-last-20-years-2000-2019>).
- UN. 2015.** *Transforming our world: the 2030 Agenda for Sustainable Development (A/RES/70/1)*. 35 pp. (available at https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E).
- UN. 2016.** *Report of the Secretary-General for the World Humanitarian Summit (A/70/709). One humanity: shared responsibility (a.k.a. Agenda for Humanity)*. 62 pp. (available at [https://agendaforhumanity.org/sites/default/files/resources/2019/jun/\[A-70-709\]%20Secretary-General's%20Report%20for%20WHS_o.pdf](https://agendaforhumanity.org/sites/default/files/resources/2019/jun/[A-70-709]%20Secretary-General's%20Report%20for%20WHS_o.pdf)).
- UN. 2020.** *Comprehensive and coordinated response to the coronavirus disease (COVID-19) pandemic (A/74/L.92)*. 14 pp. (available at <https://undocs.org/A/74/L.92>).
- UNDRR. 2015.** *Sendai Framework for Disaster Risk Reduction 2015–2030 (A/RES/70/1)*. 37 pp. (available at https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf).
- UNFCCC. 2015.** *The Paris Agreement*. 27 pp. (available at https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf).

Publications and literature

- Abatzoglou, J.T. & Williams, A.P. 2016.** “Impact of anthropogenic climate change on wildfire across western US forests.” *Proceedings of the National Academy of Sciences of the United States of America (PNAS)* 113(4): 11770–11775. (available at <https://www.pnas.org/content/113/42/11770>).
- Aon. 2019.** *Weather, Climate & Catastrophe Insight. 2019 Annual Report.* 83 pp. (available at http://thoughtleadership.aon.com/Documents/20200122-if-natcat2020.pdf?utm_source=ceros&utm_medium=storypage&utm_campaign=natcat20).
- Aublet, K. 2011.** *Évaluation de l'impact de la recrudescence acridienne sur les cultures et les pâturages. Campagne de lutte antiacridienne 2010–2011. Mission du 5 au 18 Juin 2011. Technical report for project “Emergency Assistance to Locust Control in Madagascar” (OSRO/MAG/004/USA).* Rome, FAO. 46 pp.
- Bardhan, D., Kumar, S., Anandsekaran, G., Chaudhury, J.K., Meraj, M., Singh, R.K., Verma, M.R., Kumar, D., Kumar P.T., N., Ahmed Lon, S., Mishra, V., Mohanty, B.S, Korade, N. & De, U.K. 2017.** “The economic impact of peste des petits ruminants in India.” *Revue scientifique et technique (International Office of Epizootics)* 36(1): 245–263. (available at <https://pdfs.semanticscholar.org/01fa/a803220c19cf2395696dcf566c33eboco965.pdf>)
- Benkhelifa, I., Nouali-Taboudjemat, N., Moussaoui, S. 2014.** “Disaster Management Projects using Wireless Sensor Networks: An Overview.” In *28th International Conference on Advanced Information Networking and Applications Workshops.* Victoria, British Colombia, Canada: Institute of Electrical and Electronics Engineers, pp. 605–610. (available at <https://ieeexplore.ieee.org/document/6844704/citations#citations>).
- Borges, M., Hastings, F., Rizzo, G., Campos, F.M., García, G., Jones, C., Vuolo, M.R., Fujisawa, M. & Kanamaru, H. 2020.** *Evaluación de los impactos del cambio climático en la agricultura en Uruguay.* Rome, FAO. (available at <https://doi.org/10.4060/ca7134es>).
- 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: 1–6. (available at <https://www.nature.com/articles/s41559-016-0058#citeas>).
- Brainard, R.E, Oliver, T., McPhaden, M. J., Cohen, A., Venegas, R., Heenan, A., Vargas-Ángel, B., Rotjan, R., Mangubhai, S., Flint, E. & Hunter, S.A. 2018.** “Ecological impacts of the 2015–2016 El Niño in the central equatorial Pacific.” *Bulletin of the American Meteorological Society (BAMS)* 99: 21–26. (available at <http://www.ametsoc.net/ee/2016/ch5.pdf>).
- Burger, M., Horton, R. & Wentz, J. 2020.** “The Law and Science of Climate Change Attribution.” *Columbia Journal of Environmental Law* 45(1): 60–80. (available at <https://journals.library.columbia.edu/index.php/cjel/article/view/4730/2118>).
- Carnegie, A.J., Venn, T., Lawson, S., Nagel, M., Wardlaw, T., Cameron, N. & Last, I. 2018.** “An analysis of pest risk and potential economic impact of pine wilt disease to Pinus plantations in Australia.” *Australian Forestry* 81: 24–36. (available at <https://www.tandfonline.com/doi/abs/10.1080/00049158.2018.1440467>).
- CEPAL. 1991.** *Manual para la estimación de los efectos socioeconómicos de los desastres naturales.* Santiago, Chile. 364 pp. (available at <https://repositorio.cepal.org/handle/11362/31185>).
- CEPAL. 2012.** *Valoración de daños y pérdidas. Ola invernal en Colombia 2010–2011.* Bogotá, Colombia. 240 pp. (available at http://www.minambiente.gov.co/images/cambioclimatico/pdf/Plan_nacional_de_adaptacion/3._Da%C3%B1os_y_p%C3%A9rdidas_ola_invernal.pdf).
- 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. 42 pp. (available at <http://www.fao.org/3/ca6990en/CA6990EN.pdf>).
- CRED & UNDRR. N.d.** *The Human Cost of Disasters: an overview of the last 20 years (2000–2019).* 32 pp. (available at <https://www.undrr.org/sites/default/files/inline-files/Human%20Cost%20of%20Disasters%202000-2019%20FINAL.pdf>).
- Denslow, J.S. 2002.** “Invasive alien woody species in Pacific island forests.” *Unasylva* 209: 62–63. (available at <http://www.fao.org/tempref/docrep/fao/004/y3582e/y3582e11.pdf>).

- Doxoran, P., Bustamante, J., Dogliotti, A.I., Malthus & T.J., eds. 2019.** *Special Issue: Remote Sensing in Coastal Zone Monitoring and Management – How Can Remote Sensing Challenge the Broad Spectrum of Temporal and Spatial Scales in Coastal Zone Dynamic* [online]. Basel, Switzerland. [Cited 30 December 2020]. https://www.mdpi.com/journal/remotesensing/special_issues/Coastal_Zone_rs
- Duranton, J.-F. & Lecoq, M. 1990.** *Le Criquet Pèlerin au Sahel. Collection Acridologie Opérationnelle n. 6.* Montpellier, France, CIRAD. 84 pp. (available at http://locust.cirad.fr/ouvrages_pratiques/pdf/DFPV6.pdf).
- Duranton, J.-F., Franc, A., Luong-Skovmand, M.H. & Rachadi, T., 2009.** *Manuel de lutte préventive antiacridienne à Madagascar à l'usage des prospecteurs.* Montpellier, France, CIRAD. 307 pp. (available at http://publications.cirad.fr/une_notice.php?dk=551454).
- Dwinell, L.D. & Nickle, W.R.** *An Overview of the Pine Wood Nematode Ban in North America.* Gen. Tech. Rep. SE-55, Asheville, USA, US Department of Agriculture, Forest Service, Southeast Forest Experiment Station. 13 pp. (available at <https://www.fs.usda.gov/treearch/pubs/857>).
- Eckstein, D., Künzel, V., Schäfer, L. & Wings, M. 2019.** *Global Climate Risk Index 2020. Who suffers most from extreme weather events? Weather-related loss events in 2018 and 1999 to 2018.* Bonn, Germany, Germanwatch. 44 pp. (available at https://germanwatch.org/sites/germanwatch.org/files/20-2-01e%20Global%20Climate%20Risk%20Index%202020_14.pdf).
- European Union, UNDG & World Bank. 2013.** *Post-Disaster Needs Assessments. Volume A. Guidelines.* 26 pp. (available at <https://www.gfdr.org/sites/gfdr/files/PDNA-Volume-A.pdf>).
- European Union, UNDG & World Bank. 2014.** *Agriculture, Livestock, Fisheries and Forestry. PDNA Guidelines Volume B.* 49 pp. (available at <http://documents1.worldbank.org/curated/en/341131493098412619/pdf/114518-WP-PUBLIC-ADD-SERIES-pdna-guidelines-vol-b-agriculture-livestock-fisheries-forestry-o.pdf>).
- FAO. 2002.** “Main Aquatic Weed Problems in Africa.” In *Management of Problematic Aquatic Weeds in Africa* [online]. [Cited 30 December 2020]. <http://www.fao.org/3/y4270e/y4270e03.htm>
- FAO. 2006.** *Towards a More Effective Response to Desert Locusts and their Impacts on Food Security, Livelihoods and Poverty. Multilateral Evaluation of the 2003–05 Desert Locust Campaign.* Rome. 96 pp. (available at <http://www.fao.org/ag/locusts/common/ecg/1913/en/DesertLocustEvalReportE.pdf>).
- FAO. 2008.** Climate-related transboundary pests and diseases. Technical background document from the expert consultation held on 25 to 27 February 2008. Rome. 59 pp. (available at <http://www.fao.org/3/a-ai785e.pdf>).
- FAO. 2011.** *FAO Animal Production and Health Guidelines n. 11: Good Emergency Management Practice: The Essentials.* Rome. 131 pp. (available at <http://www.fao.org/3/a-ba0137e.pdf>).
- FAO. 2013.** *Réponse à l'invasion acridienne. Programme – Campagne n° 1 2013/2014.* 34 pp. (available at http://www.fao.org/fileadmin/user_upload/emergencies/docs/Madagascar_FAO_Programme_Campagne_No1_2013-2014.pdf).
- FAO. 2015a.** *Réponse à l'invasion acridienne. Programme – Campagne n° 2 2014/2015.* 51 pp. (available at <http://www.fao.org/3/a-bl262f.pdf>).
- FAO. 2015b.** *Réponse à l'invasion acridienne. Programme – Campagne n° 3 Septembre 2015 à juin 2016.* (available at <http://www.fao.org/resilience/resources/ressources-detail/fr/c/345294/>).
- FAO. 2016a.** *FAO Animal Production and Health Guidelines n. 18: Economic analysis of animal diseases.* Rome. 94 pp. (available at <http://www.fao.org/3/a-i5512e.pdf>).
- FAO. 2016b.** *FCC–Empres Information Sheet 11: FAO and OIE to Eradicate the Small Ruminants Plague: Peste des Petits Ruminants.* Rome. 2 pp. (available at <http://www.fao.org/3/a-i6566e.pdf>).
- FAO. 2016c.** “Notes on an Information System on Damage and Losses from Disasters on Crops, Livestock, Fisheries and Forestry. A Strategic Programme 5 – Resilience Initiative.” *FAO Statistics Division Working Paper Series ESS/11–16.* Rome, FAO. 29 pp. (available at <http://www.fao.org/3/i5659e/i5659e.pdf>).

- FAO. 2017a.** *Averting Risks to the Food Chain. A compendium of proven emergency prevention methods and tools.* Rome. 108 pp. (available at <http://www.fao.org/3/b-i6538e.pdf>).
- FAO. 2017b.** *Counting the Cost: Agriculture in Syria after Six Years of Crisis.* Rome. 20 pp. (available at <http://www.fao.org/3/b-i7081e.pdf>).
- FAO. 2017c.** *Handbook on remote sensing for agricultural statistics.* Rome. 287 pp. (available at <http://www.fao.org/3/ca6394en/ca6394en.pdf>).
- FAO. 2017d.** *Strategic work of FAO to Increase the Resilience of Livelihoods.* Rome. 28 pp. (available at <http://www.fao.org/3/a-i6463e.pdf>).
- FAO. 2018a.** *The Global Foot and Mouth Disease Control Strategy.* Rome. 2 pp. (available at <http://www.fao.org/3/i9857en/i9857EN.PDF>).
- FAO. 2018b.** *The impact of disasters and crises on agriculture and food security.* Rome. 168 pp. (available at <http://www.fao.org/3/l8656EN/i8656en.pdf>).
- FAO. 2018c.** *The State of the World's Forests. Forest Pathways to Sustainable Development.* Rome. 139 pp. (available at <http://www.fao.org/3/i9535en/i9535en.pdf>).
- FAO. 2019a.** *Disaster risk reduction at farm level: Multiple benefits no regrets.* Rome. 160 pp. (available at <http://www.fao.org/publications/card/en/c/CA4429EN/>).
- FAO. 2019b.** *Forests for resilience to natural, climate and human-induced disasters and crises* [online]. [Cited 30 December 2020]. 6 pp. <http://www.fao.org/3/ca6920en/CA6920EN.pdf>
- FAO. 2019c.** *H5N8 HPAI Global Situation Update* [online]. [Cited 30 December 2020]. http://www.fao.org/ag/againfo/programmes/en/empres/H5N8/situation_update.html
- FAO. 2019d.** *The State of Food and Agriculture. Moving Forward on Food Loss and Waste Reduction.* Rome. 182 pp. (available at <http://www.fao.org/3/ca6030en/ca6030en.pdf>).
- FAO. 2020a.** *Coronavirus disease 2019 (COVID-19). Addressing the impacts of COVID-19 in food crises (April–December 2020) – May update.* Rome. 20 pp. (available at <http://www.fao.org/in-action/kore/publications/publications-details/en/c/1276175/>).
- FAO. 2020b.** *COVID-19: Channels of transmission to food and agriculture.* Rome. 44 pp. (available at <http://www.fao.org/documents/card/en/c/ca8430en/>).
- FAO. 2020c.** *Fisheries Emergency Rapid Assessment Tool (FERAT).* Rome. 74 pp. (available at <http://www.fao.org/documents/card/en/c/ca8261en/>).
- FAO. 2020d.** *Global Forest Resource Assessment 2020.* Rome. 184 pp. (available at <http://www.fao.org/documents/card/en/c/ca9825en/>).
- FAO. 2020e.** *Rapid Assessment of Food and Nutrition Security in the context of COVID-19 in Bangladesh, May 2020.* 19 pp. (available at https://fscluster.org/sites/default/files/documents/fao_bangladesh_covid-19_rapid_assessment_report_09-05-2020_final13may2020.pdf).
- FAO. 2020f.** *The State of World Fisheries and Aquaculture 2020. Sustainability in Action.* Rome. 244 pp. (available at <http://www.fao.org/3/ca9229en/CA9229EN.pdf>).
- FAO. N.d.** *Climate change and transboundary pests and diseases.* Rome. 2 pp. (available at <http://www.fao.org/tempref/docrep/fao/010/i0142e/i0142e06.pdf>).
- FAO & IOM. 2007** *Assessment of fuel wood supply and demand in displacement settings and surrounding areas in Cox's Bazar District (revised).* 96 pp. (available at https://fscluster.org/rohingya_crisis/document/assessment-fuel-wood-supply-and-demand).
- FAO & UNEP. 2020.** *The State of the World's Forests 2020. Forests, biodiversity and people.* Rome. 214 pp. (available at <http://www.fao.org/3/ca8642en/ca8642en.pdf>).
- FAO & WFP. 2010.** *The State of Food Security and Nutrition in the World. Addressing food insecurity in protracted crises.* Rome. 62 pp. (available at <http://www.fao.org/3/a-i1683e.pdf>).

- FAO & WFP. 2013.** *Rapport spécial – Mission FAO/PAM d'évaluation de la sécurité alimentaire à Madagascar*. 75 pp. (available at <http://www.fao.org/3/a-aq115f.pdf>).
- FAO & WFP. 2014.** *Rapport spécial – mission FAO/PAM d'évaluation de la sécurité alimentaire à Madagascar*. 71 p. (available at <http://www.fao.org/3/a-l4111f.pdf>).
- FAO & WFP. 2015.** *Rapport spécial – mission FAO/PAM d'évaluation de la sécurité alimentaire à Madagascar*. 77 pp. (available at <http://www.fao.org/3/a-i5082f.pdf>).
- FAO & WFP. 2016.** *Rapport spécial – mission FAO/PAM d'évaluation de la sécurité alimentaire à Madagascar*. 94 pp. (available at <http://www.fao.org/3/a-i6335f.pdf>).
- FAO & WHO. 2016.** *UN Decade of Action on Nutrition (2016–2025)* [online]. [Cited 30 December 2020]. <http://www.fao.org/3/a-i6130e.pdf>
- FAO, IFAD, UNICEF, WFP & WHO. 2018.** *The State of Food Security and Nutrition in the World. Building Climate Resilience for Food Security and Nutrition*. Rome. 202 pp. (available at <http://www.fao.org/3/i9553en/i9553en.pdf>).
- FAO, IFAD, UNICEF, WFP & WHO. 2019.** *The State of Food Security and Nutrition in the World. Safeguarding Against Economic Slowdowns and Downturns*. Rome. 239 pp. (available at <http://www.fao.org/3/ca5162en/ca5162en.pdf>).
- FAO, IFAD, UNICEF, WFP & WHO. 2020.** *The State of Food Security and Nutrition in the World. Transforming Food Systems for Affordable Healthy Diets*. Rome. 320 pp. (available at <http://www.fao.org/3/ca9692en/CA9692EN.pdf>).
- FAO Regional Conference for Europe. 2020.** *FAO's Hand-in-Hand Initiative: a New Approach (ERC/20/12 Rev. 1)*. 14 pp. (available at <http://www.fao.org/3/nc347en/nc347en.pdf>).
- Gall, M. 2015.** “The suitability of disaster loss databases to measure loss and damage from climate change.” *International Journal of Global Warming* 8(2): 170-190. (available at https://www.researchgate.net/publication/273451486_The_suitability_of_disaster_loss_databases_to_measure_loss_and_damage_from_climate_change).
- GFDRR. 2020.** *Natural disaster challenges in China: key trends and insights* [online]. [Cited 30 December 2020]. <https://www.gfdr.org/en/feature-story/natural-disaster-challenges-china-key-trends-and-insights>
- GNAFC & FSIN. 2020.** *Global Report on Food Crises 2020*. 240 pp. (available at https://www.fsinplatform.org/sites/default/files/resources/files/GRFC_2020_ONLINE_200420.pdf).
- Grossi, G., Goglio, P., Vitali, A. & Williams, A.G. 2019.** “Livestock and climate change: impact of livestock on climate and mitigation strategies.” *Animal Frontiers* 9: 69–76. (available at <http://www.fao.org/3/a-i6345e.pdf>).
- Helms, J.A. 1998.** *The Dictionary of Forestry*. Bethesda, USA, CAB & the Society of American Foresters. 210 pp.
- Hirata, A., Nakamura K., Nakao, K., Kominami, Y., Tanaka, N., Ohashi, H., Takano, K.T., Takeuchi, W. & Matsui, T. 2017.** “Potential distribution of pine wilt disease under future climate change scenarios.” *PLoS One* 12(8): e0182837. (available at <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0182837>).
- Hussain, M., Irshad, H. & Khan, M.Q. 2008.** “Laboratory Diagnosis of Transboundary Animal Diseases in Pakistan.” *Transboundary and Emerging Diseases* 55(5–6): 190–195. (available at https://www.researchgate.net/publication/23137381_Laboratory_Diagnosis_of_Transboundary_Animal_Diseases_in_Pakistan).
- IACC. 2019.** *No Time to Wait: Securing the Future from Drug-Resistant Infections. Report to the Secretary-General of the United Nations April 2019*. 28 pp. (available at https://www.who.int/antimicrobial-resistance/interagency-coordination-group/IACG_final_report_EN.pdf).
- 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: 5405–5417. (available at <https://rmets.onlinelibrary.wiley.com/doi/10.1002/joc.5818>).
- ILO, FAO, IFAD & WHO. 2020.** *Joint statement 13 October 2020: Impact of COVID-19 on people's livelihoods, their health and our food systems* [online]. [Cited 30 December 2020]. <http://www.fao.org/news/story/en/item/1313598/icode/>

- INSTAT Madagascar. 2013.** *Enquête Nationale sur le Suivi des Objectifs du Millénaire pour le Développement à Madagascar. Résumé des rapports sur l'ensomid 2012–2013.* 64 pp. (available at https://madagascar.unfpa.org/sites/default/files/pub-pdf/OMD_Resume.pdf).
- IPCC. 2012.** *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* New York, USA, Cambridge University Press. 594 pp. (available at https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_Full_Report-1.pdf).
- IPCC. 2014.** *Fifth Assessment Report (AR5) – Climate Change 2014: Synthesis Report.* Geneva, Switzerland. 169 pp. (available at https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf).
- IPCC. 2018.** *Global Warming of 1.5 C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Geneva, Switzerland. 138 pp. (available at <https://www.ipcc.ch/sr15/chapter/chapter-3/>).
- IPCC. 2019.** *Special Report on the Ocean and Cryosphere in a Changing Climate.* Geneva, Switzerland. 1189 pp. (available at <https://www.ipcc.ch/srocc/>).
- IUCN. 2012.** *Guide to some invasive plants affecting Lake Tanganyika.* Nairobi. 64 pp. (available at http://www.invassep.eu/invassep_eng/Invasive%20plant%20of%20from%20Tanganika%20Lake%202012-048.pdf).
- James, R.A., Jones, R.G., Boyd, E., Young, H.R., Otto, F.E.L., Huggel, C. & Fuglestedt, J.S. 2019.** “Attribution: How Is It Relevant for Loss and Damage Policy and Practice?” Mechler, R., *et al.*, eds. *Loss and Damage from Climate Change: Concepts, Methods and Policy Options*, pp. 113–154. Cham, Switzerland. (available at https://link.springer.com/chapter/10.1007/978-3-319-72026-5_5).
- Jézéquel, A., Dépoues, V. Guillemot, H., Trolliet, M., Vanderlinden, J.-P. & You, P. 2018.** “Behind the veil of extreme event attribution.” *Climatic Change* 149 (2018): 367–383. (available at <https://link.springer.com/article/10.1007/s10584-018-2252-9>).
- Jha, R.K., Singh, A., Tewari, A., Shrivastava, P. 2015.** “Performance Analysis of Disaster Management using WSN technology.” *Procedia Computer Science* 49: 162–169. (available at <https://www.sciencedirect.com/science/article/pii/S1877050915007498>).
- Kawase, H., Imada, Y., Tsuguti, H., Nakaegawa, T., Seino, N., Murata, A. & Takayabu, I. 2020.** “The heavy rain event of July 2018 in Japan enhanced by historical warming.” In *Explaining Extreme Events of 2018 from a Climate Perspective. Special Supplement to the Bulletin of the American Meteorological Society*, vol. 101(1), S109–S114. (available at <https://journals.ametsoc.org/bams/article/101/1/S1/346398/Explaining-Extreme-Events-of-2018-from-a-Climate>).
- Khomenko, S., Abolnik, C., Roberts, L., Waller, L. et al. 2018.** “2016–2018 Spread of H5N8 highly pathogenic avian influenza (HPAI) in sub-Saharan Africa: epidemiological and ecological observations.” *Focus On* n. 12. Rome, FAO. 20 pp. (available at <http://www.fao.org/3/ca1209en/CA1209EN.pdf>).
- Kim, W., Iizumi, T. & Nishimori, M. 2019.** “Global Patterns of Crop Production Losses Associated with Droughts from 1983 to 2009.” *Journal of Applied Meteorology and Climatology* 58(6): 1233–1244. (available at <https://doi.org/10.1175/JAMC-D-18-0174.1>).
- Kirchmeier-Young, M.C., Gillett, N.P., Zwiers, F.W., Cannon, A.J. & Anslow, F.S. 2019.** “Attribution of the Influence of Human-Induced Climate Change on an Extreme Fire Season.” *Earth’s Future* 7(1): 2–10. (available at <https://doi.org/10.1029/2018EF001050>).
- Knutson, T., Kossin, J., Mears, C., Perlwitz, J. & Wehner, M. 2017.** “Detection and attribution of climate change.” In: *Climate Science Special Report: A Sustained Assessment Activity of the U.S. Global Change Research Program.* Wuebbles, D.J. *et al.*, eds. Washington, DC, U.S. Global Change Research Program, pp. 162–185. (available at <https://digitalcommons.unl.edu/usdeptcommercepub/590/>).
- Latchininsky, A.V. 2013.** “Locusts and remote sensing: a review.” *Journal of Applied Remote Sensing* 7(1): 075099. (available at <https://www.spiedigitallibrary.org/journals/journal-of-applied-remote-sensing/volume-7/issue-01/075099/Locusts-and-remote-sensing-a-review/10.1117/1.JRS.7.075099.full?SSO=1>).

- Lecoq, M. 2001.** “Recent progress in Desert and Migratory Locust management in Africa. Are preventative actions possible?” *Journal of Orthoptera Research* 10(2): 277–291.
(available at https://www.researchgate.net/publication/232689583_Recent_progress_in_Desert_and_Migratory_Locust_management_in_Africa_Are_preventative_actions_possible).
- Lecoq, M., Andriamaroahina, T.R.Z., Solofonaina, H. & Gay, P.-E. 2011.** “Ecology and Population Dynamics of Solitary Red Locusts in Southern Madagascar.” *Journal of Orthoptera Research* 20(2): 141–158.
(available at <https://doi.org/10.1665/034.020.0202>).
- Lee, R.U., Read, A., Marttin, F., Poulain, F. & Funge-Smith, S. 2020.** *Fisheries Emergency Rapid Assessment Tool (FERAT)*. Rome, FAO. 74 pp. (available at <http://www.fao.org/3/ca8261en/CA8261EN.pdf>).
- Lesk, C., Rowhani, P. & Ramankutty, N. 2016.** “Influence of extreme weather disasters on global crop production.” *Nature* 529: 84–87. (available at <https://www.nature.com/articles/nature16467>).
- Lewis, S. C. & Mallela, J. 2018.** “A multifactor risk analysis of the record 2016 Great Barrier Reef bleaching.” *Bulletin of the American Meteorological Society (BAMS)* 99: 145–149.
(available at <https://pdfs.semanticscholar.org/5431/9c05373463cf37083e0041a717945b5b05f4.pdf>).
- Li, M., Liu, H., Bi, Y. et al. 2017.** “Highly Pathogenic Avian Influenza A (H5N8) Virus in Wild Migratory Birds, Qinghai Lake, China.” *Emerging Infectious Diseases* 23(4): 637–641.
(available <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5367427/>).
- Lin, Y., Fissel, D.B., Mudge, T. & Borg, K. 2018.** “Baroclinic Effect on Modeling Deep Flow in Brown Passage, BC, Canada.” *Journal of Marine Science and Engineering* 6(4): 117. 21 pp.
(available at <https://www.mdpi.com/2077-1312/6/4/117>).
- Lobell, D.B. & Field, C.B. 2007.** “Global scale climate – crop yield relationships and the impacts of recent warming.” *Environmental Research Letters* 2: 014002. 2 pp. (available at <https://iopscience.iop.org/article/10.1088/1748-9326/2/1/014002/meta>).
- Lobell, D.B., Schlenker, W. & Costa-Roberts, J. 2011.** “Climate trends and global crop production since 1980.” *Science* 333(6042): 616–620. (available at <https://science.sciencemag.org/content/333/6042/616>).
- Mangani, R., Tesfamariam, E. H., Engelbrecht, C.J., Bellocchi, G., Hassen, A. & Mangani, T. 2019.** “Potential impacts of extreme weather events in main maize (*Zea mays* L.) producing areas of South Africa under rainfed conditions.” *Regional Environmental Change* 19: 1441–1452.
(available at <https://link.springer.com/article/10.1007/s10113-019-01500-z>).
- McKinsey & Company. 2020.** *Safeguarding Africa’s food systems through and beyond the crisis* [online]. [Cited 30 December 2020]. <https://www.mckinsey.com/featured-insights/middle-east-and-africa/safeguarding-africas-food-systems-through-and-beyond-the-crisis>
- Meiyan, J., Lianchun, S., Tong, J., Di, Z. & Jianqing, Z. 2015.** “China’s Implementation of Impact and Risk-based Early Warning.” *Bulletin* 64(2): 11–14. (available at https://library.wmo.int/index.php?lvl=notice_display&id=19039).
- Ministry of Livestock, Agriculture and Fisheries of Uruguay (MGAP). 2019.** *Plan Nacional de Adaptación a la Variabilidad y el Cambio Climático para el Sector Agropecuario*. Montevideo, MGAP. 128 pp.
(available at https://www.gub.uy/ministerio-ganaderia-agricultura-pesca/sites/ministerio-ganaderia-agricultura-pesca/files/documentos/noticias/pna-agro-digital_o.pdf).
- Mota, M.M. & Vieira, P., eds. 2008.** *Pine wilt disease: a worldwide threat to forest ecosystems*. Dordrecht, Netherlands, Springer. 424 pp.
- Naithani, J., Deleersnijder, E. & Plisnier, P.-D. 2003.** “Analysis of Wind-Induced Thermocline Oscillations of Lake Tanganyika.” *Environmental Fluid Mechanics* 3: 23–39. (available at <https://link.springer.com/article/10.1023/A:1021116727232>).
- National Academies of Sciences, Engineering, and Medicine. 2016.** *Attribution of Extreme Weather Events in the Context of Climate Change*. Washington, DC, The National Academies Press. 186 pp.
(available at <https://doi.org/10.17226/21852>).

- OCHA. 2020.** *Global Humanitarian Response Plan. COVID-19. United Nations Coordinated Appeal April – December 2020, May Update.* Geneva, Switzerland. 79 pp. (available at https://www.unocha.org/sites/unocha/files/GHRP-COVID19_May_Update.pdf).
- Ohta, T. 2012.** *The role of forests in the Great East Japan Earthquake and sustainable forest management and its usage. Keynote speech delivered at the International Seminar on Role of Forests in Natural Disasters and Revival of Forests and Forestry* [online]. [Cited 30 November 2020]. 7 pp. https://www.rinya.maff.go.jp/j/kaigai/pdf/keynote_final_english.pdf
- OIE & FAO. 2015.** *Global Strategy for the Control and Eradication of PPR.* Paris, OIE & FAO. 88 pp. (available at <http://www.fao.org/3/a-i4460e.pdf>).
- OIE. 2020.** *Foot & Mouth disease (FMD)* [online]. [Cited 30 December 2020]. <https://www.oie.int/en/animal-health-in-the-world/animal-diseases/foot-and-mouth-disease/>
- Otto, F.E.L., Boyd, E., Jones, R.G., Cornforth, R.J., James, R., Parker, H.R. & Allen, M.R. 2015.** “Attribution of extreme weather events in Africa: a preliminary exploration of the science and policy implications.” *Climatic Change* 132: 531–543. (available at <https://link.springer.com/article/10.1007/s10584-015-1432-0>).
- Otto, F.E.L., James, R. & Allen, M. 2014.** *The science of attributing extreme weather events and its potential contribution to assessing loss and damage associated with climate change impacts.* Oxford, UK. 4 pp. (available at https://unfccc.int/files/adaptation/workstreams/loss_and_damage/application/pdf/attributingextremeevents.pdf).
- Otto, F.E.L., van Oldenborgh, G.J., Eden, J., Stott, P.A., Koroly, D.J. & Myles, R.A. 2016.** “The attribution question.” *Nature Climate Change* 6: 813–816. (available at <https://www.nature.com/articles/nclimate3089>).
- Padère, J.-P. 2014.** “Improving animal health and livestock productivity to reduce poverty.” *Revue scientifique et technique (International Office of Epizootics)* 33(3): 735–744, 723–744. (available at <https://pubmed.ncbi.nlm.nih.gov/25812201/>).
- Pearse, P.H. 1990.** *Introduction to Forestry Economics.* Vancouver, Canada, UBC Press. 226 pp.
- Pidcock, R., Pearce, R. & McSweeney, R. 2020.** *Mapped: How climate change affects extreme weather around the world* [online]. [Cited 30 December 2020]. <https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world>
- Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O’Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T. & Tsomondo, T. 2001.** “Economic and environmental threats of alien plant, animal, and microbe invasions.” *Agriculture, Ecosystems and Environment* 84: 1–20. (available at <https://www.sciencedirect.com/science/article/abs/pii/S01678809000178X>).
- Ramlogan, N.R., McConney, P. & Oxenford, H.A. 2017.** “Socio-economic impacts of Sargassum influx events on the fishery castor of Barbados” [online]. *CERMES Technical Report* no. 81. Cave Hill, Barbados, CERMES. [Cited 30 December 2020]. 2 pp. https://www.cavehill.uwi.edu/cermes/getdoc/ceecd5b8-2111-4fc9-b481-9b-18d9e785bd/ramlogan_et_al_2017_sargassum_influx_barbados_fish.aspx
- Roberts, E.L. & Huq, S. 2015.** “Coming full circle: The history of loss and damage under the UNFCCC.” *International Journal of Global Warming* 8(2): 141–157. (available at <https://pdfs.semanticscholar.org/0e8d/98cd9b53c74da7138eea8fd48f7f6118ed3f.pdf>).
- Robinet, C., Roques, A., Pan, H., Fang, G., Ye, J., Zhang, Y. & Sun, J. 2009.** “Role of human-mediated dispersal in the spread of the pinewood nematode in China.” *PLoS One* 4(2): e4646. (available at <https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0004646&type=printable>).
- Sakamoto, T. 2012.** *Regeneration of coastal forests affected by tsunami* [online]. Tsukuba, Japan, FFPRI. [Cited 30 November 2020]. 27 pp. (available at <https://www.ffpri.affrc.go.jp/pubs/chukiseika/document-s/3rd-chuukiseika29.pdf>).
- Savary, S., Willcoquet, L., Pethybridge, S.J., Esker, P., McRoberts, N. & Nelson, A. 2019.** “The global burden of pathogens and pests on major food crops.” *Nature Ecology & Evolution* 3(3): 430–439. (available at <https://www.nature.com/articles/s41559-018-0793-y>).

- Shepherd, T.G., Boyd, E., Calel, R.A., Chapman, S. et al. 2018.** “Storylines: an alternative approach to representing uncertainty in physical aspects of climate change.” *Climatic Change* 151 (3): 155–571. (available at <https://link.springer.com/article/10.1007/s10584-018-2317-9>).
- Soliman, T., Mourits, M.C.M., van der Werf, W., Hengeveld, G.H., Robinet, C. & Oude Lansik, A.G.J.M. 2012.** “Framework for modelling economic impacts of invasive species, applied to pine wood nematode in Europe.” *PLoS One* 7(9):e455505. (available at <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0045505>).
- Springgay, E., Ramirez, S.C., Janzen, S. & Brito, V.V. 2019.** “The Forest-Water Nexus: An International Perspective.” *Forests* 10(10), 915. (available at <https://www.mdpi.com/1999-4907/10/10/915>).
- Spurrier, L., Van Breda, A., Martin, S., Bartlett, R. & Newman, K.** “Nature-based solutions for water-related disasters.” *Unasylva* 251: 67. (available at <http://www.fao.org/3/ca6842en/CA6842EN.pdf>).
- Stott, P.A. 2016.** “How climate change affects extreme weather events.” *Science* 352 (6293): 1517–1518. (available at <https://science.sciencemag.org/content/352/6293/1517>).
- Stott, P.A., Christidis, N., Otto, F.E.L., Sun, Y., Vanderlinden, J.-P., van Oldenborgh, G.J., Vautard, R., von Storch, H., Walton, P. Yiou, P. & Swiers, F.W. 2016.** “Attribution of extreme weather and climate-related events.” *WIREs Climate Change* 7(1): 23–41. (available at <https://onlinelibrary.wiley.com/doi/epdf/10.1002/wcc.380>).
- 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* 9, article n. 12834. (available at <https://www.nature.com/articles/s41598-019-49167-0>).
- Szomiński, S., Kaleta, Z., Turek, W., & Cetnarowicz, K. 2015.** “Predictive Planning Method for Rescue Robots in Buildings.” 2015 IEEE International Symposium on Robotics and Intelligent Sensors (IEEE IRIS2015). *Procedia Computer Science* 76: 539 – 546. (available at <https://www.sciencedirect.com/science/article/pii/S1877050915038417>).
- Tadokoro, S. 2016.** *Disaster Robotics for the Disaster Risk Reduction* [online]. Sendai, Japan, International Research Institute of Disaster Science, Tohoku University. [Cited 30 December 2020]. https://www.preventionweb.net/files/45270_070.pdf
- UN Secretary-General. 18 May 2020.** *Remarks to the World Health Assembly, 18 May 2020* [online]. [Cited 30 December 2020]. <https://www.un.org/sg/en/content/sg/statement/2020-05-18/secretary-generals-remarks-the-world-health-assembly-bilingual-delivered-scroll-down-for-english-and-french-version>
- UN. 2015.** *Addis Ababa Action Agenda of the Third International Conference on Financing for Development*. New York, USA. 68 pp. (available at https://sustainabledevelopment.un.org/content/documents/2051AAAA_Outcome.pdf).
- UN. 2020.** *Shared Responsibility, Global Solidarity: Responding to the socio-economic impacts of COVID-19* [online]. [Cited 30 December 2020]. 26 pp. https://www.un.org/sites/un2.un.org/files/sg_report_socio-economic_impact_of_covid19.pdf
- UNDRR. 2019.** *The Global Assessment Report on Disaster Risk Reduction 2019*. Geneva, Switzerland. 425 pp. (available at <https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019>).
- UNEP, CAR–SPAW–RAC. 2016.** *Sargassum influx in the wider Caribbean region* [online]. Guadeloupe, France. [Cited 30 December 2020]. 2 pp. https://wedocs.unep.org/bitstream/handle/20.500.11822/27269/caribbean_sargassum_summary.pdf?sequence=1&isAllowed=y
- UNEP. 2016.** *Loss and Damage: The Role of Ecosystem Services*. Nairobi. 84 pp. (available at https://uneplive.unep.org/media/docs/assessments/loss_and_damage.pdf).
- UNESCAP. 2016.** *ICT in Disaster Risk Management Initiatives in Asia and the Pacific*. Bangkok, Thailand, UNESCAP. 28 pp. (available at <https://www.unclearn.org/wp-content/uploads/library/ict.pdf>).
- UNFCCC. 2013.** *Non-economic losses in the context of the work programme on loss and damage. Technical paper*. FCCC/TP/2013/2. Bonn, Germany. 65 pp. (available at <https://unfccc.int/resource/docs/2013/tp/02.pdf>).

- UNFCCC. 2020.** *Loss and Damage Online Guide* [online]. Bonn, Germany. [Cited 30 December 2020]. 37 pp. https://unfccc.int/sites/default/files/resource/Online_Guide_feb_2020.pdf
- 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(7): 78–88. (available at <https://www.sciencedirect.com/science/article/pii/S0378112715003369>).
- Weisse, M. & Goldman, L. 2020.** “We Lost a Football Pitch of Primary Rainforest Every 6 seconds in 2019,” [online]. *Global Forest Watch* (blog), 2 June 2020. [Cited 30 December 2020]. <https://blog.globalforestwatch.org/data-and-research/global-tree-cover-loss-data-2019>
- Welcomme, R.L. 2003.** “Data Requirements for Inland Fisheries Management.” In *New Approaches for the Improvement of Inland Capture Fishery Statistics in the Mekong Basin* [online]. Rome, FAO. [Cited 30 December 2020]. <http://www.fao.org/3/ado70e/ado70e09.htm>
- WMO. 2019.** *WMO Statement on the State of the Global Climate in 2018*. Geneva, Switzerland. 44 pp. (available at https://library.wmo.int/doc_num.php?explnum_id=5789).
- WMO. 2020a.** *WMO Statement on the State of the Global Climate in 2019*. Geneva, Switzerland. 44 pp. (available at https://library.wmo.int/doc_num.php?explnum_id=10211).
- WMO. 2020b.** *2020 State of Climate Services Report. Risk Information and Early Warning Systems*. Geneva, Switzerland. 25 pp. (available at https://library.wmo.int/doc_num.php?explnum_id=10385).
- World Bank. 2010.** *People, Pathogens and Our Planet, vol. 1: Towards a One Health Approach for Controlling Zoonotic Diseases*. Washington, DC. 74 pp. (available at <http://documents1.worldbank.org/curated/en/214701468338937565/pdf/508330ESW0whit1410Bo1PUBLIC1PPP1Web.pdf>).
- World Bank. 2012.** *People, Pathogens and Our Planet, vol. 2: The Economics of One Health*. Washington, DC. 65 pp. (available at <http://documents1.worldbank.org/curated/en/612341468147856529/pdf/691450ESW0whitoDoESW12oPPPvol12oweb.pdf>).
- World Bank. 2017.** *Drug-Resistant Infections: A Threat to Our Economic Future*. Washington, DC. 172 pp. (available at <http://documents1.worldbank.org/curated/en/323311493396993758/pdf/final-report.pdf>).
- World Bank. 2019.** *Pulling Together to Beat Superbugs. Knowledge and Implementation Gaps in Addressing Antimicrobial Resistance*. Washington, D.C. 95 pp. (available at <http://documents1.worldbank.org/curated/en/430051570735014540/pdf/Pulling-Together-to-Beat-Superbugs-Knowledge-and-Implementation-Gaps-in-Addressing-Antimicrobial-Resistance.pdf>).
- World Bank. 2020.** *The Global Economic Outlook During the COVID-19 Pandemic: A Changed World* [online]. Washington, DC. [Cited 30 December 2020]. <https://www.worldbank.org/en/news/feature/2020/06/08/the-global-economic-outlook-during-the-covid-19-pandemic-a-changed-world>
- World Bank & FAO. 2020.** *Assessment of Forest Resource Degradation and Intervention Options in Refugee-Hosting Areas of Western and Southwestern Uganda*. Washington, DC & Rome. 92 pp. (available at <http://www.fao.org/3/ca7832en/CA7832EN.pdf>).
- Zhai, P. M., Zhou, B. Q. & Chen, Y. 2018.** “A review of climate change attribution studies.” *Journal of Meteorological Research* 32: 671–692. 21 pp. (available at <https://link.springer.com/article/10.1007/s13351-018-8041-6>).
- Zhang, D. & Pearse, P.H. 2011.** *Forest Economics*. Vancouver & Toronto, Canada, UBC Press. 390 pp.
- Zhao, B.G. 2008.** “Pine wilt disease in China.” In *Pine wilt disease*, pp. 18–25. Zhao, B.G. & Futai, K., Sutherland, J.R. & Takeuchi, Y., eds. Tokyo, Springer.

The impact of disasters and crises on agriculture and food security, 2021

On top of a decade of exacerbated disaster loss, exceptional global heat, retreating ice and rising sea levels, humanity and our food security face a range of new and unprecedented hazards, such as megafires, extreme weather events, desert locust swarms of magnitudes previously unseen, and the COVID-19 pandemic. At no other point in history has agriculture been faced with such an array of familiar and unfamiliar risks, interacting in a hyperconnected world and a precipitously changing landscape. And agriculture continues to absorb a disproportionate share of the damage and loss wrought by disasters. Their growing frequency and intensity, along with the systemic nature of risk, are upending people's lives, devastating livelihoods, and jeopardizing our entire food system. This report makes a powerful case for investing in resilience and disaster risk reduction – especially data gathering and analysis for evidence-informed action – to ensure agriculture's crucial role in achieving the future we want.



ISBN 978-92-5-134071-4



9 789251 340714

CB3673EN/1/03.21