IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems

Summary for Policymakers

First Draft for Expert and Government review

Date of Draft: 19th November 2018

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Introduction

This report responds to proposals from governments and observer organisations made at the start of the IPCC Sixth Assessment cycle.[1] It assesses sustainable land management, climate adaptation and mitigation responses to the challenges of desertification, land degradation and food security, in the context of sustainable development. The report sits alongside other IPCC reports, notably the *Special Report on Global Warming of 1.5°C*, and related reports from other UN Bodies.[2] It has been produced with careful attention to these other assessments with the aim of achieving coherence and complementarity, as well as providing an updated assessment of the current state of knowledge.[3]

This Summary for Policymakers (SPM) is structured in four parts: A) *land and atmosphere interactions in a changing climate*; B) *adaptation and mitigation response options*; C) *enabling climate mitigation and adaptation responses in the context of desertification, land degradation and food security*; and D) *opportunities for immediate action*. Confidence in key findings is indicated using the IPCC calibrated language[4]; the underlying scientific basis of each key finding is indicated by references provided to chapter elements.

[1] Footnote: The relevant proposals were: Climate Change and Desertification; Desertification with Regional Aspects; Land Degradation – An Assessment of the Inter-linkages and Integrated Strategies for Mitigation and Adaptation; Agriculture, Forestry and Land Use; Climate Change, Food and Agriculture; and Food Security and Climate Change.

[2] Footnote: Related reports from other UN Bodies include the thematic assessment of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) on Land Degradation and Restoration and the Global Land Outlook of the UN Convention to Combat Desertification (UNCCD

[3] Footnote: The assessment covers literature accepted for publication by 7 April 2019.

[4] Footnote: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp

A. Land and atmosphere interactions in a changing climate

A1. Human well-being, land use and anthropogenic climate change are inextricably linked. Land management decisions not only affect the livelihoods of billions of people but they are projected to play an increasingly important role in responding to and adapting to climate change. {1.2.1, 1.2.2, 1.3.2, 2.4, 2.6, 7.4}

A1.1. By the end of the first decade of the 21st century, approximately 3 billion people derived their income and employment from agriculture-related activities which generated between 1% and 25% of countries' GDP. Agricultural systems are particularly sensitive to climate change and evidence suggests that, as global mean surface temperature increases, economic activity in all regions of the world will be affected, with lower income countries suffering the greatest negative impact. {1.2.1, 7.4.1, Figure SPM 2}

A1.2. The current extent of human land use, together with the large and rapidly increasing appropriation of the ecosystem services it provides, is unprecedented in human history (*very high confidence*). Of the total terrestrial surface area that is ice-free (~130MKm$^{2)}$ ~12% (~15.9Mkm^2) is cropland, ~25% (~32.7MKm^2) is used for intensive (~2%) and extensive (~23%) pasture, ~30% (40MKm^2) is covered by managed (21%) and natural (9%) forests. The remaining area (~33%) includes all other land types including urban areas (~0.6%, ~0.73MKm2) and deserts. {1.2.2, SPM Figure 2}

A1.3. Climate, alongside socio-economic drivers and land management decisions determines global and regional land cover. It is estimated that globally about 75% of the ice-free land area has been altered by human activity. At the same time, land cover influences global climate through biogeochemical processes, and regional climate through biogeophysical processes (*very high confidence*). {1.2.2, 2.4, 2.6.4}

A1.4. Most modelled pathways that limit global warming entail the large-scale deployment of land-based climate change mitigation measures (*high confidence*). Without the widespread uptake of sustainable land management, such deployment has the potential to jeopardise sustainable development and the achievement of the sustainable development goals (SDGs) that depend on land-based, ecosystem services (*high confidence*). {SR1.5; 1.3.2}

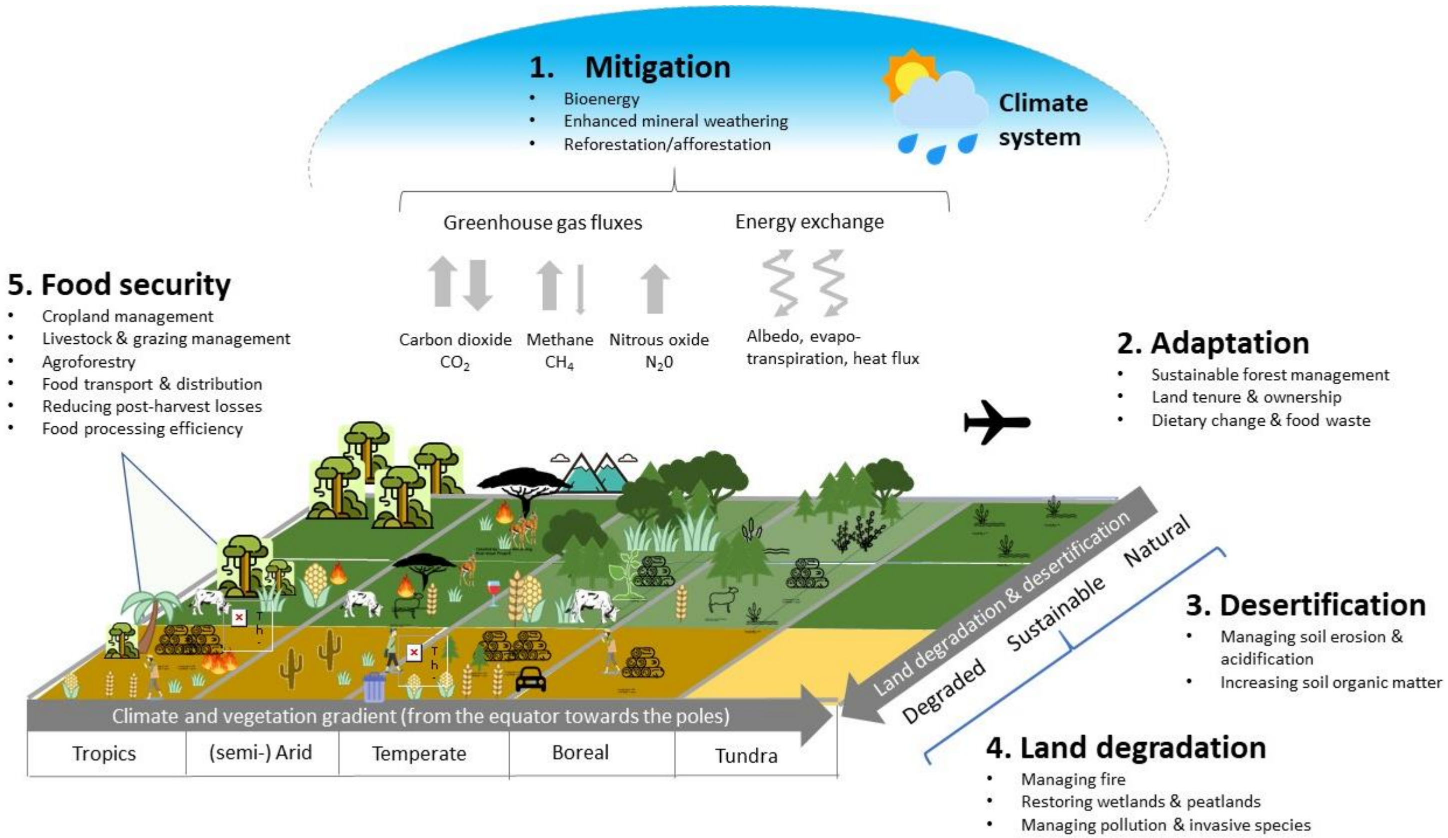


Figure SPM 1. Climate and land - challenges and land-climate system processes assessed in this report. The figure shows a stylised set of landscapes that reflect a generalised climate and vegetation gradient from the equator towards the poles. Each segment shows a specific climatic zone that is supports different biomes (ecosystem types), which are determined by the location along the gradient: tropics, (semi-)arid, temperate, boreal and tundra. The vegetation to the rear of the stylised landscape represents 'pristine' or natural ecosystems (i.e. with little or no human intervention), which become increasingly degraded and desertified toward the front of the landscape arising from increased (unsustainable) human pressures. For each land challenge (1. mitigation, 2. adaptation, 3. desertification, 4. land degradation and 5. food security) examples are given of the types of response options that are most relevant to that land challenge. Note, however, that the response options have an effect on all of the land challenges to different extents. The figure also demonstrates the key relationships between the land surface and the climate system including: greenhouse gas fluxes (principally CO_2, N_20 and CH_4) and energy exchanges between the land surface and the climate system through biogeophysical effects (albedo, evapotranspiration and heat flux). Some aspects of interplays are not represented (e.g. aerosols which also affect air quality).

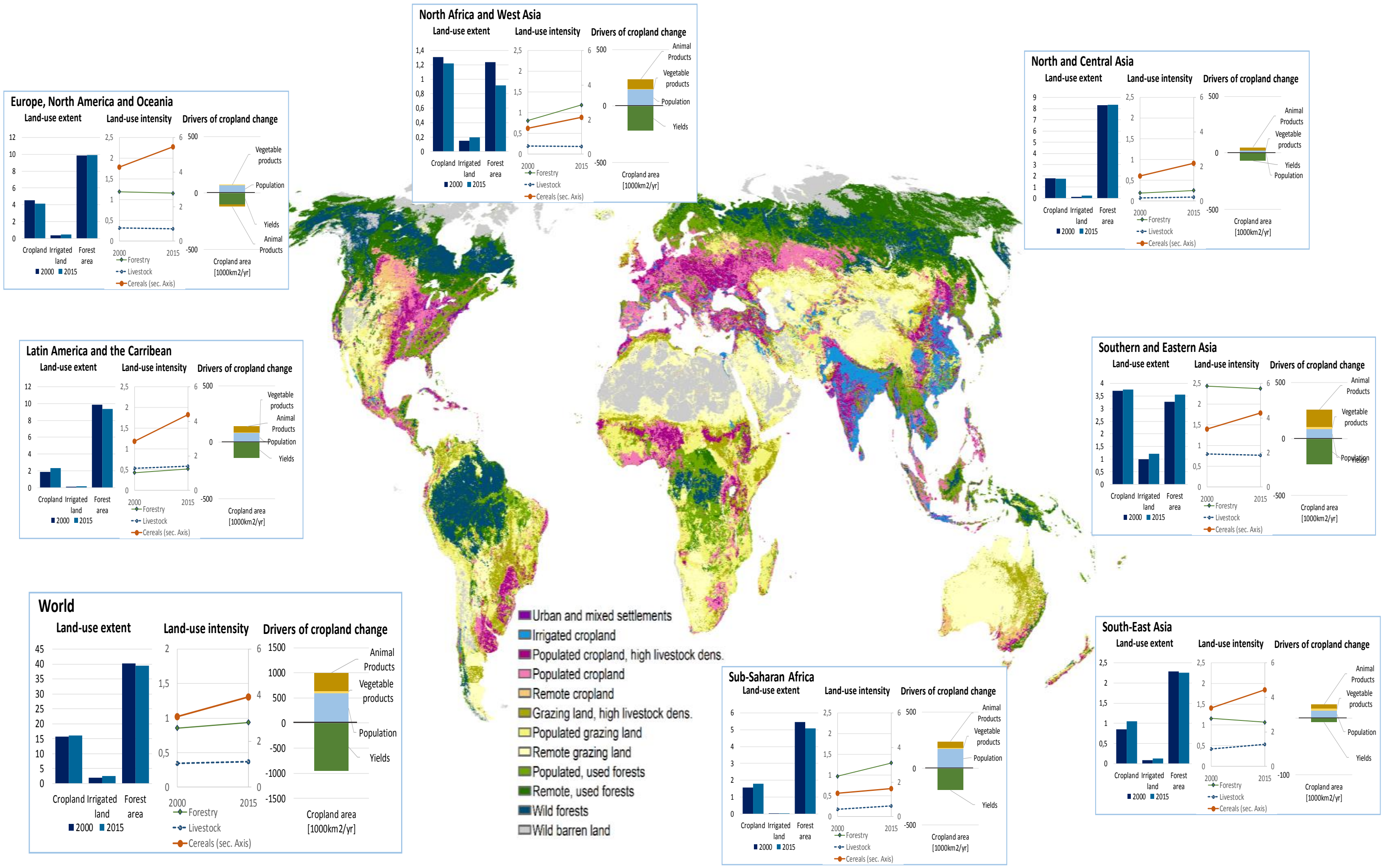


Figure SPM 2. Global land cover and trends.

The map shows the spatial pattern of land systems with livestock systems {1.2.2}. The inlay figures summarise key trends in the land systems and their drivers. Land use area change between 2000 and 2015 is displayed in Mkm² = 10^6 km²) and land use intensity is expressed with three indicators: cereal yields measured in tonnes ha^{-1} yr^{-1}, forest harvest in m³ ha^{-1}, and livestock density in Livestock Units per ha; all data (FAOSTAT 2018). Major drivers of the change in cropland area for food production, are expressed as annual average change of cropland in 10^3 km² between 1994 and 2011.

A2. Land resources are already under stress. A major cause of increasing pressure on land derives from population growth and changing consumption patterns, including increasing demand for animal-based food, feed, fibre, fuel and other ecosystem services. Climate change is an additional stress that exacerbates existing land degradation and desertification processes and threatens food security (*high confidence*). {1.2.2, 1.3.1, 4.3.1, 4.3.3}

A2.1. Human over-exploitation causes rapid depletion of land resources, reducing crop yields, freshwater access, and biodiversity in many regions (*high confidence*). Climate change interacts with human land use to exacerbate rates of land resource depletion (*virtually certain*). At the same time, land management decisions have the potential to contribute to climate change mitigation and adaptation (*high confidence*). {1.2.2, 1.3.2, 1.4.4}

A2.2. Climate change is already causing regional land cover zones to shift beyond the range of historical natural variability *(medium evidence, high agreement).* As global mean temperatures increase, tropical and sub-tropical regions will see the emergence of new hot climate zones in areas where rainfall is projected to decrease. In mid- and high- latitudes, climate zones will shift exposing regional ecosystems to disturbances beyond the range of current natural variability *(medium evidence, high agreement)* {2.3}. In high-latitude areas warming is projected to accelerate permafrost thawing and to increase disturbance in boreal forests through abiotic (e.g., drought, fire) and biotic (e.g., pests, disease) agents. In Arctic regions, warming-induced greening, northward migration of tree line and earlier thawing of snow and permafrost enhances local warming during winter, and spring (*robust evidence, high agreement*). {2.3.1, 2.3.2, 2.6.3}

A2.3. Climate change threatens to reduce the yield of staple food crops and each degree Celsius of global mean temperature increase is projected to reduce global yields of wheat by 6%, rice yields by 3.2%, and maize by 7.4%, while CO_2 fertilisation effects on vegetation will impact the nutritional content of crops, mostly negatively {7.3}. Changes in land-climate interactions as temperatures increase also introduce novel degradation pathways in wild and semi-natural ecosystems (*high confidence*). In high latitudes, land productivity may increase but the net balance of positive impacts of productivity in some regions and negative impacts in others is uncertain. There is, however, *high agreement* that the majority of the affected human populations directly affected are located in the global South (*medium evidence, high agreement*). {4.4.1, 4.4.2}

A3. Ongoing and future changes in regional climates are shaped not only by concentrations of greenhouse gases (GHGs) but by changes in local and regional land use and land cover as a result of exchanges in water, energy, short-lived chemical species and biophysical interactions. Changes in local land cover and land use can also moderate or amplify climate change impacts at a regional scale (*medium confidence*) {2.6}. Multiple feedback processes act to increase or decrease atmospheric GHG concentrations at a global scale, with land potentially acting as a source and/or sink for emissions (see BOX SPM 1).

A3.1. Climate change risks are interlinked such that impacts in one system – e.g. on ecosystem services, human health, livelihoods, or infrastructure – may cascade through other systems with potential adverse consequences. Multi food basket failures provide an example where cascading risks affect multiple systems and governance levels. {7.3.3}

A3.2. As global mean surface temperature increases, the likelihood of exceeding potential tipping points that permanently alter land cover and ecosystem function also increases {SR 1.5}. Exceeding tipping points will cause irreversible damage and further loss of ecosystem services in terrestrial ecosystems, especially unique and threatened ecosystems (*very high confidence*), and Arctic and coastal ecosystems (*high confidence*). {1.2.2, 1.3.1,2,3,7, SR1.5}

A3.3. Land use practices can amplify or moderate regional climate change (*high confidence*). In agricultural areas irrigation moderates warming during the growing season (*robust evidence, high* *agreement*). Deforestation in tropical regions will enhance surface warming in areas where trees have been removed (*robust evidence, high agreement*). In high latitudes deforestation causes regional cooling during the snowy season due to increased albedo. Urbanisation will enhance warming in cities and their surroundings, especially during heat wave episodes (*robust evidence, high agreement*). {2.2, 2.6.1, 2.6.2}

A3.4. The way land surface cover and the atmosphere interact also influences the likelihood, magnitude and duration of extreme events including heat waves, droughts (*robust evidence, high agreement*) and heavy precipitation events *(medium evidence, medium agreement)* {2.6.1, 2.6.2, 2.6.3}. Such events can substantially affect ecosystems and agricultural production, further exacerbating desertification and land degradation and impacting food security (*high confidence*). Surface albedo, sand and dust aerosols and GHG fluxes exert an increasing influence on climate as changes in vegetation cover associated with land degradation and desertification increase. Both managed and unmanaged land surface processes can increase or decrease the impact of many extreme events (*high confidence*). {2.3, 2.6, 3.2, 3.3, 3.6, 5.2, 4.4, 4.6}

A3.5. Slow onset climate change impacts and long term deterioration in habitability of regions risks aggravating conflict, and could trigger spatial population shifts. {7.3.3}

A3.6. Land use and land management decisions – including the extent and scale to which land-based mitigation options (including afforestation, and biomass crops) are deployed – will continue to affect the climate system, and directly and indirectly impact food security and other socio-economic systems (*high confidence*). {4.3.1, 4.3.3, Table 1}

A4. Land degradation outcomes are determined by complex interactions between climate change impacts, land use, and land management {4.5.1, 4.5.2}. Of the 1 billion people who lack adequate nutrition today, people living in land degraded areas are among the worst affected.

A4.1. Limiting warming would lower risks across all aspects of desertification, land degradation and food security: water scarcity, soil and coastal erosion, fire, changes in vegetation, permafrost thaw and degradation, decreased crop yields and lower nutrition value of food (*high confidence*) {Figure SPM 3a and 3b}.

A4.2. In Central Asia, it is estimated that land degradation affects between 4-10% of cropped land, 27-68% of pasture land and 1-8% of forested land. This equates to about 40-66% of land in total. The costs counteracting land degradation in Central Asia are estimated to be six times greater than the cost of action in the form of sustainable land management (*low evidence, medium agreement*). {4.4.4, 4.5.1, 4.5.2, 7.4.1}

A4.3. Under global warming of 1.5 °C, combinations of climate change and land use change will likely drive 7% of current ecosystems to new biome types, such as forest to grassland, and grassland to arid desert (*medium evidence, high agreement*), and reduce the functionality, stability, and adaptability of ecosystems. Approximately an additional 10% of terrestrial species assessed will be at an increasingly high risk of extinction for every 1°C rise in global mean temperature {7.3.2}. These impacts are not fully reflected or quantified in integrated assessment model pathways.

A4.4. Increased rainfall intensity arising from climate change, when interacting with unsustainable land management that has reduced ground cover, could lead to significant increases in degradation risk via erosion (*very high confidence*). Changes of hydrological regimes as a combined result of human land/water use and climate change will impact floodplains and delta areas with detrimental effects on livelihoods, human habitats, and infrastructure (*very high confidence*).

A4.5. Wildfire regimes are being increasingly driven by changes in temperature, alongside droughts and human activity with implications for land use change, land degradation, and air quality (*medium evidence, medium agreement*). {Cross-Chapter Box 2.1, 4.4}

Box SPM 1: Greenhouse gas fluxes in terrestrial ecosystems

Box 1.1. The fraction of greenhouse gas (GHG) fluxes that are directly related to agriculture, forestry and other land use (AFOLU) comprises ~24% of total anthropogenic GHG emissions (medium evidence, medium agreement). Global models estimate net AFOLU emission of CO_2 to be 4.9 ± 3.0 $GtCO_2$ y^{-1} during 2007 to 2016 (12% of total anthropogenic CO_2 emissions, mainly due to deforestation for additional food production) (robust evidence, medium agreement). Land is a net source of methane, accounting for 61% of anthropogenic methane emissions during 2005 to 2015, mainly due to agriculture (137-140 $TgCH_4$ yr^{-1}), landfills (60 $TgCH_4$ yr^{-1}), and biomass burning (17 $TgCH_4$ yr^{-1}). Agriculture is the main anthropogenic source of N_2O due to fertiliser application and manure management (4.1 Tg N_2O-N yr^{-1}) {2.4, 5.4.2}.

Box 1.2. Emissions attributable to food systems also include emissions from activity in associated sectors such as transportation with the result that, in aggregate, the global food system accounts for roughly 40% (range: 30-50%) of total GHG emissions. This estimate includes emissions of: 10% (range: 7-13%) from crop and livestock activities within the farm gate; 10% (range: 5-14%) from land use and land use change including deforestation and peatland degradation; and 18% (range: 16-20%) from storage, processing, transport, retail, and other supply chain activities (medium confidence) {5.4.1}.

Box 1.3. Global vegetation models estimate a net removal of CO_2 of ~11.2 ± 3.0 $GtCO_2$ y^{-1} during 2007 to 2016 due to the effects of global change on unmanaged lands (removing around 28% of total anthropogenic CO_2 emissions) (*robust evidence, medium agreement*). In recent decades, climate change, enhanced vegetation growth from rising atmospheric concentrations of CO_2 and nitrogen availability as well as changes in soil processes resulted in the net land removal of CO_2 from the atmosphere. The effects of CO_2 fertilisation, water limitation, soil nutrient availability and microbial processes are the sources of large uncertainty in projections of the future land sink {2.2, 2.4}.

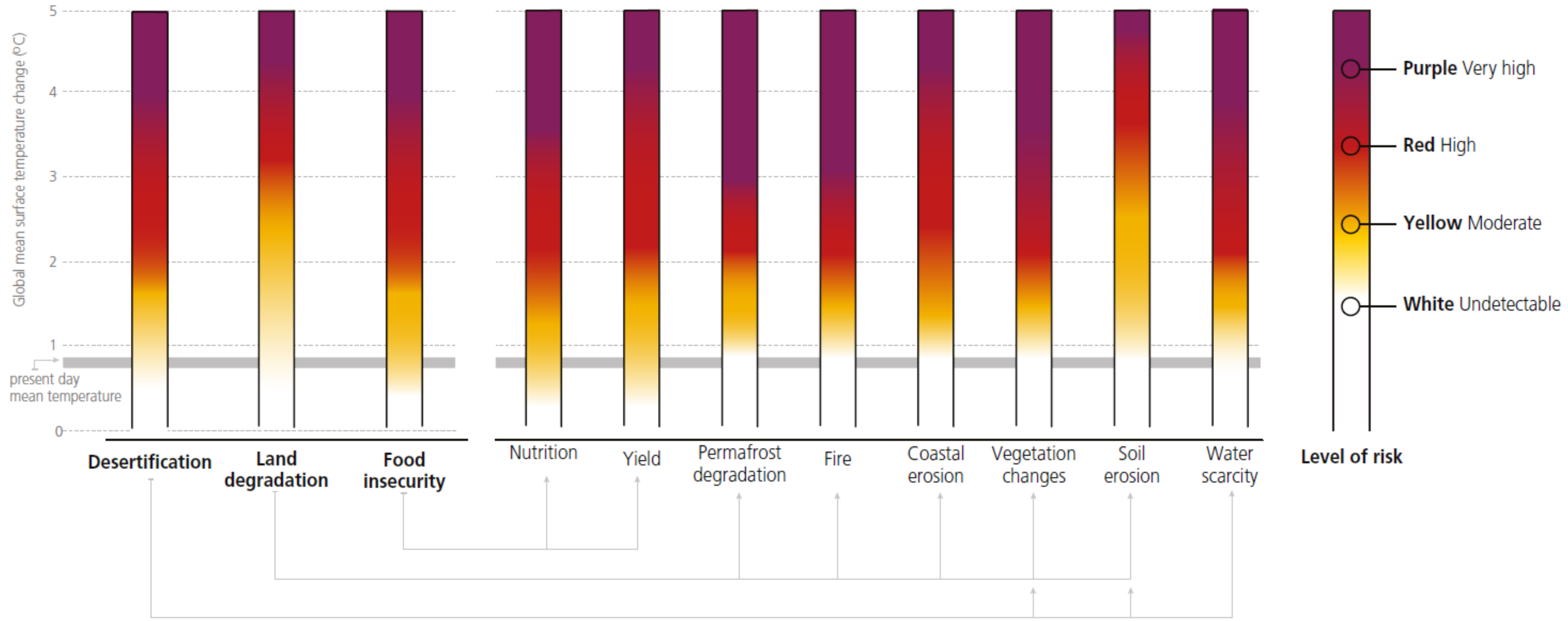


Figure SPM 3a: - Risks of desertification, land degradation and food insecurity at different degrees of warming. The grey line (0.87°C) is a measure of the extent of present day warming. Risks to specific components of desertification (Water scarcity, soil erosion and vegetation changes; arid climates only), land degradation (soil erosion, fire, vegetation changes, coastal erosion and permafrost degradation; non-arid climates only) and food insecurity (nutrition and yield) are highlighted on the lower panel. The risk scale (from undetectable to very high) indicates the level of additional risk posed by climate change.. This risk assessment is based on expert judgement by the authors of this chapter considering previous IPCC report and literature presented in chapters 3,4,5,6 and 7.

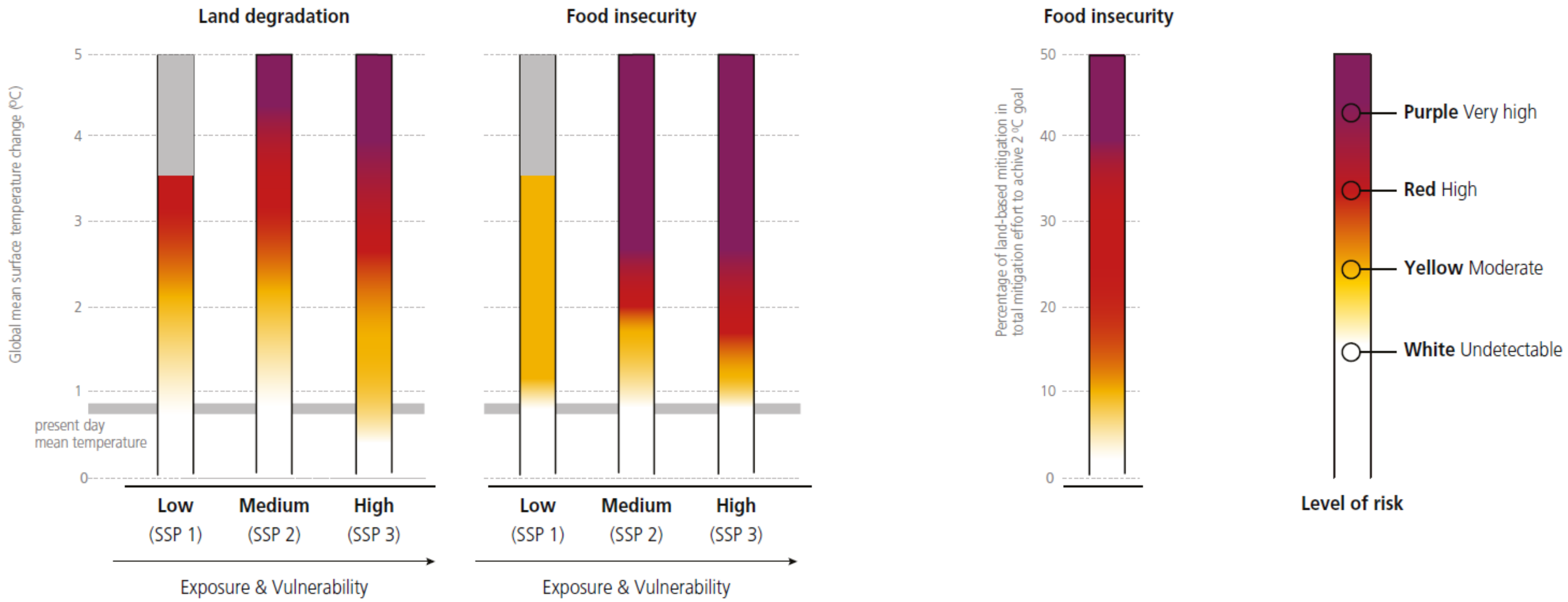


Figure SPM 3b: Summary of risks of land degradation and food insecurity as a function of global warming and under different socio-economic pathways (SSP).

SSP1 to 3 reflect increasing levels (from low to high) of exposure and vulnerability of human and natural systems. Areas in grey in SSP1, indicate that this SSP does not reach higher temperature levels. B) Risks to food security as a function of the share of land-based mitigation relative to the total mitigation effort (cumulative in 2100) required for a 2ºC stabilisation in 2100. This risk assessment is based on expert judgement by the authors considering emerging literature on socio-economic pathways. Coastal erosion was used as the indicator for land degradation and food price rise was used as an indicator for food insecurity.

A5. Desertification is exacerbated by climate change affecting the provision of essential ecosystem services including food, and increasing the risk of human migration and conflict (*medium confidence*) {3.3.2}. Increasing population pressures combined with climate change are likely to push dryland populations beyond their resilience thresholds and the limits for their autonomous adaptation. {3.5.2}

A5.1. Climate variability and change, particularly through increases both in land surface air temperature and evapotranspiration, and decrease in precipitation, are *likely* to have played a larger role in causing desertification than previously estimated for some dryland areas (*medium evidence, medium agreement*). {3.3.2; 3.3.1}

A5.2. Expansion of drylands, as measured by the aridity index, has already occurred in north-eastern Brazil, southern Argentina, the southwest of the United States, eastern Africa, the Middle East, Central Asia, the Sahel, Zambia and Zimbabwe, some regions of the Mediterranean area, north-eastern China and sub-Himalayan India during the last three decades compared to the period 1951-1980 {3.3.1.2}. In the range of 1.5˚C and 2˚C global warming above pre-industrial levels, some of the places and systems already vulnerable to water shortages, such as the Mediterranean (including North Africa and the Levant) are projected to experience more acute dry spells and decreasing water availability.

A5.3. Dryland areas are expected to become more vulnerable to desertification under climate change due to the increasing number, frequency and intensity of extreme climatic events including droughts and heat waves, with significant impacts on livelihoods and ecosystems *(high confidence)* {3.2.1, 3.3.2, 3.6.1, 3.6.2}. At 1.5°C to a 2°C global warming, the ecosystem services and biodiversity in drylands will face an increased risk from desertification (*high confidence*). {3.6.1, 3.6.2}

A5.4. The interaction of climate change and desertification reduces the provision of dryland ecosystem services and degrades ecosystem structure and function, including loss of biodiversity, affecting food (and wood) security and human well-being (*high confidence*) {3.2.1, 3.3.2, 3.6.1, 3.6.2}. Dryness limits CO_2 exchange of vegetation and soils in desert areas. The area where dryness is rate limiting has increased by 6% since 1948 and is expected to increase by at least another 8% by 2050 with the result that net carbon uptake is about 27% lower than in other areas. {3.4.3, 3.6.2}

A5.5. Desertification increases the frequency of dust storms due to vegetation loss and drying of surface cover (high confidence). Dust particles reduce the heat energy available at the land surface and increase the temperature of the atmosphere. Sand and dust storms increase the cloud reflectivity and decrease the chances of precipitation depending on the types and amounts of aerosols present, {3.4.1}. Increased dust storm activity has a high potential for negative human health impacts due to associated respiratory and cardiovascular illnesses (*medium evidence, high agreement*) {3.5.2}. Higher intensity of sand storms and sand dune movements under climate change also cause damage to transportation and solar energy generating infrastructures (*high confidence*) {3.5.22}. Deposition of dust storms on the oceans was found to have a direct effect of cooling, while the indirect effect on climate of dust storms providing a source of nutrients for the upper ocean biota is contested {3.4.1.1}.

A5.6. The combination of pressures coming from climate change and desertification contribute, in interaction with other factors, to human migration, conflict, poverty, food insecurity, and increased disease burden (*medium confidence*) {3.5.2}. Across the Sahel region, climate change-desertification interactions have already been found to exacerbate competition for land between pastoralists and crop producers. Climate change and desertification induced migration is complex. Any attribution of migration to environmental change should account for multiple drivers of mobility as well as other adaptation measures undertaken by populations exposed to environmental risk (*high confidence*). {3.5.2.4}

A6. Food system and climate change interactions lead to food insecurity through impacts on food availability, access, utilisation and stability *(high confidence).* {1.2.2., 1.3.1, 1.4, 5.1.1, 5.1.2, 5.2}

A6.1. Climate change affects food systems through the disruption of growth, storage, manufacture, transport, and retail {*high confidence*}. Such disruptions are likely to increase in the future. The scale of climate change impact on food production depends on the region. {5.2.4}

A6.2. Food system emissions are growing globally due to increasing population and demand for food *(robust evidence, high agreement)*. In the past decades, diet shifts occurring across the world have increased consumption (including of meat, dairy and vegetable oil) resulting in a larger GHG emissions footprint, excess intake and unhealthy outcomes. {5.2}

A6.3. Increasing frequency and intensity of extreme climate events together with changes in temperature, water availability, and CO_2 concentrations are already causing shocks to food systems, leading to yield losses, market failures, transport, trade and retail disruptions, with ensuing detrimental effects on food security. The specific impact depends on the agroecosystem characteristics (*robust evidence, high agreement*). {5.2.2}

A6.4. Climate change-driven impacts on food systems exacerbate competition for land. For example, rice-cultivation areas in north-eastern China have expanded since 1990 associated with significant warming experienced in the region. However, expansion of rice-cropping land area in response to warming could reduce biodiversity, expand deforestation, and encourage reclamation of wetlands. Climate change-driven impacts on food systems also exacerbates competition for water resources, including from aquifers. {Box 5.1, 5.2.3.4}

A6.5. Climate change is exacerbating global food inequality. Malnourished people, smallholder farmers, women, and the urban poor are especially vulnerable. Climate impacts on non-food cash-crop production will impact the food security of smallholders through reductions in ability to purchase food. The Sahel, the Mediterranean, central Europe, the Amazon, western and southern Africa are at risk of food shortage at 2°C warming (IPCC SR 1.5). At higher levels of warming there are high risks of declining yields across all regions (*high confidence*). {Figure SPM 3., 7.3.2}

B. Adaptation and mitigation response options

B1. Land-related adaptation and mitigation response options fall into three broad categories: *land management*, *value-chain management*, and *risk management.* Options under the three categories have significant potential to contribute to adaptation and mitigation and may also contribute to increasing food security, and avoiding, reducing, and reversing land degradation and desertification. Trade-offs between multiple objectives can be reduced, but cannot be avoided altogether. {1.3.2, 1.4, 2.3, 2.7, 3.5.2, 3.7.1, 4.10, 6.3, 6.4 6.5, Figure SPM 1}

B1.1. The effectiveness of response options to address the challenges of desertification, land degradation and food security are location specific; mitigation or adaptation effectiveness differs by, for example, bioclimatic region, existing land cover, land management system or local food system context (*robust evidence, high agreement*). Site-specific options can draw on both new scientific and management innovations and traditional, indigenous and local knowledge. {1.4, 2.7; 6.3, 6.5.5}

B1.2. Many interventions lead to both adaptation and mitigation outcomes. These include enhancing the efficient use of agro-climatic and other natural resources, reducing damage and loss due to agro-meteorological disasters, increasing agricultural biodiversity, increasing resource-use efficiency, and preventing desertification and land degradation (*high confidence*). {1.4.4, 4.10, 5.3, 5.6, 7.5}

B1.3. Considering the impact of climate change adaptation and mitigation response options in the context of desertification, land degradation and food security together will allow co-benefits to be enhanced and adverse side-effects to be reduced (*robust evidence, high agreement*) {6.5}. This will also address the SDGs related to food, biodiversity and water {6.5.4}. Some response options, (e.g., afforestation), may also have co-benefits for local climate such as cooling and reduced weather extremes. {2.6; 4.10; 6.3; 6.5}

B1.4. Land has an essential role to play in mitigating and adapting to climate change but improved land management is not sufficient by itself. Without rapid reductions in anthropogenic GHG emissions across all sectors, altered management practices in cropland, pastures and managed forests are insufficient to achieve the long-term temperature goal in the Paris Agreement (*high confidence*). {1.2.2, 1.3, 2.7.3; 7.3} {SR1.5}

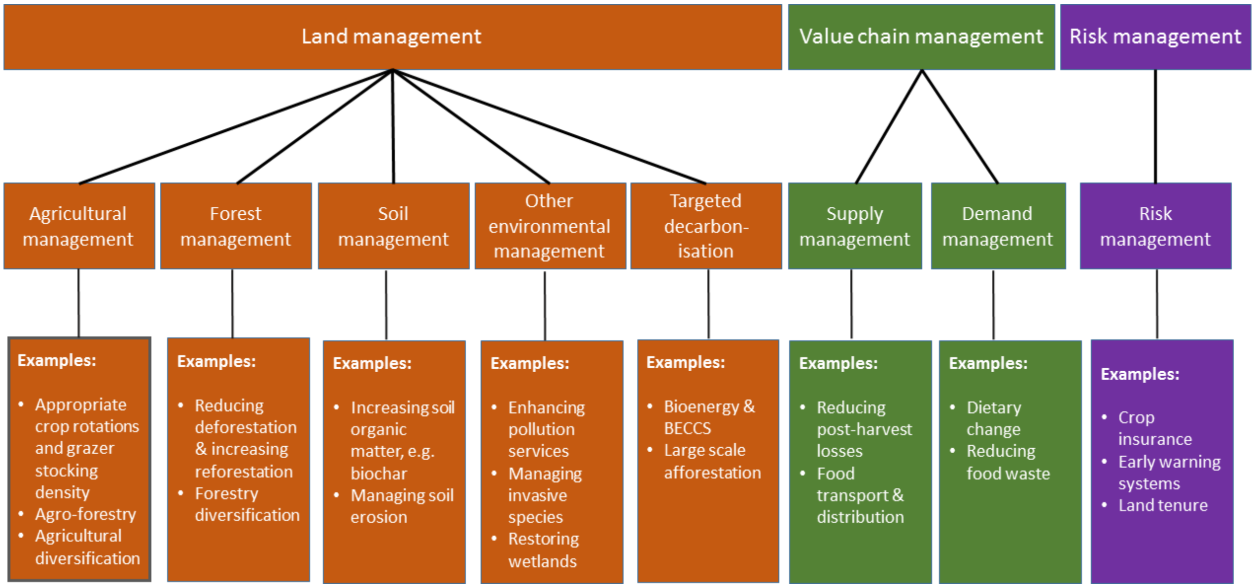


Figure SPM 4: Integrated response options assessed in this report. Response options fall into three broad groups: land management, value chain management and risk management.

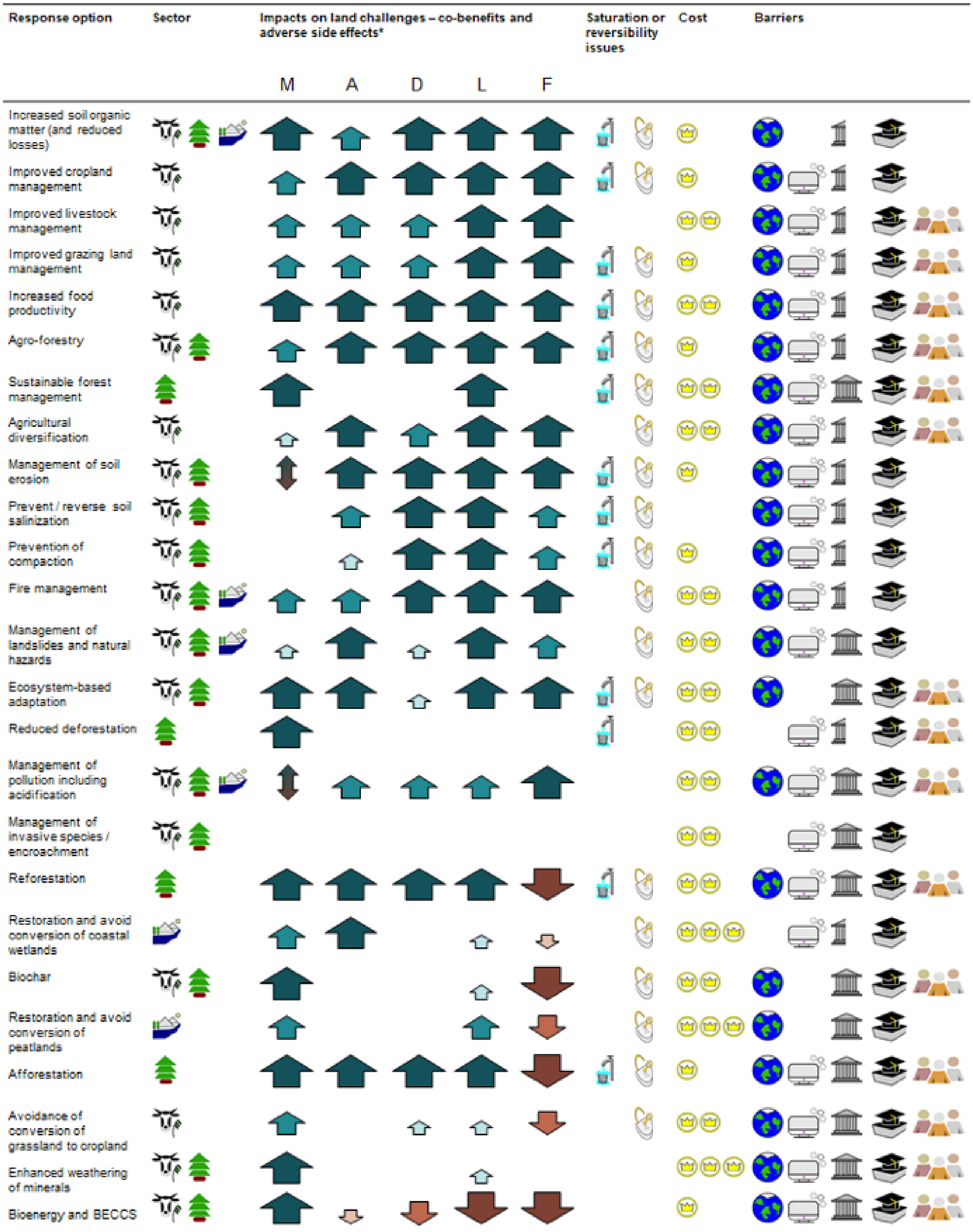
B2. The impacts of implementing *land management, value chain and risk management* response options are interlinked. Options that address a single land challenge may exacerbate other problems (*high confidence*). {1.4, 5.3, 5.6, 6.4, 6.5, Table SPM 1}

B2.1. Climate adaptation strategies can produce mitigation co-benefits, enhancing the effectiveness and feasibility of both adaptation and mitigation. For example, diversifying cropping systems and farm income – a typical feature of smallholder farming systems – increases resilience to multiple stresses. Nevertheless, there are limits to adaptive capacity. {5.3}

B2.2. Land is a finite resource and further expansion of managed land into natural ecosystems will lead to the loss of biodiversity and other ecosystem services. Further intensification on existing managed land risks exacerbating water and air pollution and increasing land degradation and desertification (*robust evidence, high agreement*) {1.2.2, 6.5}. Loss of biodiversity also reduces options for future adaptation.

B2.3. Impacts may be immediate or may occur over multiple years. Many of the trade-offs and synergies associated with managing land are manifested directly at the local level but also indirectly, for example through market mediated land-use change. The ecosystem services and societal impacts embodied in trade are important considerations in the assessment of sustainable land management, mitigation and adaptation actions, as well as the associated costs of these actions and the implications for decision making. {1.3.3, 1.3.2, 1.5.3, 2.7.1, 6.5}

A) Summary of co-benefits, adverse side effects, permanence/saturation issues, costs and barriers of **land management response options** to address land challenges.



* M = Mitigation, A = Adaptation, D = Desertification, L = Land Degradation and F = Food Security

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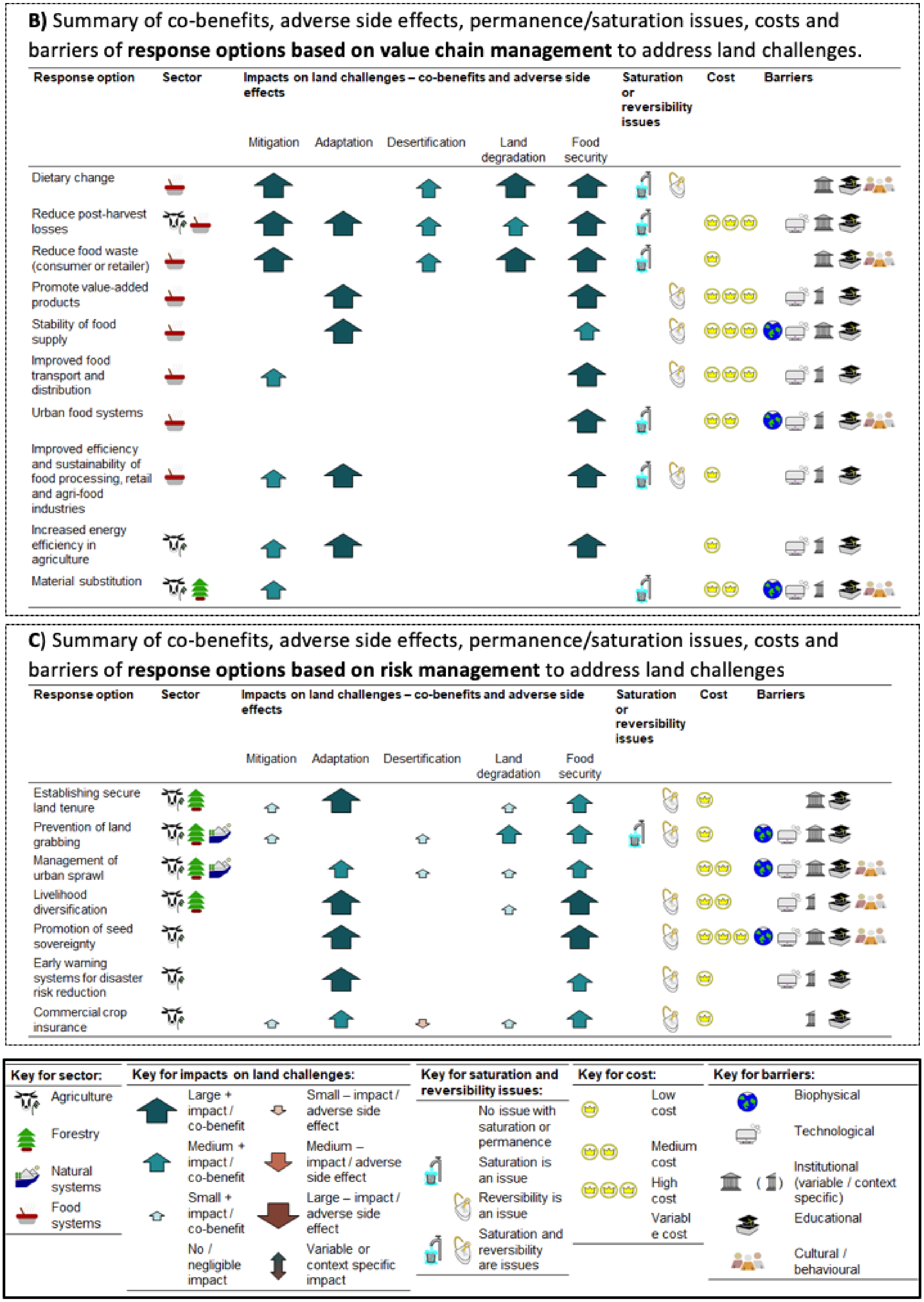
B) Summary of co-benefits, adverse side effects, permanence/saturation issues, costs and barriers of **response options based on value chain management** to address land challenges.
Response option
Sector
Impacts on land challenges – co-benefits and adverse side effects
Saturation or reversibility issues
Cost
Barriers
Mitigation
Adaptation
Desertification
Land degradation
Food security
Dietary change
Reduce post-harvest losses
Reduce food waste (consumer or retailer)
Promote value-added products
Stability of food supply
Improved food transport and distribution
Urban food systems
Improved efficiency and sustainability of food processing, retail and agri-food industries
Increased energy efficiency in agriculture
Material substitution
C) Summary of co-benefits, adverse side effects, permanence/saturation issues, costs and barriers of **response options based on risk management** to address land challenges
Response option
Sector
Impacts on land challenges – co-benefits and adverse side effects
Saturation or reversibility issues
Cost
Barriers
Mitigation
Adaptation
Desertification
Land degradation
Food security
Establishing secure land tenure
Prevention of land grabbing
Management of urban sprawl
Livelihood diversification
Promotion of seed sovereignty
Early warning systems for disaster risk reduction
Commercial crop insurance
Key for sector:
Agriculture
Forestry
Natural systems
Food systems
Key for impacts on land challenges:
Large + impact / co-benefit
Medium + impact / co-benefit
Small + impact / co-benefit
No / negligible impact
Small – impact / adverse side effect
Medium – impact / adverse side effect
Large – impact / adverse side effect
Variable or context specific impact
Key for saturation and reversibility issues:
No issue with saturation or permanence
Saturation is an issue
Reversibility is an issue
Saturation and reversibility are issues
Key for cost:
Low cost
Medium cost
High cost
Variabl e cost
Key for barriers:
Biophysical
Technological
Institutional (variable / context specific)
Educational
Cultural / behavioural

Table SPM 1: Summary of co-benefits, adverse side effects, permanence/saturation issues, costs and barriers of A) land management, B) value chain management, and C) risk management response options. {6.5.1}.

Key for criteria used to define size of impact of each integrated response option in Table SPM 1.

	Mitigation	Adaptation	Desertification	Land Degradation	Food
Large positive	More than 3 $GtCO_2e$ per year	Positively impacts more than around 25 million people	Positively impacts more than around 300 million hectares	Positively impacts more than around 300 million hectares	Positively impacts more than around 100 million people
Moderate positive	0.3 to 3 $GtCO_2e$	1 million to 25 million	50 to 300 million hectares	50 to 300 million hectares	1 million to 100 million
Small positive	>0	Under 1 million	>0	>0	Under 1 million
Negligible	0	No effect	No effect	No effect	No effect
Small negative	<0	Under 1 million	<0	<0	Under 1 million
Moderate negative	-0.3 to -3 $GtCO_2e$	1 million to 25 million	50 to 300 million hectares	50 to 300 million hectares	1 million to 100 million
Large negative	More than -3 $GtCO_2e$ per year	Negatively impacts more than around 25 million people	Negatively impacts more than around 300 million hectares	Negatively impacts more than around 300 million hectares	Negatively impacts more than around 100 million people

Note: All numbers are for global scale; all values are for technical potential. For mitigation, the target is set at around the level of large single mitigation measure (~1 GtC yr^{-1} = 3.67 $GtCO_2e$ yr^{-1}), with a combined target to meet 100 $GtCO_2$ in 2100, to go from baseline to 2˚C. For adaptation, numbers are set relative to the ~5 million lives lost per year attributable to climate change and the 100 million lives predicted to be lost between 2010 and 2030 with the largest category representing 25% of this total. For desertification and land degradation, categories are set relative to the 1-6 billion hectares of currently degraded land with the largest category representing 30% of the lower estimate. For food security, categories are set relative to the ~800 million people currently undernourished with the largest category representing around 12.5% of this total. {6.4, 6.4.1, 6.4.2}

B3. Future climate change mitigation pathways could contribute to the shaping of the land system. The majority of assessed climate mitigation scenario pathways for 2030, 2050, and 2100 include substantial changes in the global area of forests, pasture, food crops, and land dedicated to bioenergy crops (*high confidence*). {1.3.2, 6.2.4, Figure SPM 5}

B3.1. In Representative Concentration Pathway (RCP) 2.6 scenarios, the global forest area is projected to change, ranging from a reduction of about 500 Mha up to an increase of 1000 Mha in 2100 compared to 2010. Demand for second generation bioenergy crops can range from less than 5,000 up to about 20,000 million tonnes per year, sourced from about 200–1,500 million ha of land (*robust evidence, high agreement*). Changes in land use on this scale have important implications for land carbon storage and biophysical effects on regional temperature (*robust evidence, high agreement*). {2.7}

B3.2. The net carbon effects of different response options over time depend on where land change occurs and on prior land use. In land that has a high carbon stock (such as forest, grassland / savannah, and peatlands), the carbon benefits of land protection are greater in the short-term than converting land to bioenergy crops, which can take several harvest cycles to "pay-back" the carbon lost (*medium evidence, medium agreement*). {2.7.1}

B3.3. A small number of scenarios describe pathways that achieve climate change targets with less need for carbon dioxide removal (CDR) techniques requiring large areas of land. These pathways rely on lifestyle changes and agricultural intensification in which reduced cattle stocks play an important role, with rapid and early reduction of GHG emissions and earlier CDR in the land sector as well as in other sectors (*robust evidence, high agreement*). {2.7.2, 5.5.1}

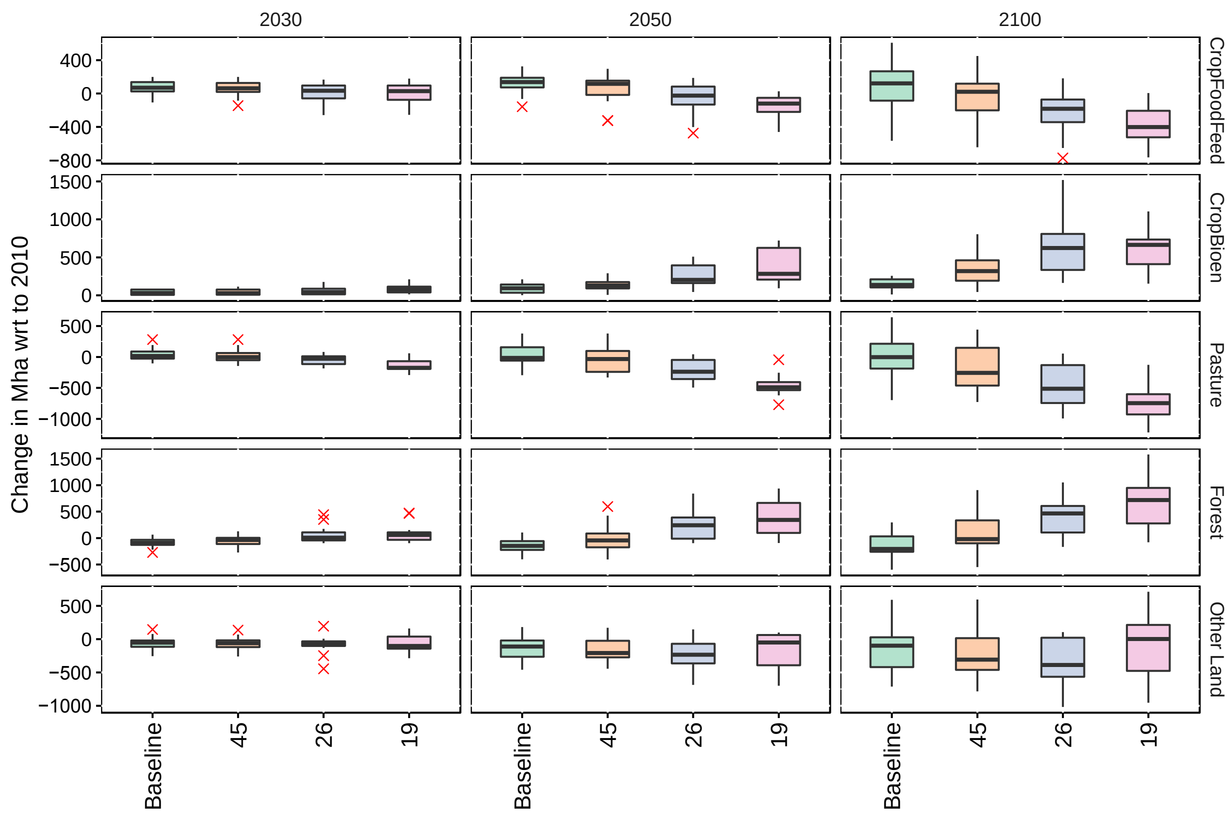

Figure SPM 5: Land-use change in 2030, 2050 and 2100 relative to 2010 for Baseline, RCP4.5, RCP2.6 and RCP1.9 [Representative Concentration Pathways/scenarios] based on the Shared Socioeconomic Pathways (SSP). {2.7.2, Figure 2.7.3}

Boxplots show median (horizontal line), interquartile range IQR (box) and the range of values within 1.5 x IQR at either end of the box (vertical lines) across 5 SSPs and across 5 Integrated Assessment Models (IAMs). Outliers (red crosses) are values greater than 1.5 x IQR at either end of the box. In 2010, pasture was estimated to cover about 3-3.5 Mha, food and feed crops about 1.5-1.6 1Mha, energy crops about 0-14 Mha and forest about 3.7-4.2 Mha, across the IAMs that reported SSP pathways.

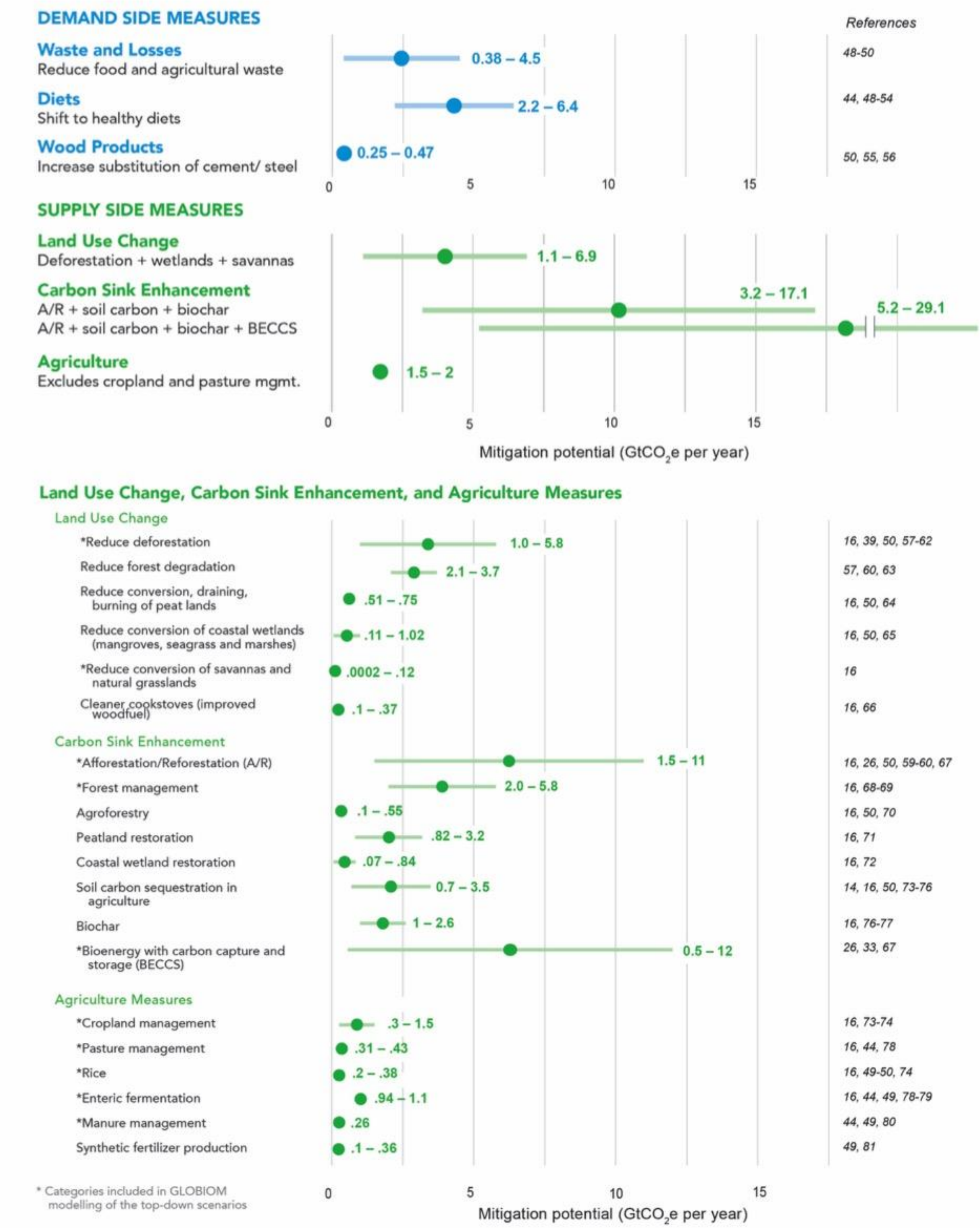

Figure SPM 6: Technical potential of land-based climate mitigation response options. These estimates of technical potential may not simply be added together because some options compete for land and other resources, while others may reduce the demand for land {2.7.1, 2.7.3}. While some estimates of technical potential include sustainability and cost considerations, most do not include socio-economic barriers, the impacts of future climate change or non-GHG climate forcing.

B4. The large-scale deployment of land-intensive carbon dioxide removal (CDR) options—bioenergy with carbon capture and storage (BECCS), afforestation and reforestation and biochar—are expected to increase pressure on land leading to trade-offs and cascading effects, that conflict with other objectives such as environmental sustainability, food security and jeopardising achievement of other sustainable development goals (SDGs), including access to water (*high confidence*). {1.3.2, cross chapter box afforestation/reforestation, 4.7.1, 4.7.2, 4.7.3, 4.7.6, 5.6.1, 6.5, 2.6, 2.7}

B4.1. Land-based mitigation could provide around a third of the near-term 2030 to 2050 mitigation potential required to reach the long-term temperature goal in the Paris Agreement. Estimates of the technical potential of individual land-based response options cannot be simply aggregated to obtain the global technical potential. {2.7.1, 2.7.3, Figure SPM 6}

B4.2. Most modelling scenarios assume very rapid deployment of BECCS, afforestation and reforestation, and biochar between 2030 and 2050 reaching rates of expansion in land use exceeding 20 Mha yr^{-1}; there is no precedent for this rate of expansion by any crop since at least 1961. {2.7.2, 5.6.1}

B4.3. Most land stocks potentially available for CDR are currently classified as meadows and pastureland (estimated as 3.3 Gha globally). Grasslands often occur in areas peripheral to intensive cropping regions where they often border on primary vegetation with little infrastructure. Many of these grassland areas are very biodiverse but currently have low average food crop productivity. Integrated practices, such as conservation agriculture and climate-smart agriculture, may provide opportunities for sustainable intensification increasing soil carbon stocks but at the risk of exacerbating biodiversity loss, and deforestation. {5.6.1}

B4.4. Large-scale deployment of land-based CDRs also implies ambitious investments and policy interventions as well as strong regulation and governance of bioenergy production for protection of ecosystem services, including food production. Such conditions may be challenging particularly to developing countries. {5.6.1}

B5. All components of the food system (i.e., production, transport, packaging, processing, storage, food choice and consumption, loss and waste) can contribute to climate change mitigation and adaptation. {5.5, Figure SPM 7}

B5.1. Supply-side mitigation practices in the food system can contribute to climate change adaptation and mitigation by sustainably and efficiently intensifying the use of land and sequestering carbon in soils and biomass (*robust evidence, high agreement*). Supply-side options implemented by farmers, processors, and retailers can contribute to livelihoods, help countries move towards sustainable land management, and lead to reduction of total emissions under appropriate policy interventions. {1.4, 5.5.1}

B5.2. Options for GHG mitigation in cropping systems include improved land and fertiliser management, biochar applications, breeding for larger root systems, and bridging yield gaps. The total mitigation potential is estimated to be 2.0-5.0 $GtCO_2eq\ yr^{-1}$ by 2030. . Options for mitigation in livestock systems include better manure management, improved grazing land management, and better feeding practices for animals. The total mitigation potential is estimated to be 1.8-2.4 $GtCO_2eq\ yr^{-1}$ by 2050. Reductions in GHG emissions intensity (emissions per unit product) from livestock and animal products can support reductions in absolute emissions in some contexts (e.g., reduction in herd size at constant pasture area, reduction in overall pasture area) (*medium evidence, medium agreement*). Agroforestry mitigation practices include rotational woodlots, long-term fallow, and integrated land use. The total mitigation potential is estimated to be 4.27-21.5 GtCO_2eq yr^{-1}. {5.5.1}

B5.3. Diversification of many components of the food system is a key element for increasing resilience to climate change and reducing risks. There are many alternative pathways that can increase resilience, including increasing agrobiodiversity, using indigenous knowledge and local knowledge, and developing local food systems. Agrobiodiversity can also contribute to health via improving nutrition including from indigenous foods, particularly in times of food shortages. {5.3.1}

B5.4. Demand-side changes, e.g., in food choices and consumption, can help to achieve global GHG emission reductions and improve human health (*robust evidence, high agreement*). Diets with low embodied GHG emissions tend on average to be healthier and have smaller land footprints. By 2050, the mitigation potential of dietary changes relative to business-as-usual food demand projections ranges from 2.7 - 3.4 Gt CO_2eq yr^{-1} for Mediterranean diets, 3.6-6.4 Gt CO_2eq yr^{-1} for healthy diets, 4.3-5.3 Gt CO_2eq yr^{-1} for vegetarian diets and 5.2-5.7 Gt CO_2eq yr^{-1} for a flexitarian diet with limited meat and dairy products (*robust evidence, high agreement*). {1.4.2, 5.5.2}

B5.5. In high-income industrial countries, there is scope for reducing consumption of animal-sourced foods, particularly processed and red meat and dairy, with tangible environmental and health benefits; in developing countries, high meat-based diets are less prevalent and scope for reductions may be more limited. To encourage low-carbon diets, policies such as awareness-raising campaigns, public procurement, and health insurance incentives have been tested in differing contexts. {5.5.2}

B5.6. Reducing food loss and waste throughout the food system (production, supply chains, and consumption) will also reduce GHG emissions and improve food supply without agricultural expansion {5.5.2, Figure SPM 7}.

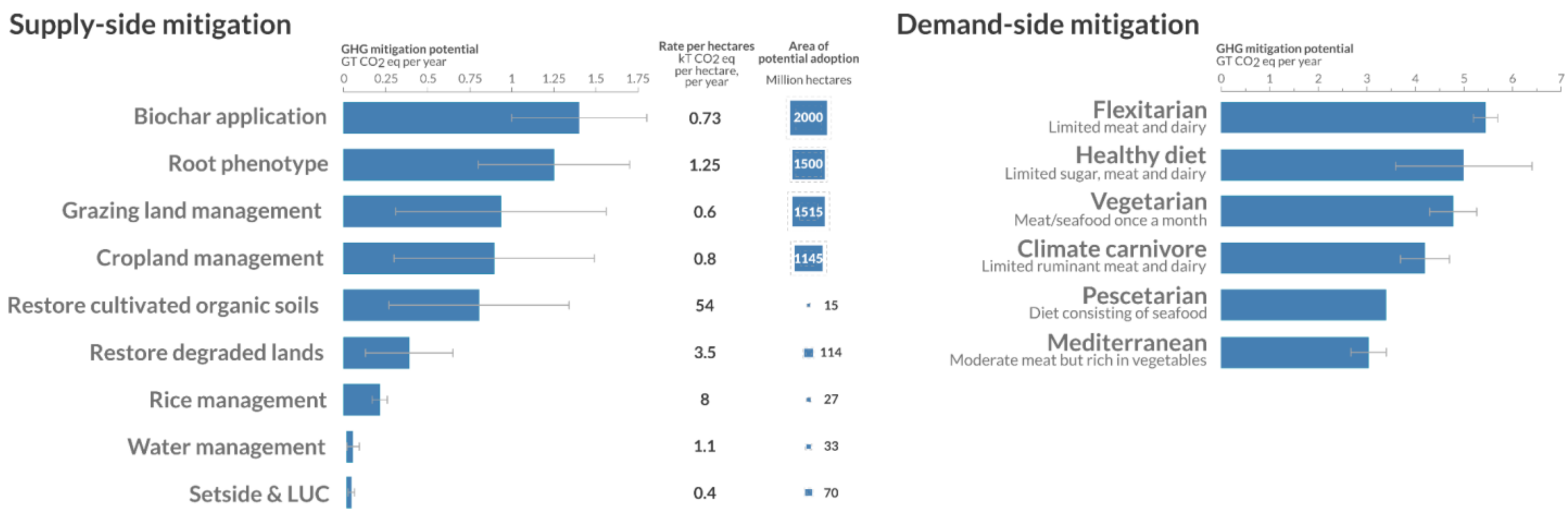

Figure SPM 7: Opportunities for mitigation in global food systems.

A) Supply side-mitigation: rate, area available and total potential of supply-side mitigation measures. B) Demand-side mitigation: GHG mitigation potential of different diets. There are many supply-side mitigation options available. This will require a substantial proportion of the agricultural land base. Different diets provide a range of demand-side mitigation potential. How much mitigation potential is achievable will depend on the effectiveness of implementation strategies, socioeconomic contexts, and policies. {5.5.1, 5.5.2}

C. Enabling climate mitigation and adaptation responses in the context of desertification, land degradation and food security

C1. Sustainable land management approaches can help combat land degradation and desertification, improve land use efficiency, deliver economic benefits, minimise conflict around land and biomass use at the local level, and can be aligned with climate change adaptation (*medium confidence*). {4.10.2, 4.10.4, 7.7.2}

C1.1. Sustainable land management practices may integrate multiple response options. Integration can occur across levels (local, regional, and national), across sectors (including agriculture, energy, and forestry), across applications or uses and at the landscape level with integrated landscape planning involving a range of actors at the local area from multiple institutions and levels. {4.10.2, 4.10.4, 7.7.2}.

C1.2. Sustainable land management practices can reverse or minimise economic losses of land degradation related to ecosystem service decline. These losses are estimated at between USD 6.3 and 10.6 trillion annually, representing 10-17% of the world's GDP and more than five times the entire value of agriculture in the market economy (*medium confidence*). {1.4.1, 7.4.1}

C1.3. Compared with current practices, sustainable land management can more than double the economic value of pasture land including the market value of pasture forage, current value of livestock with year-round grazing, and commodity costs of livestock product. Sustainable land management practices in drylands can deliver superior economic outcomes for farmer income, stable livelihood systems that help poor communities, improved performance of hydroelectric dams due to less siltation, and more stable and increased crop yields (from 2.5 to 5% increases compared with conventional methods). {7.4.1}

C1.4. Rangeland management and agroforestry practices result in increased carbon sequestration, reduced soil erosion and improved soil and water conservation (*medium confidence*). Afforestation programs for the creation of windbreaks in the form of "green walls", "green belts", and "green dams" have stabilised and lowered the frequency of sand storms, helping avert wind driven desertification, and increased the carbon sinks. Replacement of traditional biomass use with modern fuels and electricity ameliorates land pressures, enhances carbon sinks and reduces emissions associated with overharvesting of woody biomass and inefficient end-use. {3.7.1, 3.8.2, 7.5.6}

C1.5. Despite their benefits in addressing land degradation, desertification, mitigating and adapting to climate change, many sustainable land management practices are not widely adopted due to insecure property rights, lack of access to credit and agricultural advisory services, insufficient private incentives, and lack of knowledge *(robust evidence, high agreement*). {3.7.1, 3.7.2}

C2. Collaboration between multiple institutions and actors and the local engagement of stakeholders are crucial when developing and implementing sustainable land management decisions (*high confidence*). {4.10.4, 7.4, 7.5.8, 7.6.5, 7.7.6}

C2.1. Modelled socio-economic pathways that lower social inequalities and enable rapid adoption of sustainable development principles can strongly reduce the vulnerability and exposure of human and natural systems to climate change, and by implication ameliorate the risks of desertification, land degradation and food insecurity (*high confidence).* {7.6.5}

C2.2. Patterns of human land use arise and change dynamically as a result of multiple intersecting socio-economic influences including land tenure arrangements, market access, trade and governance structures, and the availability of technology. Whereas some policies and policy packages are intended to directly affect the decisions of land managers, many others act indirectly over both short and long timescales. No single policy measure can respond to the complex risks posed by climate change and effective responses often require multiple actors working across different sectors, timescales and governance levels. (*high confidence*). {4.10.2, 7.5.1, 7.7.2}

C2.3. A coherent policy mix is key in responding to hazards and building adaptive capacity that includes a consideration of all policy instruments, their synergies and trade-offs (*high confidence*). Co-benefits exist if policies that advance food security and land degradation neutrality are implemented simultaneously. Instruments for conserving biodiversity and ecosystem services, advancing international land degradation neutrality, standards and certification together with good practices and guidelines advance sustainable land management and improve food security. Policy frameworks promoting the adoption of sustainable land management solutions contribute to addressing desertification as well as mitigating and adapting to climate change, with significant co-benefits for poverty reduction and food security among dryland populations (*medium confidence*). {4.10, 4.10.2, 7.5.6, 7.5.8}

C2.4. Achieving the target of land degradation neutrality would decrease the environmental footprint of agriculture, while supporting food security and sustaining human wellbeing (*high confidence*). Application of land degradation neutrality policies lead to balancing of ecosystem service performance and desertification land improvement (*low evidence, high agreement*). {7.4.1}

C2.5. On a regional basis, gender, equity, culture, ethnicity, land tenure, and access to food and capacity building are important in devising context-specific mitigation and adaptation measures, as well as strategies to improve food security *(robust evidence, high agreement).* Indigenous and local knowledge can also be distilled into traditional agroecological practices that can contribute to enhancing resilience to climate change and combating desertification (*medium confidence*). {1.5, 7.7.4, 5.2.5, 5.3.3, 5.6.3, 5.6.4 , 5.7.3, 7.6.5}

C2.6. Adaptive management is an example of a systemic approach that can support decision making and the development of locally appropriate packages of policies and response options, and has been shown to be successful in a variety of case studies. By providing a dynamic process-based approach to natural resource management that is inclusive of stakeholders in defining both objectives and implementation strategies, adaptive management can better respond to uncertainty and cascading risks. {Figure SPM8, 7.7.3}

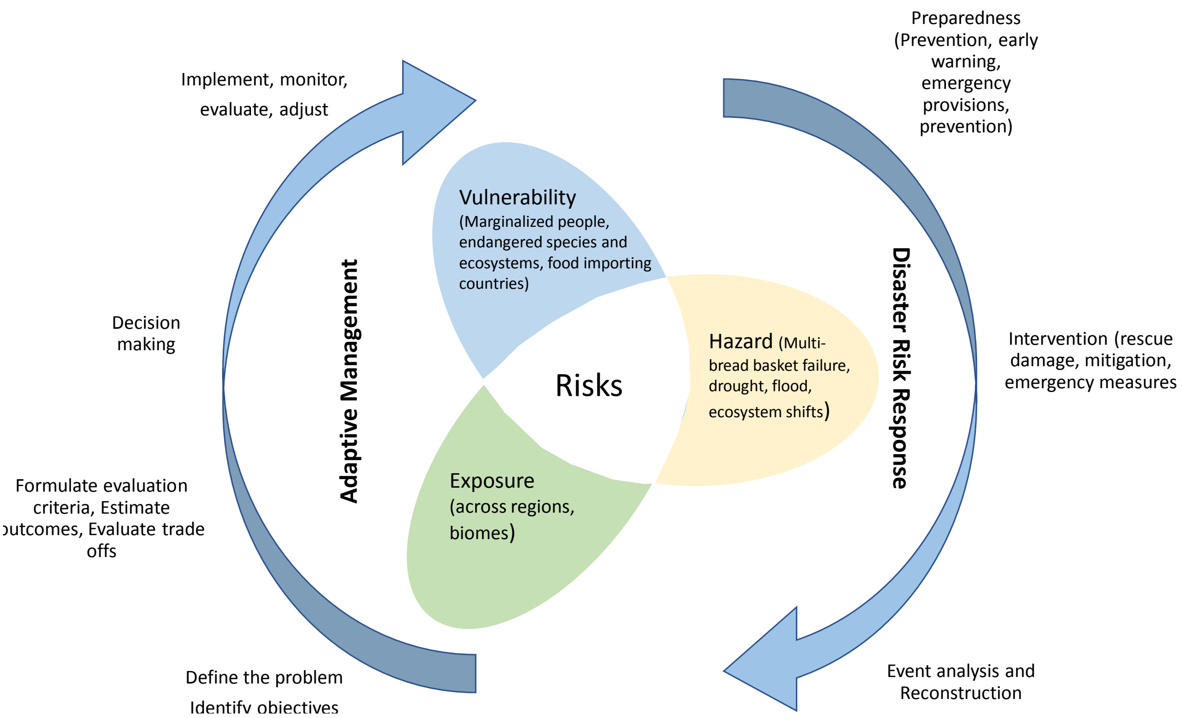

Figure SPM 8: Adaptive management and risk.
The adaptive management approach identifies and responds to exposure and vulnerability to land and climate change impacts by identifying problems and objectives, making decisions in relation to response options and instruments advancing response options in the context of uncertainty. These decisions are continuously monitored, evaluated and adjusted to changing conditions. Similarly, disaster risk management responds to hazards through preparation, prevention, response, analysis, and reconstruction in an iterative process. {Box 7.5}

C3. Many land-based policy options for adapting to and mitigating climate change have multiple co-benefits for desertification, land degradation and food security. {6.5,7.4, 7.5.9}

C3.1. While the implementation of response options is almost always location and context specific there is *high confidence* that successful implementation is helped by considering all locally applicable policy instruments and response options in terms of their trade-offs and synergies. {6.5, 7.5.8, 7.6.7}

C3.2. Many response options in the food system that lead to improved health (e.g. through improved diets) are low cost, with some even being cost negative (*robust evidence; high agreement*). Investments in land restoration and rehabilitation in dryland areas have positive economic returns (*high confidence*). {3.7.1, 5.5.2, 6.5, 7.4.1}

C3.3. On-farm and off-farm livelihood diversification strategies can increase the resilience of rural agricultural households against extreme weather events, such as droughts, and desertification (*high confidence*). Strengthening collective action is important for addressing desertification causes and impacts, and for adapting to climate change (*medium confidence*). Access to markets, such as those based on new information and communication technologies, raises agricultural profitability and motivates investment into climate change adaptation and sustainable land management (*medium confidence*). Promoting schemes that provide payments for ecosystem services can provide additional incentives to land users to adopt sustainable land management practices (*medium evidence, high agreement*). {3.7, 3.7.2, 3.7.3, 5.3.1, 5.6.3}

C3.4. The reduction of demand for agricultural commodities can help to achieve sustainable land management, reverse desertification and land degradation, reduce greenhouse gas emissions and enhance food supply (*robust evidence, high/medium agreement*). Reduction of food waste, shifting diets and different protein sources, increased appreciation of the multiple benefits arising from the protection of biodiversity all have demonstrable positive impacts on land use. {5.5.2

C3.5. Sustainable land management strategies often require upfront investment as benefits for communities and for climate change adaptation and mitigation accrue over longer time frames. {4.10.1}

C4. Sustainable land management decisions take into consideration the local engagement of stakeholders, social learning, and a suite of purposefully designed policy instruments (*high confidence)*. Collaboration between relevant institutions and actors can increase the effectiveness of policy instruments (*medium confidence*). {7.6.5, 7.7.6}

C4.1. Stakeholder involvement at all levels of decision making and policy selection utilising adaptive management and governance is an effective mechanism to foster sustainable land management (*high confidence*). Policy response to land and climate risk involves multiple actors (people, communities, farmers, decision makers, governments) across all levels of government (local, subnational, national, global), different sectors (such as disaster response, food systems, water resources and health) at different time scales (immediate extreme events of flood or fire, or slow onset impacts of desertification) (*high confidence*). {4.10.2, 7.5.1, 7.7.2}

C4.2. A portfolio of policy instruments to advance accountability, legitimacy, and responsiveness to society could include favourable loans, tax measures and financial support to catalyse entrepreneurial leadership and build awards for community resource management. Such portfolios would prevent elite capture and ensure inclusive meaningful participation. Inclusive involvement of people in natural resource management and decisions, and procedures that avoid exclusion, discrimination, or marginalisation enhance natural resource service delivery and may address informal coping strategies that result in maladaptation. {7.7.5, 7.6.7}

C4.3. Actions taken by multiple actors can address economic, biophysical, technological, institutional, educational, cultural and behavioural barriers to implementation (*robust evidence, high agreement*). Effective coordinated action involves a range of actors, including consumers, land managers, indigenous and local communities as well as policymakers (*robust evidence, high agreement*). {6.5.5}

C4.4. Indigenous and local knowledge distilled into traditional agroecological practices contributes to enhancing resilience against climate change and combating desertification (*medium confidence*). Innovative combinations of indigenous and local knowledge and modern agronomic practices can contribute to overcoming combined challenges of climate change and desertification (*medium confidence*). {3.7.1, 3.7.2}

C5. Tackling the complex challenges associated with climate change and land interactions will require innovative approaches to decision-making and policy instrument design, including co-development and participatory approaches as well as improved monitoring reporting and verification practices. {1.3.1, 1.4.1, 1.4.2, 7.5.6, 7.6.5}

C5.1. Purposefully designed policy instruments can achieve sustainable land management and address food and land tenure security (appropriate land use allocation, demand management), zero net land degradation, and biodiversity and ecosystem services conservation. They can also minimise hazards (safety nets, social protection schemes, insurance) such as droughts (early warning systems, demand side water management), floods (taxes, non-perverse subsidies, flood insurance, marketable permits and transferable development rights, catastrophe bonds, contingency finance, forecast based finance) and achieve GHG mitigation (financing mechanisms, carbon pricing, technology transfer). {7.4.2; 7.7.4}

C5.2. If sustainability criteria are considered in the global trade of land and land-based commodities, vulnerabilities to climate and socio-economic changes can be reduced (*high confidence*). Local action and global trade in agricultural and forestry commodities can enhance local food, timber or bioenergy supply and thus also contribute to food security and land restoration (*very high confidence*). Ensuring stable food supply while pursuing climate mitigation and adaptation, will benefit from evolving trade rules and policies that allow internalisation of the cost of carbon (and costs of other vital resources such as water, nutrients). Internalising the full costs of land and natural resource degradation within the price of land products would contribute to reducing resource degradation. {1.3.1, 1.4.1, 1.4.2, 1.3.1, 7.5.6}

D - Opportunities for immediate action

D1. Enough is known to take action now. Cost-effective options that take into account sustainable development needs are available for immediate local application (*high confidence*). {5.5, 6.5, 6.9}

D 1.1. Site-specific technological solutions, based both on new scientific innovations and indigenous and local knowledge, are available to avoid, reduce and reverse desertification, simultaneously contributing to climate change mitigation and adaptation (*high confidence*). Current actions are already generating site specific and immediate benefits for affected communities as well as medium- and long-term benefits at the global level in terms of climate change adaptation and mitigation. There is little risk of adverse side-effects if the best available knowledge is used to design implementation plans for these "no regrets" options (*high confidence*). {5.5.1, 5.5.2, 5.6, 6.5, 4.10, Table 4.2}

D 1.2. Many "no regrets" response options which have multiple benefits in terms of desertification, land degradation, food security, and climate mitigation and adaptation (e.g., improved health through improved diets) are low cost, with some even being cost negative (*robust evidence, high agreement*). {6.5}

D 1.3. Recognising the dimensions of risk over time and space as well as the interactions of land, climate and society hazards can help address substantive, emerging, and cascading risks, preventing tipping points while optimising synergies and avoiding trade-offs. {7.3}

D 1.4. There are potential synergies between poverty reduction efforts and the elimination of land-intensive low-productivity practices of rural populations (e.g., slash and burn agriculture, overharvesting of woodfuels) and thereby providing mitigation, adaptation and development benefits at the same time as preserving ecosystems services. {Table 4.3, 3.7, 4.10, 7.5, 7.6}

D 1.5. Land sectors that include significant impacts from short-lived climate forcers (SLCFs) such as agricultural burning and traditional woodfuels offer the potential in the near term to exploit synergies with other SDGs such as improving indoor and outdoor air pollution and health. {SR1.5, Ch2}

D2. Delayed action will exacerbate challenges linked to climate change and other pressures, decrease the potential of response options, and deprive communities of co-benefits (*high confidence*). Ample evidence suggests that the cost of inaction in mitigation and adaptation, as well as in land use exceeds the cost of immediate action in individual countries, regionally, and worldwide. {4.10, 6.5, 7.4.1}

D 2.1. Early action to address food security yields economic benefits. Each dollar spent on disaster mitigation and risk reduction leads to avoided disaster related economic losses of 4 to 11 dollars. Health interventions yield similar benefits as does early action in relation to biodiversity, water and soil quality, carbon sequestration and recreation preservation (*high confidence*). Measures that restore degraded land and preserve intact soils bolster weather dependent livelihood systems facing changes in precipitation, changes in ecosystems, and changes in land quality. {7.3.4, 7.3.3}

D 2.2. Early actions can generate both site specific and immediate benefits to affected communities as well as global benefits in terms of climate change adaptation and mitigation in the medium and long term (*high confidence*). {4.10, Table 4.2}

D 2.3. Sustainable land management often requires upfront investment. Investments in land restoration and rehabilitation in dryland areas have positive economic returns, but the benefits in terms of climate change adaptation and mitigation are delivered over multiple time frames (*high confidence*). {3.7.1, 4.10.1}

D 2.4. Uncertainty need not present a barrier to immediate decision-making, but care needs to be taken to ensure that actions with long life-times are robust against uncertainty, and that current decisions do not lead to future unintended consequences or maladaptation. Decision-support tools are emerging to assist with these decisions in the face of uncertainty, incorporating principles of flexibility, iteration and consultation (*medium evidence, high agreement*). {1.3, 7.6.2}

D3. Immediate investment in research and development (R&D), education, capacity building, knowledge and technology transfer can fill knowledge gaps and remove barriers to action for many response options (*high confidence*). {5.5, 6.5, 7.6}

D 3.1. There are knowledge gaps for some response options, particularly among the more recently emerging options (e.g., enhanced weathering of minerals, BECCS), in terms of both their efficacy and their broader impacts (*robust evidence*, *high agreement*). {5.6.1, 6.5}

D 3.2. Agricultural technology and reciprocal knowledge transfer can help optimise use of natural resources for food and nutrition security under changing climate conditions in many regions of the world. Indigenous and local knowledge can help the development of effective adaptation strategies. Knowledge is needed on both supply-side and demand-side mitigation, including how to change consumption behavior. Research is needed on how to minimise food loss and waste and to realise the potential of urban agriculture to contribute to climate change mitigation and adaptation. {5.5.1, 5.5.2, 5.6.5, 5.7}

D 3.3. Long-term capacity-building efforts for both resource management and governance mechanisms strengthens technology transfer for mitigation and adaptation in land sectors. {7.4, 7.5.4}

D 3.4. Development of indicators to measure sustainable land management and the progress of climate action is an important component of adaptive management decision-making (*high confidence*). In addition to GHG emissions, agri-environmental indicators (soil, water quality, desertification, water supply and demand, soil erosion, soil salinisation, water quality etc.) are important in measuring and evaluating success of response options and policy mixes. The involvement of people in selection of indicators is important to ensure preservation of aspects of land and climate change important to people (*high confidence*). {3.7, 7.6.6}

D 3.5. Monitoring and measuring progress in relation to the SDGs provides important indicators of sustainable land management. Considering the multiple SDGs allows for holistic consideration of interconnected water, energy, food issues. {7.6.6}

D 3.6. Improving human and institutional capacities and access to early warning, hydro-meteorological and remote sensing-based earth monitoring systems, and expanded use of digital technologies are high return investments for measuring progress in addressing desertification under changing climate (*low evidence*, *high agreement*). Effective national, regional and international monitoring and early warning systems help combat desertification and extreme events (*medium confidence*). Expanded use of new information and communication technologies, remotely sensed information and of "citizen science" for data collection helps in measuring progress towards achieving the land degradation neutrality target and raising public awareness and participation in sustainable land management (*low evidence, high agreement*). {3.7.2, 3.7.3, 3.8.6}