6SM

Interlinkages between desertification, land degradation, food security and greenhouse gas fluxes: Synergies, trade-offs and integrated response options

Supplementary Material

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Supplementary information for Section 6.4.1

Section 6.4.1 includes tables of feasibility dimensions for each of the 40 response options. This section includes the supporting material for those classifications.

Table SM6.1 | Feasibility of land management response options in agriculture, considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Increased food productivity				Limited ability to define and measure indicators of sustainable intensification (Barnes and Thomson 2014)	Better access to credit, services, inputs and markets (Schut et al. 2016)	Educational – for example, educational needs of women, (Pretty and Bharucha 2014), and cultural or behavioural (Martin et al. 2015b)	Since increasing food productivity can be limited by climatic and environmental factors (Olesen and Bindi 2002)
Improved cropland management			USD74 to USD226 ha^{-1}	For example, the need for further development of nitrification inhibitors (Singh and Verma 2007)	Can be institutional in some regions – for example, poor sustainability frameworks (Madlener et al. 2006)	Educational (e.g., lack of knowledge) (Reichardt et al. 2009) and cultural or behavioural (e.g., promotion of cover crops needs to account for farmers' needs (Roesch-McNally et al. 2017)	For example, land access (Bryan et al. 2009; Bustamante et al. 2014)
Improved grazing land management			<USD1 kg of $meat^{-1}$ (Rolfe et al. 2011)	For example, the need for further development of nitrification inhibitors (Singh and Verma 2007)	Can be institutional in some regions – for example, the need for extension services (Ndoro et al. 2014)	Educational – for example, poor knowledge of best animal husbandry practices among farmers (Ndoro et al. 2014), and cultural or behavioural – for example, strong cultural importance of livestock and traditional practices in some communities (Herrero et al. 2016)	For example, unless degraded, grazing lands are already closer to saturation than croplands (Smith et al. 2015)
Improved livestock management			120 to 621 USD ha^{-1} (Barnhart et al. 2000)	For example, many dietary additives are still at low technology readiness level (Beauchemin et al. 2008)	Can be institutional in some regions – for example, need for extension services (Ndoro et al. 2014)	Educational – for example, poor knowledge of best animal husbandry practices among farmers (Ndoro et al. 2014), and cultural or behavioural – for example, strong cultural importance of livestock in some communities (Herrero et al. 2016)	For example, climate suitability of different cattle breeds in a changing climate (Thornton et al. 2009; Rojas-Downing et al. 2017)
Agroforestry			<5 USD tCO_2e^{-1} (Torres et al. 2010) Note that lack of reliable financial support could be a barrier (Hernandez-Morcillo et al. 2018)	There are likely to be relatively few technological barriers (Smith et al. 2007)	Institutional in some regions – for example, seed availability (Lillesø et al. 2011)	Educational – for example, poor knowledge of how best to integrate trees into agro-ecosystems, (Meijer et al. 2015), lack of information, (Hernandez-Morcillo et al. 2018) and cultural or behavioural – for example, farmers' perceptions, (Meijer et al. 2015)	Susceptibility to pests (Sileshi et al. 2008)
Agricultural diversification			Minimal (Wimmer and Sauer 2016) Diversification results in cost saving and risk reduction, thus expected cost is minimal Note that it is not always economically viable (Barnes et al. 2015)	Technological, biophysical, educational, and cultural barriers may emerge that limit the adoption of more diverse farming systems by farmers (Barnett and Palutikof 2015; Ahmed and Stepp 2016; Roesch-McNally et al. 2016)		Technological, biophysical, educational, and cultural barriers may emerge that limit the adoption of more diverse farming systems by farmers (Barnett and Palutikof 2015; Ahmed and Stepp 2016; Roesch-McNally et al. 2016)	Technological, biophysical, educational, and cultural barriers may emerge that limit the adoption of more diverse farming systems by farmers (Barnett and Palutikof 2015; Ahmed and Stepp 2016; Roesch-McNally et al. 2016)

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Reduced grassland conversion to cropland			Minimal (Garibaldi et al. 2017) With increased demand for livestock products, it is expected that livestock has higher returns than crops Note that avoiding conversion is low cost, but there may be significant opportunity costs associated with foregone production of crops	Since the response option involves not cultivating a current grassland, there are likely to be few biophysical or technological barriers	There could be institutional barriers in some regions (e.g., poor governance to prevent conversion)	Educational (e.g., poor knowledge of the impacts of ploughing grasslands), and cultural or behavioural (e.g., strong cultural importance of crop production in some communities)	Since the response option involves not cultivating a current grassland, there are likely to be few biophysical or technological barriers
Integrated water management			Minimal (Lubell et al. 2014) Integrated water management expected to reduce production costs and increase economic efficiency				

Table SM6.2 | Feasibility of land management response options in forests, considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Forest management			70 to 160 USD ha^{-1} (Singer 2016)		For example, better access to credit and markets, etc	Educational (e.g., limited knowledge of the most appropriate techniques)	Forest management affects the climate also through biophysical effects and the emissions of biogenic volatile organic compounds (BVOCs), which are both influenced by species composition
Reduced deforestation and forest degradation			500 to 2,600 USD ha^{-1} Agricultural expansion is the major driver of deforestation in developing countries. Cost of reducing of deforestation is based on opportunity cost of not growing the most common crop in developing countries (Maize) for six years to reach tree maturity, with yield of 8 t ha^{-1} (high); 5 tons ha^{-1} (medium) and 1.5 t ha^{-1} and price of 329 USD t^{-1} Also, reduced deforestation practices have relatively moderate costs, but they require transaction and administration costs (Overmars et al. 2014; Kindermann et al. 2008)		For example, land tenure, economic disincentives and transaction costs (Kindermann et al. 2008)	Educational (e.g., little information available in some regions) and cultural (different realities, e.g., small holder versus industrial production)	For example, susceptibility to climate and other unpredicted events (Ellison et al. 2017)
Reforestation and forest restoration			10 to 100 USD tCO_2e^{-1} (McLaren 2012)			Educational (e.g., low genetic diversity of planted forests) and cultural (e.g., care of forest cultures)	For example, availability of native species seedlings for planting
Afforestation			10 to 100 USD tCO_2e^{-1} (McLaren 2012)		For example, policymakers' commitment (Medugu et al. 2010)		

Table SM6.3 | Feasibility of land management response options for soils, considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Increased soil organic carbon content			50 to 170 USD ha^{-1} (FAO 2014) Based on smallholder farming – which accounts for 72% farms in the world; farmers in India (medium farmers) and largescale farmers in the USA (FAO 2014). The cost indicated is only for manure application and ignores other costs for work done under business as usual (BAU). Assumes application of 10 t ha^{-1} of organic manure after every three years and minimum tillage	For example, difficult to measure and verify (Smith 2006)	Can be institutional in some regions – for example, lack of institutional capacity (Bustamante et al. 2014)	Educational (e.g., poor knowledge of best practices among farmers) (Reichardt et al. 2009) though cultural or behavioural barriers are likely to be small compared to other barriers (Smith et al. 2007; Wollenberg et al. 2016)	For example, soil type (Baveye et al. 2018)
Reduced soil erosion			50 to 240 USD ha^{-1} (Morokong and Blignaut 2019) Based on prevention of soil erosion using terraces with rocks. Costs reported are only for avoided loss of carbon sequestration	Limited technology choices and technical support (Haregeweyn et al. 2015)	For instance, in Ethiopia farmers have shown an increased understanding of the soil erosion problem, but soil conservation programmes face a host of barriers related to limited access to capital, limited benefits, land tenure insecurity (Haregeweyn et al. 2015)	Poor community participation (Haregeweyn et al. 2015)	
Reduced soil salinisation			50 to 250 USD ha^{-1} (ICARDA 2012) For NENA region, salinity control recommended practice is deep ploughing, done once every four to five years to break down the hardpan subsoil. Deep ploughing costs 200 USD ha^{-1} for the four-year cycle or 50 USD ha^{-1} for each cropping season	For example, lack of appropriate irrigation technology; (Machado and Serralheiro 2017; CGIAR 2016; Bhattacharyya et al. 2015)	Lack of alternative irrigation infrastructure (Evans and Sadler 2008; CGIAR 2016)	Educational (poor knowledge of the causes and salinisation and how to address it) (Greene et al. 2016; Dagar et al. 2016) and cultural or behavioural, such as persistence of traditional practices (Greene et al. 2016; Dagar et al. 2016)	For example, lack of alternative water sources (Bhattacharyya et al. 2015; Dagar et al. 2016)
Reduced soil compaction			Negative cost (McLaren 2012)	Both compaction process and remediation technologies are well known (Antille et al. 2016) but technological barriers exist (e.g., few decision support systems for implementation of precision management of traffic compaction)		Educational – for example, knowledge gaps (Antille et al. 2016b)	Some soils are prone to compaction (Antille et al. 2016)
Biochar addition to soil			100 to 800 USD tCO_2e^{-1} (McLaren 2012) A small amount of biochar potential could be available at negative cost, and some at low cost, depending on markets for the biochar as a soil amendment (Shackley et al. 2011; Meyer et al. 2011; Dickinson et al. 2014)	For example, feedstock and pyrolysis temperature have large impacts on biochar properties	Can be institutional in some regions – for example, lack of quality standards (Guo et al. 2016)	Educational – for example, low awareness among end users (Guo et al. 2016) and cultural or behavioural (Guo et al. 2016)	For example, land available for biomass production (Woolf et al. 2010)

Table SM6.4 | Feasibility of land management response options in any/other ecosystems, considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Fire management			0.2 to 6.5 USD billion per country per year (USA, Australia, Canada)	Technologies for fire management exist, but the cost of implementation is relatively moderate, since it requires constant maintenance (North et al. 2015) and can be excessive for some local communities	For example, lack of social or political acceptance (Freeman et al. 2017)	Educational – for example, poor knowledge of best practices, liability issues, casualty risks and little tolerance for management errors (North et al. 2015)	For example, susceptibility to climate and other unpredicted events (Hurteau et al. 2014) or steep or remote areas to its application (North et al. 2015)
Reduced landslides and natural hazards				The implementation of practices for management of landslides and natural hazards is based on engineering works and more resilient cropping systems (Noble et al. 2014; Gill and Malamud 2017), which are often limited by their high costs, as well as biophysical, technological and educational barriers	In the tropics, the most cited barriers for implementing landslide risk reduction measures are scientific and political in nature, and the ratio of implemented versus recommended landslide risk reduction measures is low for most landslide risk reduction components (Maes et al. 2017)	The implementation of practices for management of landslides and natural hazards is based on engineering works and more resilient cropping systems (Noble et al. 2014; Gill and Malamud 2017), which are often limited by their high costs, as well as biophysical, technological and educational barriers	The implementation of practices for management of landslides and natural hazards is based on engineering works and more resilient cropping systems (Noble et al. 2014; Gill and Malamud 2017), which are often limited by their high costs, as well as biophysical, technological and educational barriers
Reduced pollution including acidification			2 to 13 USD per household (Van Houtven et al. 2017)	For example, lack of technology to inject fertilisers below ground to prevent ammonia emissions (Shah et al. 2018)	For example, poor regulation and enforcement of environmental regulations (Yamineva and Romppanen 2017)		Since air pollution is transboundary, sources are often far distant from the site of impact; (Begum et al. 2011)
Management of invasive species/ encroachment			500 to 6,632 USD per ha (Jardine and Sanchirico 2018) High cost is for California invasive alien species control; low cost from control in Massachusetts	In the case of natural enemies, it can be technological (Dresner et al. 2015)	Where agricultural extension and advice services are poorly developed	Education can be a barrier, where populations are unaware of the damage caused by the invasive species. Cultural or behavioural barriers are likely to be small	Restoration programmes can take a long time (Dresner et al. 2015)
Restoration and reduced conversion of coastal wetlands			Costs for coastal wetland restoration projects vary, but they can be cost-effective at scale (Erwin 2009)		Can be institutional in some regions – for example, poor governance of wetland use in some regions (Lotze et al. 2006)	Educational (e.g., lack of knowledge of impact of wetland conversion), though technological and cultural or behavioural barriers are likely to be small compared to other barriers	For example, loss of large predators, herbivores, spawning and nursery habitat (Lotze et al. 2006)
Restoration and reduced conversion of peatlands			4 to 20 USD tCO_2e^{-1} (McLaren 2012)		Can be institutional in some regions – for example, lack of inputs (Bonn et al. 2014)	Educational – for example, lack of skilled labour (Bonn et al. 2014), though technological and cultural or behavioural barriers are likely to be small compared to other barriers	For example, site inaccessibility (Bonn et al. 2014)
Biodiversity conservation			10 to 50 USD tCO_2e^{-1} (Minx et al. 2018)				

Table SM6.5 | Feasibility of land management response options specifically for carbon dioxide removal (CDR), considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Enhanced weathering of minerals			10 to 40 USD tCO_2e^{-1} (McLaren 2012) The main cost (and large energy input) is in the mining and comminution of the minerals (Renforth et al. 2012) with higher total costs compared to other low-cost land management options (Smith et al. 2016a)	High energy costs of comminution (Smith et al. 2016a)	In some regions – for example, lack of infrastructure for this new technology (Taylor et al. 2016)	Educational (e.g., lack of knowledge of how to use these new materials in agriculture). Cultural barriers could occur in some regions, for example, due to minerals lying under undisturbed natural areas where mining might generate public acceptance issues (Renforth et al. 2012)	For example, limited and inaccessible mineral formations (Renforth et al. 2012)
Bioenergy and BECCS		BECCS 'is one of the NET options that is less vulnerable to reversal' (Fuss et al. 2018)	50 to 250 USD tCO_2e^{-1} (McLaren 2012)	While there are a few small BECCS demonstration facilities, BECCS has not been implemented at scale (Kemper 2015)	Institutional barriers include governance issues (Vaughan and Gough 2016)	Cultural barriers include social acceptance (Sanchez and Kammen 2016) with CCS facing concerns of safety and environmental issues and bioenergy facing additional scrutiny because of competition for land and water	Competition for land and water

Table SM6.6 | Feasibility of demand management response options, considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Dietary change				Inadequate storage options (e.g., for fresh fruit and vegetables)	Barriers might also be institutional in some regions – for example, poorly developed dietary health advice (Wardle et al. 2000)	Cultural or behavioural – for example, diets are deeply culturally embedded and behaviour change is extremely difficult to effect, even when health benefits are well known (Macdiarmid et al. 2016); educational – such as poor knowledge of what constitutes a healthy diet (Wardle et al. 2000)	Poor accessibility of healthy foods such and fruit and vegetables (Hearn et al. 1998; Lock et al. 2005)
Reduced post-harvest losses				Lack of low-cost storage and preservation technologies	Barriers are largely institutional, since solutions may require dismantling and redesigning current food value chains	There are few biophysical, educational or cultural barriers, since preventing food loss is a priority in many developing countries	There are few biophysical, educational or cultural barriers, since preventing food loss is a priority in many developing countries
Reduced food waste (consumer or retailer)				Barriers in developing countries include reliability of transportation networks, market reliability, education, technology, capacity, and infrastructure (Kummu et al. 2012)	Specific barriers to reducing consumption waste in industrialised countries include inconvenience, lack of financial incentives, lack of public awareness, low cost of food, quality standards and regulations, consumers' ability to buy food products at any time, generalised oversupply in the distribution, and low prioritisation, among others (Kummu et al. 2012; Graham-Rowe et al. 2014; Diaz-Ruiz et al. 2018). Barriers in developing countries include reliability of transportation networks, market reliability, education, technology, capacity, and infrastructure (Kummu et al. 2012)	Specific barriers to reducing consumption waste in industrialised countries include inconvenience, lack of financial incentives, lack of public awareness, and low prioritisation (Kummu et al. 2012; Graham-Rowe et al. 2014). Barriers in developing countries include reliability of transportation networks, market reliability, education, technology, capacity, and infrastructure (Kummu et al. 2012)	

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Material substitution			Negligible (McLaren 2012)	Improved treatments to prevent against fire and moisture needed (Ramage et al. 2017)	Construction companies hesitant to take risks associated with wooden buildings and insurance companies rate wooden buildings as higher risk (Gustavsson et al. 2006)	People perceive adverse effects of wood products on forests and increased risk of fire (Gustavsson et al. 2006)	

Table SM6.7 | Feasibility of supply management response options, considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Sustainable sourcing		Reversibility could be an issue and, while there are low-cost options, the implementations can be expensive			There are institutional barriers in some contexts (e.g., in low income African, Asian and Latin American countries where challenges associated with food insecurity and climate change vulnerability are more acute) (Ingram et al. 2016)	No obvious biophysical or cultural barriers	No obvious biophysical or cultural barriers
Management of supply chains					Political will within trade regimes, economic laissez-faire policies that discourage interventions in markets, and the difficulties of coordination across economic sectors (Cohen et al. 2009; Gilbert 2012; Poulton et al. 2006)		
Enhanced urban food systems				There are likely to be few biophysical, technological or cultural or behavioural barriers to implementing improved urban food systems, though institutional and education barriers could play a role	There are likely to be few biophysical, technological or cultural or behavioural barriers to implementing improved urban food systems, though institutional and education barriers could play a role	There are likely to be few biophysical, technological or cultural or behavioural barriers to implementing improved urban food systems, though institutional and education barriers could play a role	There are likely to be few biophysical, technological or cultural or behavioural barriers to implementing improved urban food systems, though institutional and education barriers could play a role
Improved food processing and retailing			The implementation of strategies to improve the efficiency and sustainability of retail and agri-food industries can be expensive	Adoption of specific sustainability instruments and eco-innovation practices	Successful implementation is dependent on organisational capacity, the agility and flexibility of business strategies, the strengthening of public-private policies and effectiveness of supply-chain governance	No obvious cultural or behavioural barriers, but educational barriers exist	No obvious biophysical and cultural or behavioural barriers
Improved energy use in food systems				For example, low levels of farm mechanisation	For example, energy efficiency in agriculture depends strongly on the technology level (Vlontzos et al. 2014)	Educational (e.g., poor knowledge of alternative energy sources), and behavioural or cultural – for example, high levels of repetitive labour, making farming unattractive to the youth, and disproportionally affecting women; (Baudron et al. 2015)	

Table SM6.8 | Feasibility of risk management response options, considering cost, technological, institutional, socio-cultural and environmental and geophysical barriers and saturation and reversibility.

Response option	Saturation	Reversibility	Cost	Technological	Institutional	Socio-cultural	Environmental and geophysical
Management of urban sprawl			0.5 to 3 USD trillion yr^{-1} globally (New Climate Economy 2018) Global cost of prevention of urban sprawl by: densification; provision of sustainable and affordable housing; and investment in shared, electric, and low-carbon transport		Barriers to policies against urban sprawl include institutional barriers to integrated land-use planning, and the costs to national governments of restricting or buying back development rights (Tan et al. 2009)		
Livelihood diversification			Barriers to diversification include the fact that poorer households and female headed households may lack assets to invest in new income streams or have a lack of education about new income sources (Berman et al. 2012; Ahmed and Stepp 2016; Ngigi et al. 2017)			Barriers to diversification include the fact that poorer households and female-headed households may lack assets to invest in new income streams, or have a lack of education about new income sources (Berman et al. 2012; Ahmed and Stepp 2016; Ngigi et al. 2017)	
Use of local seeds						Barriers to seed sovereignty include concerns about equitability in access to seed networks and the difficulty of sustaining such projects when development donors leave (Reisman 2017), and disputes over the intellectual property rights associated with seeds (Timmermann and Robaey 2016)	
Disaster risk management			Barriers to early warnig systems include cost; an early warning system for the 80 most climate-vulnerable countries in the world is estimated to cost 2 billion USD over five years to develop (Hallegatte 2012)		Institutional and governance barriers such as coordination and synchronisation among levels also effect some EWS (Birkmann et al. 2015)		
Risk-sharing instruments			10 to 90 USD ha^{-1} (Schnitkey and Sheridan 2017) Insurance cost depends on value of crops. We use maize as an example in USA (high) and Sub-Saharan Africa (low)				

Supplementary information for Section 6.4.3

Section 6.4.3 includes tables regarding interactions for each of the 40 response options with Nature's Contributions to People (NCP) and Sustainable Development Goals (SDGs). This section includes the supporting material for those classifications.

Table SM6.9 | Impacts on Nature's Contributions to People of integrated response options based on land management.

Integrated response options based on land management		Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, flow and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of organisms detrimental to humans	Energy	Food and feed	Materials and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Agriculture	**Increased food productivity**	Higher productivity spares land (e.g., Balmford et al. 2018) especially if intensification is done sustainably.	Likely may reduce native pollinators if reliant on increased chemical inputs (Potts et al. 2010) but not if through sustainable intensification.	N/A	N/A	Increased food productivity might be achieved through increased pesticide or fertiliser use, which causes runoff and dead zones in oceans (Beusen et al. 2016).	Food productivity increases could impact on water quality if increases in chemicals used, but evidence is mixed on sustainable intensification (Rockström et al. 2009; Mueller et al. 2012).	Food productivity increases could impact on water flow due to demand for irrigation (Rockström et al. 2009; Mueller et al. 2012).	Intensification through additional input of nitrogen fertiliser can result in negative impacts on climate, soil, water and air pollution (Tilman et al. 2002).	N/A	Increasing food production through agro-chemicals may increase pest resistance over time (Tilman et al. 2002).	N/A	Sustainable intensification has potential to close yield gaps (Tilman et al. 2011).	N/A	N/A	N/A	N/A	N/A	N/A
	Improved cropland management	Improved cropland management can contribute to diverse agroecosystems (Tscharntke et al. 2005) and promotes soil biodiversity (Oehl et al. 2017)	Better crop management can contribute to maintaining native pollinators (Gardiner et al. 2009).	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Cropland conversion has major impacts on water quantity (Scanlon et al. 2007). Cropland management practices such as conservation tillage improve downstream water quality (Fawcett et al. 1994).	Cropland conversion leads to poorer water quality due to runoff (Scanlon et al. 2007).	Improved cropland management has positive impacts on soils (see main text) (Kern and Johnson 1993)	N/A	Some forms of improved cropland management can decrease pathogens and pests (Tscharntke et al. 2016).	N.A	Conservation agriculture contributes to food productivity and reduces food insecurity (Rosegrant and Cline 2003; Dar and Laxmipathi Gowda 2013; Godfray and Garnett 2014)	N/A	N/A	N/A	N/A	Many cropping systems have cultural components (Tengberg et al. 2012)	N/A
	Improved grazing land management	Can contribute to improved habitat (Pons et al. 2003; Plantureux et al. 2005).	N/A	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Likely will improve water quality (Hibbert 1983)	Likely will improve water flow (Hibbert 1983)	Improved grassland management increases soil carbon and quality (Conant et al. 2001)	N/A	N/A	N/A	Improved grassland management could contribute to food security (O'Mara 2012)	Grassland management can provide other materials (e.g., biofuel materials) (Prochnow et al. 2009)	N/A	N/A	N/A	Many pastoralists have close cultural connections to livestock (Ainslie 2013)	N/A
	Improved livestock management	Can contribute to improved habitat if more efficient animals used, leading to less feed required (Strassburg et al. 2014)	N/A	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	N/A	Improved industrial livestock production can reduce water contamination (e.g., reduced effluents) (Hooda et al. 2000). Improved livestock management can contribute to better water quality such as through manure management (Herrero et al. 2013)	N/A	N/A	N/A	N/A	Improved livestock management can contribute to reduced food insecurity among smallholder pastoralists (Hooft et al. 2012).	Livestock production also produces materials for use (leather, etc) (Hesse 2006)	N/A	N/A	N/A	Many pastoralists have close cultural connections to livestock (Ainslie 2013)	N/A

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Interlinkages Chapter 6 Supplementary Material

Integrated response options based on land management		Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, flow and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of organisms detrimental to humans	Energy	Food and feed	Materials and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Agriculture	**Agroforestry**	Agroforestry mimics natural diversity and can improve habitat (Jose 2009)	Even intensive agroforestry can be beneficial for pollinators (Klein et al. 2002).	Trees in the landscape can remove air pollutants (Sutton et al. 2007)	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Planting trees on farms can increase soil water infiltration capacity (Ilstedt et al. 2007). Agroforestry can be used to increase ecosystem services benefits, such as water quantity and quality (Jose 2009)	N/A	Likely to improve soil (Rao et al. 1997)	Agroforestry can reduce vulnerability to hazards like wind and drought (Thorlakson and Neufeldt 2012)	Landscape diversity generally improves opportunities for biological pest control (Gardiner et al. 2009); reduces pests/pathogens on smallholder farms (Vignola et al. 2015)	Agroforestry can be used to produce biomass for energy (Mbow et al. 2014b)	Agroforestry contributes to food productivity and reduces food insecurity (Mbow et al. 2014b)	Produces timber, firewood and animal fodder (Mbow et al. 2014b)	Can provide medicinal and other resources (Rao et al. 2014)	N/A	N/A	Many cropping systems have cultural components (Rao et al. 2014)	Can contribute to maintaining diversity through native plantings (Rao et al. 2014)
	Agricultural diversification	Crop diversification improves resilience through enhanced diversity to mimic more natural systems and provide in-field habitat for natural pest defences (Lin 2011)	Diversification can enhance pollinator diversity (Altieri and Letourneau 1982; Sardiñas and Kremen 2015)	N/A	N/A	N.A	N/A	N/A	Diversification can introduce some crops that may have positive soil qualities (eg nitrogen fixation) and crop rotation with multiple crops can improve soil carbon (McDaniel et al. 2014)	N/A	Diverse agroecosystems tend to have less detrimental impacts from pests (Gardiner et al. 2009; Altieri and Letourneau 1982)	N/A	Diversification is associated with increased access to income and additional food sources for the farming household (Pretty et al. 2003; Ebert 2014)	Diversification could provide additional materials and farm benefits (Van Huylenbroeck et al. 2007)	Some agricultural diversification can produce medicinal plants (Chauhan 2010)	N/A	N/A	Many cropping systems have cultural components (Rao et al. 2014)	Can contribute to maintaining diversity through native plantings (Sardiñas and Kremen 2015)
	Avoidance of conversion of grassland to cropland	Can preserve natural habitat (Peeters 2009)	N/A	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Will likely improve water quality (inferred from improved soil quality in (Saviozzi et al. 2001)	Will likely improve water flow (inferred from improved soil quality in (Saviozzi et al. 2001)	Will improve soil quality (Saviozzi et al. 2001)	N/A	Diverse agroecosystems tend to have less detrimental impacts from pests (Gardiner et al. 2009; Altieri and Letourneau 1982)	N/A	Reducing cropland conversion can reduce food production (West et al. 2010)	N/A	N/A	N/A	N/A	N/A	Retaining natural ecosystems can preserve genetic diversity (Ekins et al. 2003)
	Integrated water management (IWM)	Ecosystem health and services can be enhanced by improving water management (Boelee et al. 2011). Securing ecosystem (Lloyd et al. 2013), integrated ecosystem-based management into water resources planning and management, linking ecosystem services and water security (Bernex 2016), improving correlation between amount of water resources and supply ecosystem services, combining water resources management and supply of ecosystem services (Liu et al. 2016)	Some integrated water management strategies generate synergies between multiple ecosystem services, such as pollination, yield and farm profitability (Hipólito et al. 2018).	IWM practices exert strong influence on ecosystem structure and function, with potentially large implications for regulating air quality (Xia et al. 2017; Nordman et al. 2018).	IWM supports favourable forests conditions, thereby influencing the storage and flow of water in watersheds (Eisenbies et al. 2007) which are important for regulating microclimates (Pierzynski et al. 2017)	N/A	Improving regulations for water sharing, trading and pricing (ADB 2016), water-smart appliance, water-smart landscapes (Dawadi and Ahmad 2013), common and unconventional water sources in use (Rengasamy 2006) will increase water quantity.	Improving regulation to prevent aquifer and surface water depletion, controlling over water extraction, improvement of water management and management of landslides and natural hazards. Watering shifting sand dunes (sprinkler), water resources conservation (Nejad 2013; Pereira et al. 2002), enhancing rainwater management, reducing recharge and increasing water use in discharge areas (DERM 2011)	IWM provide co-benefits such as healthier soils, more resilient and productive ecosystems (Grey and Sadoff 2007; Liu et al. 2017; Scott et al. 2011)	Change in water availability through improving co-managing floods and groundwater depletion at the river basin such as Managed Aquifer Recharge (MAR), Underground Taming of Floods for Irrigation (UTFI), restore over-allocated or brackish aquifers, groundwater dependent ecosystems protection, reducing evaporation losses are significantly contributed to response climate change and reduced impacts of extreme weather event in desertification areas (Dillon and Arshad 2016)		IWM can support the production of biomass for energy and firewood (Mbow et al. 2014b)	Increasing demand for food, fibre and feed will put great strains on land, water, energy and other resources (WBCSD 2014). Water conservation and balance in the use of natural resources enforcement (water resources, water conservation measures, water allocations) (Ward and Pulido-Velazquez 2008). are good options to response climate change and nature's prevention.	IWM supports favourable forests conditions thereby providing wood and fodder and other materials (Locatelli et al. 2015b). However, conservation restrictions on the storage and flow of water in watersheds (Eisenbies et al. 2007) can restrict the access to resources (e.g., firewood).					

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Forests	**Forest management and forest restoration**	Forest landscape restoration specifically aims to regain ecological integrity and enhance human well-being in deforested or degraded forest landscape (Maginnis and Jackson 2007; Stanturf et al. 2014). For example, facilitating tree species mixture means storing at least as much carbon as monocultures while enhancing biodiversity (Hulvey et al. 2013). Selective logging techniques are mid- way between deforestation and total protection, allowing to retain substantial levels of biodiversity, carbon, and timber stocks (Putz et al. 2012)	Likely contributes to native pollinators (Kremen et al. 2012, 2007)	Trees remove air pollution by the interception of particulate matter on plant surfaces and the absorption of gaseous pollutants through the leaf stomata. Computer simulations with local environmental data reveal that trees and forests in the conterminous USA removed 17.4 million tonnes (t) of air pollution in 2010 (range: 9.0–23.2 million t), with human health effects valued at 6.8 billion USD (range: 1.5–13.0 billion USD) (Nowak et al. 2014)	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Forest cover can stabilise intense runoff during storms and flood events (Locatelli et al. 2015b). Mangroves can protect coastal zones from extreme events (hurricanes) or sea level rise. However, forests can also have adverse side effects for reduction of water yield and water availability for human consumption (Bryan and Crossman 2013).	Forests tend to maintain water quality by reducing runoff and trapping sediments and nutrients (Medugu et al. 2010; Salvati et al. 2014). Precipitation filtered through forested catchments delivers purified ground and surface water (co-benefits) (Calder 2005; Ellison et al. 2017; Neary et al. 2009)	Forests counteract wind-driven degradation of soils, and contribute to soil erosion protection and soil fertility enhancement for agricultural resilience (Locatelli et al. 2015b).	Forest cover can stabilise land against catastrophic movements associated with wave action and intense runoff during storms and flood events (Locatelli et al. 2015b). Reducing harvesting rates and prolonging rotation periods may induce an increased vulnerability of stands to external disturbances and catastrophic events (Yousefpour et al. 2018). Forest management strategies may decrease stand-level structural complexity and may make forest ecosystems more susceptive to natural disasters like wind throws, fires, and diseases (Seidl et al. 2014).	Forests can contribute to weed and pest control and landscape diversity generally improves opportunities for biological pest control (Gardiner et al. 2009)	Sustainable forest management (SFM) may increase availability of biomass for energy (Sikkema et al. 2014b; Kraxner et al. 2013)	The proximity of forest to cropland constitutes a threat to livelihoods in terms of crop raiding by wild animals and in constraints in availability of land for farming (Few et al. 2017). The competition for land between afforestation/ reforestation and agricultural production is a potentially large adverse side effect (Boysen et al. 2017a,b; Kreidenweis et al. 2016; Smith et al. 2013). An increase in global forest area can lead to increases in food prices through increasing land competition (Calvin et al. 2014; Kreidenweis et al. 2016; Reilly et al. 2012; Smith et al. 2013; Wise et al. 2009)	Forests provide wood and fodder and other materials (Locatelli et al. 2015b).However, conservation restrictions to preserve ecosystem integrity can restrict the access to resources (e.g., firewood).	Can provide medicinal and other resources.	Natural ecosystems often inspire learning (Turtle et al. 2015)	Forest landscape restoration specifically aims to enhance human well-being (Maginnis and Jackson 2007; Stanturf et al. 2014). Afforestation/ reforestation and avoided deforestation benefit biodiversity and species richness, and generally improve the cultural and recreational value of ecosystems (co-benefits) (Knoke et al. 2014)	Many forest landscapes have cultural ecosystems services components (Plieninger et al. 2015)	Retaining natural ecosystems can preserve genetic diversity (Ekins et al. 2003)
	Reduced deforestation and forest degradation	Reduced deforestation can enhance connectivity between forest areas and conserve biodiversity hotspots (Ellison et al. 2017; Locatelli et al. 2011, 2015b)	Likely contributes to native pollinators (Kremen et al. 2012)	Trees can improve air pollution problems (Nowak et al. 2014)	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Forests tend to maintain water quality by reducing runoff and trapping sediments and nutrients (Medugu et al. 2010; Salvati et al. 2014)	Due to evapotranspiration, trees recharge atmospheric moisture, contributing to rainfall locally and in distant location, and trees' microbial flora and biogenic volatile organic compounds can directly promote rainfall (Arneth et al. 2010). Trees enhance soil infiltration and, under suitable conditions, improve groundwater recharge (Calder 2005; Ellison et al. 2017; Neary et al. 2009).	Forests counteract wind-driven degradation of soils, and contribute to soil erosion protection and soil fertility enhancement for agricultural resilience (Locatelli et al. 2015b)	Forest cover can stabilise land against catastrophic movements associated with wave action and intense runoff during storms and flood events (Locatelli et al. 2015b)	Landscape diversity generally improves opportunities for biological pest control (Gardiner et al. 2009)	Reduced deforestation may increase availability of some wood for energy and industry	The proximity of forest to cropland constitutes a threat to livelihoods in terms of crop raiding by wild animals (Few et al. 2017). The competition for land between afforestation/ reforestation and agricultural production is a potentially large adverse side effects (Boysen et al. 2017a,b; Kreidenweis et al. 2016; Smith et al. 2013) that can lead to increases in food prices (Calvin et al. 2014; Kreidenweis et al. 2016; Reilly et al. 2012; Smith et al. 2013; Wise et al. 2009)	Could increase availability of biomass (Griscom et al. 2017)	Reduced deforestation can protect forest medicinal plants (Arnold and Pérez 2001)	Natural ecosystems often inspire learning (Turtle et al. 2015)		Many forest landscapes have cultural ecosystems services components (Plieninger et al. 2015)	Retaining natural ecosystems can preserve genetic diversity (Ekins et al. 2003)

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Forests	**Reforestation**	Forest landscape restoration specifically aims to regain ecological integrity and enhance human well-being in deforested or degraded forest landscape (Maginnis and Jackson 2007; Stanturf et al. 2014). Adverse side effects potentially associated to forests include establishment of non-native species, especially with the risks related to the spread of exotic fast-growing tree species (Brundu and Richardson 2016; Ellison et al. 2017).	Likely contributes to native pollinators if native forest species used (Kremen et al. 2007)	Trees can improve air pollution problems (Nowak et al. 2014)	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Forests tend to maintain water quality by reducing runoff and trapping sediments and nutrients (Medugu et al. 2010; Salvati et al. 2014).	Particular activities associated with forest landscape restoration, such as mixed planting, assisted natural regeneration, and reducing impact of disturbances (e.g., prescribed burning) have positive implications for fresh water supply (Ciccarese et al. 2012; Suding et al. 2015).	Forests contribute to soil erosion protection and soil fertility enhancement (Locatelli et al. 2015b)	Forest cover can stabilise land against catastrophic movements associated with wave action and intense runoff during storms and flood events (Locatelli et al. 2015b). Some forest ecosystems can be susceptive to natural disasters like wind throws, fires, and diseases (Seidl et al. 2014)	N/A	Reforestation can increase availability of biomass for energy (Swisher 1994)	The proximity of forest to cropland constitutes a threat to livelihoods in terms of crop raiding by wild animals and in constraints in availability of land for farming (Few et al. 2017). The competition for land between afforestation/ reforestation and agricultural production is a potentially large adverse side effect (Boysen et al. 2017a,b; Kreidenweis et al. 2016; Smith et al. 2013). An increase in global forest area can lead to increases in food prices through increasing land competition (Calvin et al. 2014; Kreidenweis et al. 2016; Reilly et al. 2012; Smith et al. 2013; Wise et al. 2009)	Forests provide wood and fodder and other materials (Locatelli et al. 2015b). However, conservation restrictions to preserve ecosystem integrity can restrict the access to resources (e.g., firewood).	Source of medicines (UNEP 2016)	Natural ecosystems often inspire learning (Turtle et al. 2015)	Afforestation/ reforestation can increase areas available for recreation and tourism opportunities (Knoke et al. 2014)	Many forest landscapes have cultural ecosystems services components (Plieninger et al. 2015)	
	Afforestation	Forest landscape restoration specifically aims to regain ecological integrity and enhance human well-being in deforested or degraded forest landscape (Maginnis and Jackson 2007; Stanturf et al. 2014). In the case of afforestation, simply changing the use of land to planted forests is not sufficient to increase abundance of indigenous species, as they depend on type of vegetation, scale of the land transition, and time required for a population to establish (Barry et al. 2014).	N/a	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Depends on where reforesting occurs, and with what species (Scott et al. 2005). Trees enhance soil infiltration and, under suitable conditions, improve groundwater recharge (Calder 2005; Ellison et al. 2017; Neary et al. 2009)	Afforestation using some exotic species can upset the balance of evapotranspiration regimes, with negative impacts on water availability, particularly in arid regions (Ellison et al. 2017; Locatelli et al. 2015b; Trabucco et al. 2008). Afforestation in arid and semi-arid regions using species that have evapotranspiration rates exceeding the regional precipitation may aggravate the groundwater decline (Locatelli et al. 2015b; Lu et al. 2016). Changes in runoff affect water supply but can also contribute to changes in flood risks, and irrigation of forest plantations can increase water consumption (Sterling et al. 2013)	Afforestation and reforestation options are frequently used to counteract land degradation problems (Yirdaw et al. 2017), whereas when they are established on degraded lands they are instrumental to preserve natural forests (co-benefit) (Buongiorno and Zhu 2014). Afforestation runs the risk of decreasing soil nutrients, especially in intensively managed plantations; in one study, afforestation sites had lower soil phosphorus (P) and nitrogen (N) content (Berthrong et al. 2009)	Some afforestation may make forest ecosystems more susceptive to natural disasters like wind throws, fires, and diseases (Seidl et al. 2014)	N/A	Afforestation may increase availability of biomass for energy use (Obersteiner et al. 2006)	Future needs for food production are a constraint for large-scale afforestation plans (Locatelli et al. 2015b). Global food crop demand is expected by 50%–97% between 2005 and 2050 (Valin et al. 2014). Future carbon prices will facilitate deployment of afforestation projects at expenses of food availability (adverse side effect), but more liberalised trade in agricultural commodities could buffer food price increases following afforestation in tropical regions (Kreidenweis et al. 2016).	Could increase availability of biomass (Griscom et al. 2017)	N/A	N/A	Green spaces support psychological well-being (Coldwell and Evans 2018)	Afforestation/ reforestation can increase areas available for recreation and tourism opportunities (Knoke et al. 2014)	N/A

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Soils	**Increased soil organic carbon content**	Improving soil carbon can increase overall resilience of landscapes (Tscharntke et al. 2005)	N/A	N/A	See main text for mitigation potentials	Rivers transport dissolved organic matter to oceans (Hedges et al. 1997), but unclear if improved SOM will decrease this and by how much.	Soil organic matter (SOM) is known to increase water filtration and can regulate downstream flows (Keesstra et al. 2016)	Soil organic matter is known to increase water filtration and protects water quality (Lehmann and Kleber 2015)	Increasing SOM contributes to healthy soils (Lehmann and Kleber 2015)	N/A	Increased SOM decreases pathogens in soil (Lehmann and Kleber 2015)	N/A	Lal (2006) notes that 'Food-grain production in developing countries can be increased by 24–39 (32±11) million Mgy-1 through improving soil quality by increasing the SOC pool and reversing degradation processes.'	In terms of raw materials, numerous products (e.g., pharmaceuticals, clay for bricks and ceramics, silicon from sand used in electronics, and other minerals; (Sindelar 2015) are provided by soils.	In terms of raw materials, numerous products (e.g., pharmaceuticals, clay for bricks and ceramics, silicon from sand used in electronics, and other minerals; (Sindelar 2015) are provided by soils.	N/A	N/A	N/A	N/A
	Reduced soil erosion	Managing soil erosion decreases need for expanded cropland into habitats (Pimentel et al. 1995)	N/A	Particulate matter pollution, a main consequence of wind erosion, imposes severe adverse impacts on materials, structures and climate which directly affect the sustainability of urban cities (Al-Thani et al. 2018)	N/A	N//A	Managing soil erosion improves water quality (Pimentel et al. 1995)	Managing soil erosion improves water flow (Pimentel et al. 1995)	Will improve soil quality (Keesstra et al. 2016)	Reducing soil erosion reduces vulnerability to hazards like wind storms in dryland areas and landslides in mountainous areas (El-Swaify 1997)	N/A	N/A	Managing erosion can lead to increased food production on croplands; however, other forms of management (revegetation, zero tillage) might reduce land available for food.	N/A	N/A	N/A/	N/A	N/A	N/A
	Reduced soil salinisation	Salinisation decreases soil microbial diversity (Nie et al. 2009)	N/A	N/A	N/A	N/A	N/A	Management of soil salinity improves water quality (Kotb et al. 2000; Zalidis et al. 2002; Soane and Van Ouwerkerk 1995)	Will improve soil quality (Keesstra et al. 2016)	N/A	N/A	N/A	Reversing degradation contributes to food productivity and reduces food insecurity (Shiferaw and Holden 1999; Pimentel et al. 1995)	N/A	N/A	N/A/	N/A	N/A	N/A
	Reduced soil compaction	Preventing compaction can reduce need to expand croplands (Lal 2001)	N/A	N/A	N/A	N/A	Compaction can increase water runoff (Soane and Van Ouwerkerk 1995). Management of soil compaction improves water quality and quantity (Soane and Van Ouwerkerk 1995; Zalidis et al. 2002)	Management of soil compaction improves water quality and quantity (Soane and Van Ouwerkerk 1995; Zalidis et al. 2002)	Will improve soil quality (Keesstra et al. 2016)	Compaction in soils increases rates of runoff and can contribute to floods (Hümann et al. 2011)	N/A	N/A	Compactions reduces agricultural productivity and thus contributes to food insecurity (Nawaz et al. 2013)	N/A	N/A	N/A	N/A	N/A	N/A
	Biochar addition to soil	N/A	N/A	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Biochar improves soil water filtration and retention (Spokas et al. 2012; Beck et al. 2011)	Biochar improves soil water filtration and retention (Spokas et al. 2012; Beck et al. 2011)	Can improve soil quality (Sohi 2012)	N/A	N/A	N/A	Contributes to increased food production (Smith 2016) (Jeffery et al. 2017)	N/A	N/A	N/A	N/A	N/A	N/A
Other ecosystems	**Fire management**	Proactive fire management can improve natural habitat (Burrows 2008)	Reducing fire risk can improve habitat for pollinators (Brown et al. 2017)	Fire management improves air quality particularly in the periurban interface (Bowman and Johnston 2005)	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Fires affect water quality and flow due to erosion exposure (Townsend and Douglas 2000)	Fires affect water quality and flow due to erosion exposure (Townsend and Douglas 2000)	Fire cause damage to soils, therefore fire management can improve them (Certini 2005)	Will reduce risk of wildfires as a hazard (McCaffrey 2004)	Landscape diversity generally improves opportunities for biological pest control (Gardiner et al. 2009)	Will increase availability of biomass, as fuel removal is a key management strategy (Becker et al. 2009)	N/A	N/A	N/A	N/A	Reduced wildlife risk will increase recreation opportunities in landscapes (Venn and Calkin 2011)	N/A	Retaining natural ecosystems can preserve genetic diversity (Ekins et al. 2003)
	Reduced landslides and natural hazards	Can preserve natural habitat (Dolidon et al. 2009)	N/A	N/A	N/A	N/A	Likely will improve water quality (Dolidon et al. 2009)	Likely will improve water flow (Dolidon et al. 2009)	Will improve soil quality (Keesstra et al. 2016)	Will reduce risk of disasters (Dolidon et al. 2009; Kousky 2010)	N/A	N/A	Landslides are one of the natural disasters that have impacts on food security (De Haen and Hemrich 2007)	N/A	N/A	N/A	N/A	N/A	N/A

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Other ecosystems	**Reduced pollution including acidification**	Air pollution like acid rain has major impacts on habitats like lakes (Schindler et al. 1989)	Pollution interferes with scents, which impact pollinators ability to detect resources (McFrederick et al. 2008)	Will improve air quality with public health benefits (Nemet et al. 2010)	See main text for mitigation potentials	N/A	N/A	Pollution increases acidity of surface water, with likely ecological effects (Larssen et al. 1999)	Soil acidification due to air pollution in a serious problem in many countries (Hou et al. 2013)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Management of invasive species/ encroachment	Improved management of IAS can lead to improved habitat and ecosystems (Richardson and Wilgen 2004)	Invasive species can disrupt native plant-pollinator relations (Ghazoul 2004)	N/A	N.A	N/A	Many invasives can reduce water flow (Richardson and Wilgen 2004)	Invasive species can reduce water quality (Burnett et al. 2007; Chamier et al. 2012)	Likely to improve soil as invasive species generally have negative effects (Ehrenfeld and Scott 2001)	N/A	Many IAS are harmful pests (Charles and Dukes 2008)	N/A	IAS can compete with crops and reduce crop yields by billions of dollars annually (Pejchar and Mooney 2009)	Many invasives are important suppliers of materials (Pejchar and Mooney 2009)	N/A	N/A	N/A	N/A	Reducing invasives can increase biological diversity of native organisms (Simberloff 2005)
	Restoration and avoided conversion of coastal wetlands	Will preserve natural habitat (Griscom et al. 2017)	Will promote natural pollinators (Seddon et al. 2016)	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	The creation or restoration of wetlands, tidal marshes, or mangroves provide water retention and protect coastal cities from storm surge flooding and shoreline erosion during storms. Wetlands store freshwater and enhance water quality (Bobbink et al. 2006)	Wetlands store freshwater and enhance water quality (Bobbink et al. 2006)	Will improve soil quality (Griscom et al. 2017)	The creation or restoration of wetlands, tidal marshes, or mangroves provide water retention and protect coastal cities from storm surge flooding and shoreline erosion during storms (Gittman et al. 2014; Haddad et al. 2016; Kaplan and Hepcan 2009)	Landscape diversity generally improves opportunities for biological pest control (Gardiner et al. 2009)	N/A	Mixed evidence: can affect agriculture/ fisheries production when competition for land occurs, or could increase food production when ecosystems are restored (Crooks et al. 2011)	Could increase availability of biomass (Griscom et al. 2017)	Wetlands can be sources of medicines (UNEP 2016)	Natural ecosystems often inspire learning (Turtle et al. 2015)	Natural environments support psychological well-being (Coldwell and Evans 2018)	Natural environments support psychological well-being (Coldwell and Evans 2018)	Retaining natural ecosystems can preserve genetic diversity (Ekins et al. 2003)
	Restoration and avoided conversion of peatlands	Will preserve natural habitat (Griscom et al. 2017)	Could promote natural pollinators (Seddon et al. 2016)	N/A	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Peatland restoration will improve water quality as they play important roles in water retention and drainage (Johnston 1991)	Peatland restoration will improve water quality as they play important roles in water retention and drainage (Johnston 1991)	Will improve soil quality (Griscom et al. 2017)	N/A	Landscape diversity generally improves opportunities for biological pest control (Gardiner et al. 2009)	Will reduce supply of any biomass or energy sourced from peatlands (Pin Koh 2007)	May reduce land available for smallholders in tropical peatlands (Jewitt et al. 2014)	Will reduce supply of some materials sourced from peatlands (e.g palm oil, timber) (Murdiyarso et al. 2010)	Natural ecosystems are often source of medicines (UNEP 2016)	Natural ecosystems often inspire learning (Turtle et al. 2015)	Natural environments support psychological well-being (Coldwell and Evans 2018)	Natural environments support psychological well-being (Coldwell and Evans 2018)	Retaining natural ecosystems can preserve genetic diversity (Ekins et al. 2003)
	Biodiversity conservation	Biodiversity conservation includes measures aiming to promote species richness and natural habitats, and to mantain them through protected areas (Cromsigt et al. 2018)	Reduced or absent populations of seed-dispersing animals result in poor to no dispersal, especially of large-seeded trees that depend on large animals such as elephants (Anzures-Dadda et al. 2011; Brodie and Aslan 2012; Beaune et al. 2013; Brockerhoff et al. 2017). Animal pollination, which is fundamental to the reproduction and persistence of most flowering plants, is an important ecosystem service (Millennium Ecosystem Assessment (MA) 2005) As biodiversity contributes to various ecosystem processes, functions and services, the declining diversity and abundance of pollinators (mainly insects and birds) has raised concerns about the effects on both wild and crop plants (Potts et al. 2010)	Trees in the landscape ensured by protected areas can remove air pollutants (Sutton et al. 2007)	See main text for mitigation potentials		Many actions taken to increase biodiversity (eg protected areas) can also have incidental effects of improving water quantity (Egoh et al. 2009)	Many actions taken to increase biodiversity (eg protected areas) can also have incidental effects of improving water quality (Egoh et al. 2009)	Management of wild animals and protected habitats can influence soil conditions via changes in fire frequency (as grazers lower grass and vegetation densities as potential fuels) and nutrient cycling and transport (by adding nutrients to soils). Conserving and restoring megafauna in northern regions also prevents thawing of permafrost. Management of wild animals can influence land degradation processes by grazing, trampling and compacting soil surfaces, thereby altering surface temperatures and chemical reactions affecting sediment and carbon retention. (Cromsigt et al. 2018; Schmitz et al. 2018)	Management of wild animals can influence fire frequency as grazers lower grass and vegetation densities as potential fuels (Schmitz et al. 2014)			Regulation of wild animals affects food for hunting and availability of potential feed for livestock (Cromsigt et al. 2018)		Source of medicines (UNEP 2016)	Natural ecosystems often inspire learning (Turtle et al. 2015)	indigenous peoples commonly link forest landscapes and biodiversity to tribal identities, association with place, kinship ties, customs and protocols, stories, and songs (Gould et al. 2014); (Lyver et al. 2017b,a)		Retaining natural ecosystems can preserve genetic diversity (Ekins et al. 2003)

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Integrated response options based on land management		Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, flow and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of organisms detrimental to humans	Energy	Food and feed	Materials and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Carbon dioxide removal	**Enhanced weathering of minerals**	N/A	N/A	N/A	See main text for mitigation potentials	Addition of basic minerals counteracts ocean acidification (Taylor et al. 2016).	N/A	May have negative effects on water quality (Atekwana et al. 2005)	Could improve soil quality (Rau and Caldeira 1999; Kantola et al. 2017)	N/A	N/A	N/A	Can contribute to increase food production by replenishing plant available silicon, potassium and other plant nutrients (Beerling et al. 2018)	N/A	N/A	N/A	N/A	N/a	N/A
	Bioenergy and BECCS	Likely will reduce natural habitat with negative effects on biodiversity (Hof et al. 2018)	Would reduce natural pollinators due to decreased natural habitat if in competition (Keitt 2009)	The use of BECCS could reduce air pollution (IPCC 2018)	See main text for mitigation potentials	Mitigation potential (see main text) will reduce ocean acidification.	Will likely require water for plantations of fast growing trees and models show high risk of water scarcity if BECCS is deployed on widespread scale (Smith et al. 2016a; Hejazi et al. 2014a; Popp et al. 2011a) through both increases in water withdrawals (Hejazi et al. 2014a; Bonsch et al. 2015) and changes in surface runoff (Cibin et al. 2016)	Bioenergy can affect freshwater quality via changes in nitrogen runoff from fertiliser application. However, the sign of the effect depends on what would have happened absent any bioenergy production, with some studies indicating improvements in water quality (Ng et al. 2010) and others showing declines (Sinha et al. 2019)	Will likely decrease soil quality if exotic fast growing trees used (Stoy et al. 2018)	N/A	N/A	BECCS and biofuels can contribute up to 300 EJ of primary energy by 2100 (Clarke et al. 2014)	BECCS will likely lead to significant trade-offs with food production (Smith et al. 2016a; Popp et al. 2017; Fujimori et al. 2019)	N/A	N/A	N/A	BECCS would drive land-use conversion and reduce opportunities for recreation/tourism.	BECCS would drive land-use conversion and reduce culturally significant landscapes.	BECCS would drive land-use conversion and reduce genetic diversity.

Table SM6.10 | Impacts on Nature's Contributions to People of integrated response options based on value chain management.

Integrated response options based on value chain management		Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, flow and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of organisms detrimental to humans	Energy	Food and feed	Materials and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Demand management	**Dietary change**	Will lead to reduced expansion of ag lands, which can increase natural habitat (Tilman et al. 2001)	N/A	N/A	See main text on climate mitigation impacts	N/A	Will reduce water consumption if less water-intensive food/livestock needs to be produced (Tilman et al. 2001)	Reduced meat consumption will improve water quality (Stoll-Kleemann and O'Riordan 2015)	N/A	N/A	N/A	N/A	Will help increase global food supplies (Kastner et al. 2012)	N/A	N/A	N/A	N/A	N/A	N/A
	Reduced post-harvest losses	Will lead to reduced expansion of ag lands, which can increase natural habitat (Tilman et al. 2001)	N/A	N/A	See main text on climate mitigation impacts	N/A	Will reduce water consumption if less water-intensive food/livestock needs to be produced (Tilman et al. 2001)	N/A	N/A	N/A	Reducing postharvest losses will include measures to deal with pests, some of which could be biological (Wilson and Pusey 1985)	N/A	Will help increase global food supplies (Kastner et al. 2012)	N/A	N/A	N/A	N/A	N/A	N/A
	Reduced food waste (consumer or retailer)	Improved storage and distribution reduces food waste and the need for compensatory intensification of agricultural areas thereby creating co-benefits for reduced land degradation (Stathers et al. 2013)			See main text on climate mitigation impacts		Will reduce water consumption if less water-intensive food/livestock needs to be produced (Tilman et al. 2001)	Reduced food production will reduce N fertiliser use, improving water quality (Kibler et al. 2018)	N/A	N/A	N/A	N/A	Will help increase global food supplies (Kastner et al. 2012)	N/A	N/A	N/A	N/A	N/A	N/A

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Integrated response options based on value chain management		Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, flow and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of organisms detrimental to humans	Energy	Food and feed	Materials and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Demand management	**Material substitution**	Material substitution increases demand for wood, which can lead to loss of habitat (Sathre and Gustavsson 2006)			See main text on climate mitigation impacts	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Material substitution supplies building materials to replace concrete and other nonrewewables (Gustavsson and Sathre 2011)	N/A	N/A	N/A	N/A	N/A
Supply management	**Sustainable sourcing**	Forest certification and other sustainable sourcing schemes can reduce habitat fragmentation as compared to conventional supply chains (Brown et al. 2001; Rueda et al. 2015)	N/A	Forest certification improved air quality in Indonesia by 5% due to reduced incidence of fire (Miteva et al. 2015)	N/A	N/A	Forest certification has led to improved water flow due to decreased road construction for logging (Miteva et al. 2015)	Forest certificaiton has improved riparian waterways and reduced chemical inputs in some schemes (Rueda et al. 2015)	N/A	N/A	N/A	Sustainable sourcing can supply energy like biomass (Sikkema et al. 2014a)	Sustainable sourcing can supply food and other goods (Smith 2008a)	Sustainable sourcing is increasingly important in timber imports (Irland 2008)	Sustainable sourcing can supply medicinals (Pierce and Laird 2003)	N/A	N/A	N/A	N/A
	Management of supply chains	N/A	N/A	Better management of supply chains may reduce energy use and air pollution in transport (Zhu et al. 2018)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Improved supply chains will help increase global food supplies (Hamprecht et al. 2005)	Improved supply chains will help increase material supplies due to efficiency gains (Burritt and Schaltegger 2014)	N/A	N/A	N/A	N/A	N/A
	Enhanced urban food systems	Urban gardening can improve habitat and biodiversity in cities (Orsini et al. 2014; Lin et al. 2015)	Urban beekeeping has been important in keeping pollinators alive (Gunnarsson and Federsel 2014)	Urban agriculture can increase vegetation cover and improve air quality in urban areas (Cameron et al. 2012; Lin et al. 2015)	See main text on climate mitigation impacts	N/A	Water access often a constraint on urban agriculture and can increase demands (de Bon et al. 2010; Badami and Ramankutty 2015)	Urban agriculture can exacerbate urban water pollution problems (pesticide runoff, etc) (Pothukuchi and Kaufman 1999)	N/A	N/A	N/A	N/A	Local urban food production is often more accessible to local populations and can increase food security (Eigenbrod and Gruda 2015)	N/A	N/A	Urban agriculture can be used for teaching and learning (Travaline and Hunold 2010)	N/A	Urban agriculture can promote cultural identities (Baker 2010)	Urban food can contribute to preserving local genetic diversity
	Improved food processing and retail	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Improved energy use in food systems	N/A	N/A	N/A	See main text on climate mitigation impacts	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table SM6.11 | Impacts on Nature's Contributions to People of integrated response options based on risk management.

Integrated response options based on risk management	Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, flow and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of organisms detrimental to humans	Energy	Food and feed	Materials and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Management of urban sprawl	Reducing urban sprawl can help preserve natural habitat in periurban areas (Pataki et al. 2011)	Reducing urban sprawl will help reduce loss of natural pollinators from habitat conversion (Cane 2005)	Urban sprawl is a major contributor to air pollution (Frumkin 2002)	See main text on climate mitigation impacts		Managing urban sprawl can increase water availability (Pataki et al. 2011)	Urban sprawl is associated with higher levels of water pollution due to loss of filtering vegetation and increasing impervious surfaces (Romero and Ordenes 2004; Tu et al. 2007; Pataki et al. 2011)	Likely to be beneficial for soils as soil sealing is major problem in urban areas (Scalenghe and Marsan 2009)	N/A	N/A		Urban sprawl often competes with land for food production and can reduce overall yields (Chen 2007; Barbero-Sierra et al. 2013)	N/A	N/A	N/A	N/A	N/A	N/A
Livelihood diversification	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Diversification is associated with increased access to income and additional food sources for the household (Pretty et al. 2003)	Diversification can increase access to materials (Smith et al. 2017)	N/A	N/A	N/A	N/A	N/A

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Integrated response options based on risk management	Habitat creation and maintenance	Pollination and dispersal of seeds and other propagules	Regulation of air quality	Regulation of climate	Regulation of ocean acidification	Regulation of freshwater quantity, flow and timing	Regulation of freshwater and coastal water quality	Formation, protection and decontamination of soils and sediments	Regulation of hazards and extreme events	Regulation of organisms detrimental to humans	Energy	Food and feed	Materials and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psychological experiences	Supporting identities	Maintenance of options
Use of local seeds	Use of commercial seeds can contribute to habitat loss (Upreti and Upreti 2002)	Use of open pollinated seeds is beneficial for pollinators and creates political will to conserve them (Helicke 2015)	N/A	N/A	N/A	Local seeds often have lower water demands, as well as less use of pesticides that can contaminate water (Adhikari 2014)	Likely to contribute to less pollution as local seeds are usually grown organically (Adhikari 2014)	Likely to contribute to better soils as local seeds are usually grown organically (Adhikari 2014)	N/A	Local seeds often need less pesticides thereby reducing pest resistance (Adhikari 2014)	N/A	Local seeds can lead to more diverse and healthy food in areas with strong food sovereignty networks (Coomes et al. 2015; Bisht et al. 2018). However local seeds often are less productive than improved varieties.		Many local seeds can have multiple functions, including medicinals (Hammer and Teklu 2008)	Passing on seed information is important cultural learning process (Coomes et al. 2015)		Seeds associated with specific cultural identities for many (Coomes et al. 2015)	Food sovereignty movements have promoted saving of genetic diversity of crops through on-farm maintenance (Isakson 2009)
Disaster risk management	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Disaster risk management (DRM) helps people avoid extreme events and adapt to climate change (Mechler et al. 2014)	N/A	N/A	Famine early warning systems have been successful in Sahelian Africa to alert authorities to impending food shortages so that food acquisition and transportation from outside the region can begin, potentially helping millions of people (Genesio et al. 2011; Hillbruner and Moloney 2012)		N/A	N/A	N/A	N/A	N/A
Risk sharing instruments	Commercial crop insurance often encourages habitat conversion; Wright and Wimberly (2013) found a 531,000 ha decline in grasslands in the Upper Midwest of the USA 2006–2010 due to crop conversion driven by higher prices and access to insurance.	Crop insurance is likely to impact natural pollinators due to incentives for production (Horowitz and Lichtenberg 1993)	N/A	N/A	N/A	N/A	Likely to have negative effect as crop insurance encourages more pesticide use (Horowitz and Lichtenberg 1993)	One study found a 1% increase in farm receipts generated from subsidised farm programmes (including crop insurance and others) increased soil erosion by 0.135 tons per acre (Goodwin and Smith 2003)	N/A	Crop insurance increases nitrogen use and leads to treating more acreage with both herbicides and insecticides (Horowitz and Lichtenberg 1993)	N/A	Crop insurance has generally lead to (modest) expansions in cultivated land area and increased food production (Claassen et al. 2011a; Goodwin et al. 2004)		Insurance encourages monocropping leading to loss of genetic diversity for future (Glauber 2004)	N/A	N/A	N/A	Insurance encourages monocropping leading to loss of genetic diversity for future (Glauber 2004)

Table SM6.12 | Impacts on the UN SDG of integrated response options based on land management.

Integrated response options based on land management		GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to Achieve the Goal
Agriculture	**Increased food productivity**	Increasing farm yields for smallholders contributes to poverty reduction (Pretty et al. 2003; Irz et al. 2001)	Increasing farm yields for smallholders reduces food insecurity (Pretty et al. 2003; Irz et al. 2001)	Increased food productivity leads to better health status (Rosegrant and Cline 2003; Dar and Laxmipathi Gowda 2013)	N/A	Increased productivity can benefit female farmers, who make up 50% of agricultural labor in sub-Saharan Africa (Ross et al. 2015)	Food productivity increases could impact water quality if increases in chemicals used, but evidence is mixed on sustainable intensification (Rockström et al. 2009; Mueller et al. 2012)	N/A	Increased agricultural production generally (Lal 2006) contributes to increased economic growth.	N/A	Increased agricultural production can contribute to reducing inequality among smallholders (Datt and Ravallion 1998)	Increased food production can increase urban food security (Ellis and Sumberg 1998)	N/A	See main text on climate mitigation and adaptation	Increased food productivity might be achieved through increased pesticide or fertiliser use, which causes runoff and dead zones in oceans (Beusen et al. 2016)	See main text on desertification and degradation	N/A	Improved agricultural productivity generally correlates with increases in trade in agricultural goods (Fader et al. 2013)
	Improved cropland management	Improved cropland management increases yields for smallholders and contributes to poverty reduction (Pretty et al. 2003; Irz et al. 2001; Schneider and Gugerty 2011)	Conservation agriculture contributes to food productivity and reduces food insecurity (Rosegrant and Cline 2003; Dar and Laxmipathi Gowda 2013; Godfray and Garnett 2014) Land consolidation has played an active role in China to in increase cultivated land area, promoting agricultural production scale, improving rural production conditions and living environment, alle-viating ecological risk and supporting for rural development (Zhou et al. 2019)	Conservation agriculture contributes to improved health through several pathways, including reduced fertiliser/ pesticide use which cause health impacts (Erisman et al. 2011) as well as improved food security.	N/A	N/A	Cropland management practices such as conservation tillage improve downstream and groundwater water quality (Fawcett et al. 1994; Foster 2018). Good management practices can substantially decrease P losses from existing land use, to achieve 'good' water quality in catchment in New Zealand, United Kingdom and United States	N/A	Increased agricultural production generally (Lal 2006) contributes to increased economic growth, mainly in smallholder agriculture (Abraham and Pingali 2017)	N/A	Increased agricultural production can contribute to reducing inequality among smallholders (Datt and Ravallion 1998; Abraham and Pingali 2017)	N/A	Improved conservation agriculture contributes to sustainable production goals (Hobbs et al. 2008)	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	Improved agricultural productivity generally correlates with increases in trade in agricultural goods (Fader et al. 2013)

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Integrated response options based on land management		GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to Achieve the Goal
Agriculture	**Improved grazing land management**	Increases yields for smallholders and contributes to poverty reduction (Boval and Dixon 2012)	Improved grassland management could contribute to food security (O'Mara 2012)	Improved livestock and grazing management could contribute to better health among smallholder pastoralists (Hooft et al. 2012), but pathways are not entirely clear.	N/A	N/A	Grassland management practices can improve downstream and groundwater water quality (Foster 2018).	N/A	Improved land management for livestock can increase economic productivity, especially in global South (Pender et al. 2006)	N/A	Improved pastoral management strategies can contribute to reducing inequality but are context specific (Lesorogol 2003)	N/A	Improved grassland management contributes to sustainable production goals (O'Mara 2012)	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	Grazing land management requires collective action and therefore can increase social capital and build institutions (Mearns 1996)	N/A
	Improved livestock management	Improved livestock management (e.g., better breeding) can contribute to poverty reduction for smallholder pastoralists (Hooft et al. 2012)	Improved livestock management can contribute to reduced food insecurity among smallholder pastoralists (Hooft et al. 2012).	N/A	N/A	N/A	Improved industrial livestock production can reduce water contamination (e.g., reduced effluents) (Hooda et al. 2000). Improved livestock management can contribute to better water quality such as through manure management (Herrero et al. 2013)	N/A	Improved livestock management can increase economic productivity and employment opportunities in global South (Mack 1993)	N/A	N/A	N/A	Sustainable livestock management contributes to sustainable production goals (De Wit et al. 1995)	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	Improved livestock productivity would likely correlate with increases in trade (Herrero et al. 2009)
	Agroforestry	Agroforestry can be usefully used for poverty reduction (Leakey and Simons 1998)	Agroforestry contributes to food productivity and reduces food insecurity (Mbow et al. 2014b)	Agroforestry positively contributes to food productivity and nutritious diets (Haddad 2000)	N/A	Increased use of agroforestry can benefit female farmers as it requires low overhead, but land tenure issues must be paid attention to (Kiptot and Franzel 2012)	Agroforestry can be used to increase ecosystem services benefits, such as water quantity and quality (Jose 2009)	Agroforestry could increase biomass for energy (Mbow et al. 2014b)	Agroforestry and other forms of employment in forest management make major contributions to global GDP (Pimentel et al. 1997)	N/A	Agroforestry promotion can contribute to reducing inequality among smallholders (Leßmeister et al. 2018)	N/A	Agroforestry contributes to sustainable production goals (Mbow et al. 2014b)	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Agricultural diversification	Agricultural diversification is associated with increased welfare and incomes and decreased levels of poverty in several country studies (Arslan et al. 2018; Asfaw et al. 2018; Weinberger and Lumpkin 2007)	Diversification is associated with increased access to income and additional food sources for the farming household (Pretty et al. 2003; Ebert 2014). Diversification can also reduce the risk of crop pathogens spreading across landscapes (Lin 2011)	More diversified agriculture leads to diversified diets which have better health outcomes (Block and Webb 2001; Ebert 2014; Kadiyala et al. 2014), particularly for women and children (Pretty et al. 2003)	N/A	N/A	N/A	N/A	Agricultural diversification can lead to economic growth (Rahman 2009; Pingali and Rosegrant 1995). It allows farmers to choose a strategy that both increases resilience and provides economic benefits, including functional biodiversity at multiple spatial and/or temporal scales, through practices developed via traditional and/or agroecological scientific knowledge (Lin 2011; Kremen et al. 2012)	N/A	Increased agricultural diversification can contribute to reducing inequality among smallholders (Makate et al. 2016) although there is mixed evidence of inequality also increasing in commercialised systems (Pingali and Rosegrant 1995; Weinberger and Lumpkin 2007)	N/A	N/A		N/A	See main text on desertification and degradation	N/A	N/A
	Avoidance of conversion of grassland to cropland	May reduce land available for cropping or livestock for poorer farmers; some grassland restoration programmes in China have been detrimental to poor pastoralists (Foggin 2008)	Can affect food security when competition for land occurs (O'Mara 2012)	N/A	N/A	N/A	Retaining grasslands contributes to better water retention and improved quality (Scanlon et al. 2007)	N/A	Reduced cropland expansion may decrease GDP (Lewandrowski et al. 1999)	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A

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Agriculture	**Integrated water management**	Green water harvesting contributes to alleviate poverty in Sub-Saharan Africa (Rockström and Falkenmark 2015). Improving water irrigation (Rengasamy 2006) improving rainfed agriculture (integrating soil and water management, rainfall infiltration and water harvesting, provides a large co-benefit to delivery of food security and poverty reduction (UNCTAD 2011)	Integrated, efficient, equitable and sustainable water resource management (as water for agroecosystem) plays importance for food production and benefits to people (Lloyd et al. 2013)	Water is a finite and irreplaceable resource that is fundamental to human well-being. It is only renewable if well managed. Integrated water management is vital option for reducing the global burden of disease and improving the health, welfare and productivity of populations. Today, more than 1.7 billion people live in river basins where depletion through use exceeds natural recharge, a trend that will see two-thirds of the world's population living in water-stressed countries by 2025 (UNWater 2015)	N/A	Involving both women and men in integrated water resources initiatives can increase project effectiveness and efficiency (Green and Baden 1995)	Water resource management is intended to solve watershed problems on a sustainable basis, and these problems can be categorised into lack of water (quantity), deterioration in water quality, ecological effects, poor public participation, and low output economic value for investment in watershed-related activities (Lee et al. 2018) Integrated water management, increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity (UNWater 2015).	N/A	Water is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself. Integrated water managment can play a key enabling role in strengthening the resilience of social, economic and environmental systems in the light of rapid and unpredictable changes (UNWater 2015).	N/A	IWM can increase access of industry to water for economic growth (Rahaman and Varis 2005)	Water is a limiting factor in urban growth and IWM can help improve access to urban water supplies (Bao and Fang 2012)	Poor sectoral coordination and institutional fragmentation have triggered an unsustainable use of resources and threatened the long-term sustainability of food, water, and energy security (Rasul 2016)	See main text on climate mitigation and adaptation	IWM on land is likely to improve water quality runoff into oceans (Agboola and Braimoh 2009)	See main text on desertification and degradation	Integrated water management, increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity (UNWater 2015).	
Forestry	**Forest management and forest restoration**	May contribute to poverty reduction if conditions are right (Blomley and Ramadhani 2006; Donovan et al. 2006) but conflicting data, as it may also favor large landowners who are less poor (Rametsteiner and Simula 2003).	Forest expansion can affect crop production when competition for land occurs (Angelsen 2010). An increase in global forest area can lead to increases in food prices through increasing land competition (Calvin et al. 2014; Kreidenweis et al. 2016; Reilly et al. 2012; Smith et al. 2013; Wise et al. 2009)	N/A	N/A	Women face challenges in sustainable forest management (Mwangi et al. 2011) but N/A how SFM affects gender equity.	Forests tend to maintain water quality by reducing runoff and trapping sediments and nutrients (Medugu et al. 2010; Salvati et al. 2014). Due to evapotranspiration, trees recharge atmospheric moisture, contributing to rainfall locally and in distant location, and trees' microbial flora and biogenic volatile organic compounds can directly promote rainfall (Arneth et al. 2010). Trees enhance soil infiltration and, under suitable conditions, improve groundwater recharge Calder 2005; Ellison et al. 2017a; Neary et al. 2009b). Particular activities associated with forest landscape restoration, such as mixed planting, assisted natural regeneration, and reducing impact of disturbances (e.g., prescribed burning) have positive implications for fresh water supply (Ciccarese et al. 2012; Suding et al. 2015).	SFM may increase availability of biomass for energy (Kraxner et al. 2013; Sikkema et al. 2013)	Forest management often require employment for active replanting, etc. (Ros-Tonen et al. 2008)	Forestry supplies wood for industrial use (Gustavsson and Sathre 2011)	N/A	Community forest management can contribute to stronger communities (Pagdee et al. 2006)	Forest management contributes to sustainable production goals, e.g., through certification of timber (Rametsteiner and Simula 2003).	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	Sustainable forest management often requires collective action institutions (Ros-Tonen et al. 2008)	Sustainable forest management can contribute to increases in demand for wood products (e.g., certification) (McDonald and Lane 2004)

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Integrated response options based on land management		GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to Achieve the Goal
Forestry	**Reduced deforestation and forest degradation**	May contribute to poverty reduction but conflicting data. Although poverty is a focus of many REDD+ projects (Arhin 2014), evidence is thin that poverty reduction has actually happened (Corbera et al. 2017; Pokorny et al. 2013; Scheba 2018) and in some cases benefits have been captured by wealthier participants	Avoided deforestation can affect crop production when competition for land occurs (Angelsen 2010).	Reduced deforestation can enhance human well-being by microclimatic regulation for protecting people from heat stresses (Locatelli et al. 2015b) and generally improve the cultural and recreational value of ecosystems (Knoke et al. 2014).	N/A	Unclear how avoided deforestation might enhance gender equity, but REDD+ projects need to pay attention to gender issues to be successful (Westholm and Arora-Jonsson 2015)	Forests tend to maintain water quality by reducing runoff and trapping sediments and nutrients (Medugu et al. 2010; Salvati et al. 2014). Due to evapotranspiration, trees recharge atmospheric moisture, contributing to rainfall locally and in distant location, and trees' microbial flora and biogenic volatile organic compounds can directly promote rainfall (Arneth et al. 2010). Trees enhance soil infiltration and, under suitable conditions, improve groundwater recharge (Calder 2005; Ellison et al. 2017; Neary et al. 2009).	Avoiding deforestation can take biofuel land out of production as they both tend to compete for land (Dixon et al. 2016)	Reduced forest exploitation may decrease GDP and thus needs to be compensated for (e.g., REDD+) (Combes Motel et al. 2009)	N/A	REDD+ has been shown to have no impact on inequality (Shrestha et al. 2017) or to increase inequality in some project areas (Andersson et al. 2018; Pelletier et al. 2018)	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	Likely to contribute to decline in trade in forest products, but increases in partnerships between donors and countries with REDD+ (Combes Motel et al. 2009)
Forestry	**Reforestation**	May contribute to poverty reduction but conflicting data (Tschakert 2007). Many projects for reforestation may have some small impacts on poor households, while others actually increased poverty due to land losses or lack of economic impacts (Jindal et al. 2008)	Forest expansion can affect crop production when competition for land occurs (Angelsen 2010). An increase in global forest area can lead to increases in food prices through increasing land competition (Calvin et al. 2014; Kreidenweis et al. 2016; Reilly et al. 2012; Smith et al. 2013; Wise et al. 2009)	Reforestation can enhance human well-being by microclimatic regulation for protecting people from heat stresses (Locatelli et al. 2015b) and generally improve the cultural and recreational value of ecosystems (Knoke et al. 2014). Trends of forest resources of nations are found to positively correlate with UNDP Human Development Index (Kauppi et al. 2018).	N/A	N/A	Particular activities associated with forest landscape restoration, such as mixed planting, assisted natural regeneration, and reducing impact of disturbances (e.g., prescribed burning) have positive implications for fresh water supply (Ciccarese et al. 2012; Suding et al. 2015).	Reforestation can increase availability of biomass for energy (Swisher 1994)	Reforestation often require employment for active replanting, etc (Jindal et al. 2008)	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
Forestry	**Afforestation**	Although some have argued that afforestation can be a tool for poverty reduction (Holden et al. 2003), afforestation can compete with land available for cropping and poor farmers often do not benefit from afforestation projects (McElwee 2009)	Future needs for food production are a constraint for large-scale afforestation plans (Locatelli et al. 2015b). Global food crop demand is expected by 50%–97% between 2005 and 2050 (Valin et al. 2014). Future carbon prices will facilitate deployment of afforestation projects at expenses of food availability (adverse side effect), but more liberalised trade in agricultural commodities could buffer food price increases following afforestation in tropical regions (Kreidenweis et al. 2016)	Afforestation can enhance human well-being by microclimatic regulation for protecting people from heat stresses (Locatelli et al. 2015b) and generally improve the cultural and recreational value of ecosystems (Knoke et al. 2014). Trends of forest resources of nations are found to positively correlate with UNDP Human Development Index (Kauppi et al. 2018)	N/A	N/A	Afforestation using some exotic species can upset the balance of evapotranspiration regimes, with negative impacts on water availability particularly in arid regions (Ellison et al. 2017; Locatelli et al. 2015b; Trabucco et al. 2008). Afforestation in arid and semi-arid regions using species that have evapotranspiration rates exceeding the regional precipitation may aggravate the groundwater decline (Locatelli et al. 2015b; Lu et al. 2016). Changes in runoff affect water supply but can also contribute to changes in flood risks, and irrigation of forest plantations can increase water consumption (Sterling et al. 2013)	Afforestation may increase availability of biomass for energy use (Obersteiner et al. 2016).	Afforestation often requires employment for active replanting, etc. (Mather and Murray 1987)	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
Soil management	**Increased soil organic carbon content**	Can increase yields for smallholders, which can contribute to poverty reduction, but because adoption often depends on exogenous factors, these need to be taken into consideration (Wollni et al. 2010; Kassie et al. 2013)	Lal (2006) notes that 'Food-grain production in developing countries can be increased by 24–39 (32+-11) million Mgy-1 through improving soil quality by increasing the SOC pool and reversing degradation processes.'	There is evidence that increasing soil organic carbon could be effective in reducing the prevalence of disease-causing helminths (Lal 2016; Wall et al. 2015). Also indirectly contributes to food productivity which may have impact on diets.	N/A	Gender impacts use of soil organic matter (SOM) practices (Quansah et al. 2001), but N/A how the relationship works in reverse.	SOM is known to increase water filtration and protects water quality (Lehmann and Kleber 2015)	N/A	Increased agricultural production generally (Lal 2006) contributes to increased economic growth.	N/A	Increased agricultural production can contribute to reducing inequality among smallholders (Datt and Ravallion 1998).	N/A	Improved conservation agriculture contributes to sustainable production goals (Hobbs et al. 2008)	See main text on climate mitigation and adaptation	Rivers transport dissolved organic matter to oceans (Hedges et al. 1997), but unclear if improved SOM will decrease this and by how much.	See main text on desertification and degradation	N/A	N/A

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Soil management	**Reduced soil erosion**	Can increases yields for smallholders and contributes to poverty reduction (Ananda and Herath 2003)	Contributes to agricultural productivity and reduces food insecurity (Shiferaw and Holden 1999; Pimentel et al. 1995)	Contributes to food productivity and improves farmer health (Shiferaw and Holden 1999; Pimentel et al. 1995)	N/A	N/A	Various researchers showed a relationship between impact of soil erosion and degradation on water quality indicating the source of pollutant as anthropogenic and industrial activities. in China (Issaka and Ashraf 2017). Managing soil erosion improves water quality (Pimentel et al. 1995)	N/A	N/A	N/A	N/A	Particulate matter pollution, a main consequence of wind erosion, imposes severe adverse impacts on materials, structures and climate which directly affect the sustainability of urban cities (Al-Thani et al. 2018)	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Reduced soil salinisation	Salinisation can impoverish farmers (Duraiappah 1998), therefore preventing or reversing can increases yields for smallholders and contributes to poverty reduction.	Reversing degradation contributes to food productivity and reduces food insecurity (Shiferaw and Holden 1999; Pimentel et al. 1995)	Salinisation is known to have human health impacts: wind-borne dust and respiratory health; altered ecology of mosquito-borne diseases; and mental health consequences (Jardine et al. 2007)	N/A	N/A	Management of soil salinity improves water quality and quantity (Kotb et al. 2000; Zalidis et al. 2002)	N/A	N/A	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Reduced soil compaction	Soil compaction and other forms of degradation can impoverish farmers (Scherr 2000) prevention of compaction thus contributes to poverty reduction.	Compactions reduces agricultural productivity and thus contributes to food insecurity (Nawaz et al. 2013)	Soil compaction has human health consequences as it contributes to runoff of water and pollutants into surface and groundwaters (Soane and Van Ouwerkerk 1994)	N/A	N/A	Management of soil compaction improves water quality and quantity (Soane and Van Ouwerkerk 1994; Zalidis et al. 2002)	N/A	N/A	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Biochar addition to soil	Land to produce biochar may reduce land available for smallholders, and it tends to be unaffordable for poor farmers; as of yet, few biochar projects have shown poverty reduction benefits (Leach et al. 2012)	Could potentially affect crop production if competition for land occurs (Ennis et al. 2012)	N/A	N/A	N/A	Biochar improves soil water filtration and retention (Spokas et al. 2012)	N/A	N/A	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
Other ecosystem management	**Fire management**	N/A	N/A	Fire management reduces health risks from particulates (Bowman and Johnston 2005)	N/A	N/A	Fires affect water quality and flow due to erosion exposure (Townsend and Douglas 2000)	N/A	N/A	N/A	N/A	Wildfires can threaten property and human health in urban areas, with unique vulnerabilities (Gill and Stephens 2009); Winter and Fried 2010), therefore management will reduce risk to urban areas.	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Reduced landslides and natural hazards	Landslides can increase vulnerability to poverty (Msilimba 2010), therefore management will reduce risks to the poor.	Landslides are one of the natural disasters that have impacts on food security (De Haen and Hemrich 2007)	Managing landslides reduces health risks (Haines et al. 2006)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Landslide hazards are a major risk to urban areas (Smyth and Royle 2000)	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Reduced pollution including acidification	N/A	N/A	Reducing acid deposition reduces health risks, including respiratory illnesses and increased morbidity (Lübkert-Alcamo and Krzyzanowski 1995; Larssen et al. 1999)	N/A	N/A	Pollution increases acidity of surface water, with likely ecological effects (Larssen et al. 1999)	N/A	N/A	Management of pollution can increase demand for new technologies (Popp 2006).	N/A	Management of pollution can reduce exposure to health risks in urban areas (Bartone 1991)	N/A	See main text on climate mitigation and adaptation	Reduction in pollution can improve water quality running to oceans (Doney et al. 2007)	See main text on desertification and degradation	N/A	N/A

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	Integrated response options based on land management	GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to Achieve the Goal
Other ecosystem management	**Management of invasive species/ encroachment**	Invasive species removal policies have been beneficial to the poor (Van Wilgen and Wannenburgh 2016)	Invasive alien species (IAS) can compete with crops and reduce crop yields by billions of dollars annually (Pejchar and Mooney 2009)	IAS have strong negative effects on human well-being (Pejchar and Mooney 2009)	N/A	N/A	IAS like the golden apple snail/zebra mussel have damaged aquatic ecosystems (Pejchar and Mooney 2009)	N/A	IAS removal policies can increase employment due to need for labour (Van Wilgen and Wannenburgh 2016)	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Restoration and avoided conversion of coastal wetlands	Impacts on poverty are mixed (Kumar et al. 2011). May reduce land available for cropping, and poor design can impoverish people (Ingram et al. 2006; Mangora 2011). Can also decrease vulnerability to coastal storms, however (Jones et al. 2012; Feagin et al. 2010)	Mixed evidence: can affect agriculture/fisheries production when competition for land occurs, or could increase food production when ecosystems are restored (Crooks et al. 2011)	Wetlands contribute to local well-being (Crooks et al. 2011) and restoration generally improve the cultural and recreational value of ecosystems (Knoke et al. 2014).	N/A	N/A	Wetlands store freshwater and enhance water quality (Bobbink et al. 2006)	N/A	Restoration projects often require employment for active replanting, etc. (Crooks et al. 2011)	Protecting coastal wetlands may reduce infrastructure projects in coastal areas (e.g., sea dikes, etc.) (Jones et al. 2012)	N/A	N/A	N/A	See main text on climate mitigation and adaptation	Restoration of coastal wetlands can play a large role in providing habitat for marine fish species (Bobbink et al. 2006; Hale et al. 2009)	See main text on desertification and degradation	N/A	N/A
	Restoration and avoided conversion of peatlands	May reduce land available for smallholders in tropical peatlands (Jewitt et al. 2014)	Can affect crop production when competition for land occurs, although much use of peatlands in tropics is for palm oil, not food (Senaratna Sellamuttu et al. 2011)	N/A	N/A	N/A	Peatland restoration will improve water quality as they play important roles in water retention and drainage (Johnston 1991)	Peatlands in tropics are often used for biofuels and palm oil, so may reduce the availability of these (Danielsen et al. 2009)	Reduced peatland exploitation may decrease GDP in Southeast Asia (Koh et al. 2011)	N/A	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
	Biodiversity conservation	There is mixed evidence on the impacts of biodiversity conservation measures on poverty	Biodiversity, and its management, is crucial for improving sustainable and diversified diets (Global Panel on Agriculture and Food Systems for Nutrition 2016). Indirectly, the loss of pollinators (due to combined causes, including the loss of habitats and flowering species) would contribute to 1.42 million additional deaths per year from non-communicable and malnutrition-related diseases, and 27.0 million lost disability-adjusted life-years (DALYs) per year (Smith et al. 2015). However, at the same time, some options to preserve biodiversity, like protected areas, may potentially conflict with food production by local communities (Molotoks et al. 2017)	Biodiversity, and its management, is crucial for improving sustainable and diversified diets (Global Panel on Agriculture and Food Systems for Nutrition 2016).	N/A	N/A	33 out of 105 of the largest urban areas worldwide rely on biodiversity conservation measures such as protected areas for some, or all, of their drinking water (Secretariat of the Convention on Biological Diversity 2008)	Some biodiversity conservation measures might increase access to biomass supplies (Erb et al. 2012)							Biodiversity conservation measures like protected areas can increase ocean biodiversity (Selig et al. 2014)	Indigenous peoples' roles in biodiversity conservation can increase institutions and conflict resolution (Garnett et al. 2018)	Indigenous peoples commonly link forest landscapes and biodiversity to tribal identities, association with place, kinship ties, customs and protocols, stories, and songs (Gould 2014; Lyver et al. 2017b,a)	
	Enhanced weathering of minerals	N/A	N/A	N/A	N/A	N/A	Mineral weathering can affect the chemical composition of soil and surface waters (Katz 1989)	N/A	N/A	Will require development of new technologies (Schuiling and Krijgsman 2006)	N/A	N/A	N/A	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
Carbon dioxide removal (CDR)	**Bioenergy and bioenergy with carbon capture and storage (BECCS)**	Bioenergy production could create jobs in agriculture, but could also compete for land with alternative uses. Therefore, bioenergy could have positive or negative effects on poverty rates among smallholders, among other social effects (IPCC 2018).	Biofuel plantations may lead to decreased food security through competition for land (Locatelli et al. 2015b). BECCS will likely lead to significant trade-offs with food production (Popp et al. 2011b; Smith et al. 2016a).	BECCS could have positive effects through improvements in air and water quality (IPCC 2018), but BECCS could have negative effects on health and well-being through impacts on food systems (Burns and Nicholson 2017). Additionally, there is a non-negligible risk of leakage of sequestered CO_2 (IPCC 2018).	No direct interaction (IPCC 2018).	No direct interaction (IPCC 2018).	Will likely require water for plantations of fast-growing trees and models show high risk of water scarcity if BECCS is deployed on widespread scale (IPCC 2018).	BECCS and biofuels can contribute up to 300 EJ of primary energy by 2100 (Cross-Chapter Box 7); bioenergy can provide clean, affordable energy (IPCC 2018).	Access to clean, affordable energy will help economic growth (IPCC 2018).	BECCS will require development of new technologies (Smith et al. 2016a)	No direct interaction (IPCC 2018).	No direct interaction (IPCC 2018).	Switching to bioenergy reduces depletion of natural resources (IPCC 2018).	See main text on climate mitigation and adaptation	Reductions in carbon emissions will reduce ocean acidification. See main text on climate mitigation.	See main text on desertification and degradation	No direct interaction (IPCC 2018).	No direct interaction (IPCC 2018).

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Table SM6.13 | Impacts on the UN SDG of integrated response options based on value chain interventions.

Integrated response options based on value chain management		GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to achieve the Goal
Demand management	**Dietary change**	Reduced meat consumption can free up land for other activities to reduce poverty (Röös et al. 2017; Stoll-Kleemann and O'Riordan 2015). However, reduced demand for livestock will have a negative effect on pastoralists and could suppress demand for other inputs (grains) that would affect poor farmers (Garnett 2011; IPCC 2018)	High-meat diets in developed countries may limit improvement in food security in developing countries (Rosegrant et al. 1999); dietary change can contribute to food security goals (Godfray et al. 2010; Bajželj et al. 2014b)	Overnutrition contributes to worse health outcomes, including diabetes and obesity (Tilman and Clark 2014; McMichael et al. 2007). Dietary change away from meat consumption has major health benefits, including reduced heart disease and mortality (Popkin 2008; Friel et al. 2008). Dietary change could contribute to 5.1 million avoided deaths per year (Springmann et al. 2016)	No direct interaction (IPCC 2018)	No direct interaction (IPCC 2018)	Reduced meat consumption will reduce water consumption. Muller et al. (2017) found that lower-impact agriculture could be practiced if dietary change and waste reduction were implemented, leading to lower GHG emissions, lower rates of deforestation, and decreases in use of fertiliser (nitrogen and phosphorus), pesticides, water and energy. However, Tom et al. (2016) found water footprints of fruit/veg dietary shift in the USA to increase by 16%	Dietary shifts away from meat to fish/fruits/vegetables increases energy use in the USA by over 30% (Tom et al. 2016)	Health costs of meat-heavy diets add to health care costs and reduce GDP (Popkin 2008)	N/A	There are currently large discrepancies in diets between developed and developing nations (Sans and Combris 2015). Dietary change will reduce food inequality by reducing meat over-consumption in Western countries and free up some cereals for consumption in poorer diets (Rosegrant et al. 1999)	Dietary change is most needed in urbanised, industrialised countries and can help contribute to demand for locally grown fruits and vegetables (Tom et al. 2016)	A dietary shift away from meat can contribute to sustainable consumption by reducing GHG emissions and reducing cropland and pasture requirements (Stehfest et al. 2009; Bajželj et al. 2014b).	See main text on climate mitigation and adaptation	Dietary change away from meat might put increased pressure on fish stocks (Vranken et al. 2014; Mathijs 2015). Overall reduced emissions would decrease rate of ocean acidification (Doney et al. 2009)	See main text on desertification and degradation	N/A	N/A
Demand management	**Reduced post-harvest losses (PHL)**	Reducing food losses from storage and distribution operation can increase economic well-being without additional investment in production activities (Bradford et al. 2018; Temba et al. 2016)	Reducing food losses increases food availability, nutrition, and lower prices (Sheahan and Barrett 2017b; Abass et al. 2014; Affognon et al. 2015)	Improved storage enhances food quality and can reduce mycotoxin intake (Bradford et al. 2018; Temba et al. 2016; Stathers et al. 2013; Tirado et al. 2010) especially in humid climates (Bradford et al. 2018). The perishability and safety of fresh foods are highly susceptible to temperature increase (Bisbis et al. 2018; Ingram et al. 2016).	Reduced losses can increase income that could be spent on education, but no data is available.	Post-harvest losses do have a gender dimension (Kaminski and Christiaensen 2014), but unclear if reducing losses will contribute to gender equality (Rugumamu 2009)	Kummu et al. (2012) reported that 24% of global freshwater use and 23% of global fertiliser use is attributed to food losses. Reduced PHL can decrease need for additional agricultural production and irrigation.	Reduced losses would reduce energy demands in production; 2030 ±160 trillion BTU of energy were embedded in wasted food in 2007 in the USA (Cuéllar and Webber 2010)	In East and Southern Africa, PHL for six major cereals was 1.6 billion USD or 15% of total production value; reducing losses would thus boost GDP substantially in developing countries with PHL (Hodges et al. 2011)	Reducing PHL can involve improving infrastructure for farmers and marketers (Parfitt et al. 2010)	Poorer households tend to experience more PHL, and thus reducing PHL can contribute to reducing inequality among farmers (Hodges et al. 2011).	N/A	Reducing PHL contributes to sustainable production goals (Parfitt et al. 2010)	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	PHLs contribute to higher food prices and constraints on trade (Tefera 2012)
Demand management	**Reduced food waste (consumer or retailer)**	Food waste tends to rise as incomes rise (Parfitt et al. 2010; Liu et al. 2013), so it is not clear what the relationship to poverty is. Could be potentially beneficial as it would free up money to spend on other activities (Dorward 2012). Redistribution of food surplus to the poor could also have impacts on poverty (Papargyropoulou et al. 2014)	People who are already food insecure tend not to waste food (Nahman et al. 2012). Reduced food waste would increase the supply of food (FAO 2011b; Smith 2013), but it is unclear if this would benefit those who are food insecure in developing countries (Hertel and Baldos 2016).	Food waste can increase with healthier diets (Parizeau et al. 2015). Health and safety standards can restrict some approaches to reducing food waste (Halloran et al. 2014). Changes in packaging to reduce waste might have negative health impacts (e.g., increased contamination) (Claudio 2012)	N/A	Reducing food waste within households often falls to women (Stefan et al. 2013) and can increase their labour workload (Hebrok and Boks 2017). Women also generate more food waste and could be a site for intervention (Thyberg and Tonjes 2016)	Kummu et al. (2012) reported that 24% of global freshwater and 23% of global fertiliser is used in the production of food losses, so reduction in food waste could provide significant co-benefits for freshwater provision and on nutrient cycling (Kummu et al. 2012). Muller et al. (2017) found that lower impact agriculture could be practiced if dietary change and waste reduction were implemented, leading to lower GHG emissions, lower rates of deforestation, and decreases in use of fertiliser (nitrogen and phosphorus), pesticides, water and energy.	Reduced losses would reduce energy demands in production; 2030±160 trillion BTU of energy were embedded in wasted food in 2007 in the USA (Cuéllar and Webber 2010). Food waste can be a sustainable source of biofuel (Uçkun Kiran et al. 2014)	Waste generation has grown faster than GDP in recent years (Thøgersen 1996) Households in the UK throw out 745 USD of food and drink each year as food waste; South Africans throw out 7 billion USD worth of food per year (Nahman and de Lange 2013). Reductions of post-consumer waste would increase household income (Hodges et al. 2011)	Food waste could be an important source of needed chemicals for industrial development in resource-constrained countries (Lin et al. 2013)	Wealthier households tend to waste more food (Parfitt et al. 2010), but unclear how reducing waste may contribute to reducing inequality.	There have been large increases in the throughput of materials such as the food-waste stream, import and solid-waste accumulation in urban areas (Grimm et al. 2008). Reducing compostable food waste reduces need for landfills (Smit and Nasr 1992; Zaman and Lehmann 2011)	Post-consumer food waste in industrialised countries (222 million ton) is almost as high as the total net food production in sub- Saharan Africa (230 million ton). (FAO 2011b), thereby reducing waste contributes to sustainable consumption.	See main text on climate mitigation and adaptation	Reducing food waste may be related to food packaging, which is a major source of ocean pollution, but relationship is not known (Hoornweg et al. 2013).	See main text on desertification and degradation	N/A	Food waste can contribute to higher food prices and constraints on trade (Tefera 2012)

Interlinkages
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Integrated response options based on value chain management		GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to achieve the Goal
Demand management	**Material substitution**	N/A	Could increase demand for wood and compete with land for agriculture, but no evidence of this yet.	N/A	N/A	N/A	If water is used efficiently in production of wood, likely to be positive impact over cement production (Gustavsson and Sathre 2011)	Concrete frames require 60–80% more energy than wood (Börjesson and Gustavsson 2000). Material substitution can reduce embodied energy of buildings construction by up to 20% (Thormark 2006; Upton et al. 2008)	The relationship between material substitution and GDP growth is unclear (Moore et al. 1996)	Material substitution may reduce need for industrial production of cement etc. (Petersen and Solberg 2005)	N/A	Changing materials for urban construction can reduce cities' ecological footprint (Zaman and Lehmann 2013)	Material substitution is a form of sustainable production/ consumption which replaces cement and other energy-intensive materials with wood (Fiksel 2006)	See main text on climate mitigation and adaptation	Overall reduced emissions would decrease rate of ocean acidification (Doney et al. 2009)	See main text on desertification and degradation	N/A	N/A
Supply management	**Sustainable sourcing**	Value-adding has been promoted as a successful poverty reduction strategy in many countries (Lundy et al. 2002; Whitfield 2012; Swanson 2006). Volatility of food supply and food price spikes in 2007 increased the number of people under the poverty line by between 100 million people (Ivanic and Martin 2008) to 450 million people (Brinkman et al. 2009), and caused welfare losses of 3% or more for poor households in many countries (Zezza et al. 2009).	Poor farmers can benefit from value-adding and new markets (Bamman 2007) and may help to improve food security by increasing its economic performance and revenues to local farmers (Reidsma et al. 2010). However, much value-adding is captured upstream, not by poor producers (McMichael and Schneider 2011). Food prices strongly affect food security (Lewis and Witham 2012; Regmi and Meade 2013; Fujimori et al. 2019), and policies to decrease volatility will likely have strong impacts on food security (Timmer 2009; Torlesse et al. 2003; Raleigh et al. 2015)	Value-chains can help increase the nutritional status of food reaching consumers (Fan and Pandya-Lorch 2012)	Value-adding can increase income that could be spent on education, but no data available	Women are highly employed in value-added agriculture in many developing countries, but do not always gain substantive benefits (Dolan and Sorby 2003). Value-chains that target women could increase gender equity, but data are scare (Gengenbach et al. 2018)	Value-added products might require additional water use (Guan and Hubacek 2007), but depends on context.	N/A	Value-adding and export diversification generates additional employment and expands GDP in developing countries in particular (Newfarmer et al. 2009)	Value adding can create incentives to improve infrastructure in processing (Delgado 2010). Expanding value chains can incorporate new sources of food producers into industrial systems of distribution (Bloom and Hinrichs 2011)	Value-adding can be an important component of additional employment for poorer areas, and can contribute to reductions in overall inequality. However, data shows that high-value agriculture is not always a pathway toward enhanced welfare (Dolan and Sorby 2003), and much value-adding is captured not by smallholders but higher up the chain (Neilson 2007)	Value-adding can increase incentives to keep peri-urban agriculture, but faces threats from rising land prices in urban areas (Midmore and Jansen 2003)	Value-adding in agriculture (.e.g., fair trade, organic) can be an important source of sustainable consumption and production (De Haen and Réquillart 2014)	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	Value-adding has a strong relationship to expanding trade in developing countries in particular (Newfarmer et al. 2009)
Supply management	**Management of supply chains**	Reducing food transport costs generally helps poor farmers (Altman et al. 2009). More than 200 million USD is generated in fresh fruit and veg trade between Kenya and the UK; much has contributed to poverty reduction and better transport could increase the amount generated (MacGregor and Vorley 2006; Muriithi and Matz 2015). Volatility of food supply and food price spikes in 2007 increased the number of people under the poverty line by between 100 million people (Ivanic and Martin 2008) to 450 million people (Brinkman et al. 2009), and caused welfare losses of 3% or more for poor households.	Improving storage efficiency can reduce food waste and health risks associated with poor storage management practices (James and James 2010; Bradford et al. 2018; Temba et al. 2016; Stathers et al. 2013; Tirado et al. 2010). There is some limited evidence that improved transport on-farm increases food security in developing countries (Hine 1993).	Access to quality food is a major contributor to whether a diet is healthy or not (Neff et al. 2009). Increased distribution and access of packaged foods, however, can decrease health outcomes (Galal et al. 2010; Monteiro et al. 2011)	Reduction in staple food price costs to consumers in Bangladesh from food stability policies saved rural households 887 USD million total (Torlesse et al. 2003), but N/A if this increased spending on education in households.	Women and girls are often the most effected in households when there are food shortages (Kerr 2005; Hadley et al. 2008)	Food imports can contribute to water scarcity through 'embodied' or 'virtual' water accounting (Yang and Zehnder 2002; Guan and Hubacek 2007; Hanjra and Qureshi 2010; Jiang 2009)	Food supply chains and flows have adverse effects due to reliance on non-renewable energy (Kurian 2017; Scott 2017). Shifts to biofuels can destabilise food supplies (Tirado et al. 2010; Chakauya et al. 2009)	Food supply instability is often driven by price volatility, which can be driven by rapid economic growth, and which can contribute to consumer price inflation and higher import costs as a percentage of GDP leading to account deficits (Gilbert and Morgan 2010)	Excessive disruptions in food supply can place strains on infrastructure (e.g., needing additional storage facilities) (Yang and Zehnder 2002). Improved food transport can create demands for improved infrastructure (Akkerman et al. 2010; Shively and Thapa 2016). For example, weatherproofing transport systems and improving the efficiency of food trade (Ingram et al. 2016; Stathers et al. 2013) especially in countries with inadequate infrastructure and weak food distribution systems (Vermeulen et al. 2012b), can strengthen climate resilience against future climate-related shocks (Ingram et al. 2016; Stathers et al. 2013)	Food volatility makes it more challenging to supply food to vulnerable regions, and likely increases inequality (Baldos and Hertel 2015; Frank et al. 2017; Porter et al. 2014; Wheeler and von Braun 2013). Improved food distribution could reduce inequality in access to high-quality nutritious foods. Food -nsecure consumers benefit from better access and distribution (e.g., elimination of food deserts) (Ingram 2011; Coveney and O'Dwyer 2009)	Improved food distribution can contribute to better food access and stronger urban communities (Kantor 2001; Hendrickson et al. 2006). Food price spikes often hit urban consumers the hardest in food-importing countries, and increasing stability can reduce risk of food riots (Cohen and Garrett 2010)	Improved storage and distribution are likely to contribute to sustainable production by impacting on biomass of paper/ card and aluminum and iron-ore mining used for food packaging (Ingram et al. 2016).	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	Better transport improves chances for expanding trade in developing countries (Newfarmer et al. 2009), Well-planned trade systems may act as a buffer to supply food to vulnerable regions (Baldos and Hertel 2015; Frank et al. 2017; Porter et al. 2014; Wheeler and von Braun 2013).

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	Integrated response options based on value chain management	GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to achieve the Goal
Supply management	**Enhanced urban food systems (UFS)**	Regional food systems present opportunities for interconnectedness of the food system's component resilient food supply systems and city-regions have an important role (Brinkley et al. 2013; Rocha 2016). However, there is mixed evidence on urban agriculture's contribution to poverty reduction (Ellis and Sumberg 1998).	Food insecurity in urban areas is often invisible (Crush and Frayne 2011). Improved UFS manage flows of food into, within, and out of the cities and have large role to play in reducing urban food security (Smit 2016; Benis and Ferrão 2017; Brinkley et al. 2013; Rocha 2016; Maxwell and Wiebe 1999), particularly in fostering regional food self-reliance (Aldababseh et al. 2018; Bustamante et al. 2014).	Since urban poor spend a great deal of their budget on food and urban diets are exposed to more unhealthy 'fast foods' (Dixon et al. 2007), local UFS can contribute to enhanced nutrition in urban areas (Tao et al. 2015; Maxwell 1999; Neff et al. 2009). However, local urban agriculture also may introduce pollution into food systems through toxins in soil and water (Binns et al. 2003).	School feeding programmes in urban areas can increase educational attendance and outcomes (Ashe and Sonnino 2013).	Urban and Peri-urban Agriculture and Forestry (UPAF) addresses gender-based differences in accessing food since women play an important role in the provisioning of urban food (Tao et al. 2015; Binns and Lynch 1998). Women also dominate informal urban food provisioning (wet markets, street food) (Smith 1998).	Water access is often a constraint on urban agriculture (de Bon et al. 2010; Badami and Ramankutty 2015). Urban agriculture can exacerbate urban water pollution problems (pesticide runoff, etc) (Pothukuchi and Kaufman 1999)	Local food production and use can reduce energy use, due to lower demand of resources for production, transport and infrastructure (Lee-Smith 2010), but depends on context (Mariola 2008; Coley et al. 2009)	UFS have as one aim to stimulate local economic development and increase employment in urban agriculture and food processing (Smith 1998). As many as 50% of some cities' retail jobs are in food-related sector (Pothukuchi and Kaufman 1999)	Urban food provisioning creates demands for expanded infrastructure in processing, refrigeration, and transportation (Pothukuchi and Kaufman 1999)	Many UFS in global South (e.g., Belo Horizonte, Brazil) have goals to reduce inequality in access to food. (Dixon et al. 2007; Allen 2010)	UFS aim at improving the health status of urban dwellers, reducing their exposure to pollution levels, and stimulating economic development (Tao et al. 2015)	UFS aim to combine sustainable production and consumption with local foodsheds (Tao et al. 2015; Allen 2010)	See main text on climate mitigation and adaptation	Overall reduced emissions would decrease rate of ocean acidification (Doney et al. 2009)	See main text on desertification and degradation	Building a resilient regional food system requires adjusting to the social and cultural environment and locally-specific natural resource base and building local institutions (Akhtar et al. 2016). Production of food within cities can potentially lead to less likelihood of urban food shortages, and conflicts (Cohen and Garrett 2010)	N/A
	Improved food processing and retailing	Food processing has been a useful strategy for poverty reduction in some countries (Weinberger and Lumpkin 2007; Haggblade et al. 2010).	Efficiency in food processing and supply chains can contribute to more food reaching consumers and improved nutrition (Vermeulen et al. 2012b; Keding et al. 2013)	Improved processing and distribution and storage systems can provide safer and healthier food to consumers (Vermeulen et al. 2012b) and reduce food waste and health risks associated with poor storage management practices (James and James 2010), although overpackaged prepared foods that are less healthy are also on rise (Monteiro 2009; Monteiro et al. 2011).	N/A	Improved food processing can displace street venders and informal food sellers, who are predominantly women (Smith 1998; Dixon et al. 2007).	Food processing and packaging activities such as washing, heating, cooling are heavily dependent on freshwater, so improved postharvest storage and distribution could reduce water demand via more efficiently performing systems (Garcia and You 2016).	Food processing and packaging activities such as heating and cooling are heavily dependent on energy, so improved efficiency could reduce energy demand (Garcia and You 2016).	Phytosanitary barriers currently prevent much food export from developing countries, and improvements in processing would increase exports and GDP (Henson and Loader 2001; Jongwanich 2009).	Improvements in processing, refrigeration, and transportation will require investments in improved infrastructure (Ingram 2011).	N/A	Improved food transport can reduce cities' ecological footprints and reduce overall emissions (Du et al. 2006).	Improved food processing and agro-retailing contributes to sustainable production (Ingram 2011).	See main text on climate mitigation and adaptation	Overall reduced emissions would decrease rate of ocean acidification (Doney et al. 2009)	See main text on desertification and degradation	N/A	Improved processing increases chances for expanding trade in developing countries (Newfarmer et al. 2009)
	Improved energy use in food systems	Might possibly have impact on poverty by reducing farmer costs, but no data.	Utilising energy-saving strategies can support reduced food waste (Ingram et al. 2016) and increased production efficiencies (Smith and Gregory 2013).	Organic agriculture is associated with increased energy efficiency, which have can have co-benefits by reduced exposure to agrochemicals by farm workers (Gomiero et al. 2008).	N/A	Increased efficiency might reduce women's labour workloads on farms (Rahman 2010) but data is scarce.	Increased energy efficiency (e.g., in irrigation) can lead to more efficient water use (Rothausen and Conway 2011; Ringler and Lawford 2013).	Increased energy efficiency will reduce demands for energy but can have rebound effect in expanded acreage (Swanton et al. 1996)	There is no clear association between higher energy use in agriculture and economic growth; these have become decoupled in many countries (Bonny 1993). Data is unclear though on economic impacts of potential cost savings.	N/A	N/A	N/A	Reducing energy use in agriculture contributes to sustainable production goals (Ingram et al. 2016).	See main text on climate mitigation and adaptation	Overall reduced emissions would decrease rate of ocean acidification (Doney et al. 2009).	See main text on desertification and degradation	N/A	N/A

Table SM6.14 | Impacts on the UN SDG of integrated response options based on risk management.

Integrated response options based on risk management	GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to achieve the Goal
Management of urban sprawl	Inner-city poverty closely associated with urban sprawl in US context (Frumkin 2002; Powell 1999; Jargowsky 2002; Deng and Huang 2004).	There are likely to be some benefits for food security since it is often agricultural land that is sealed by the urban expansion (Barbero-Sierra et al. 2013). Some evidence for sprawl reducing food production, particularly in China (Chen 2007).	Strong association between urban sprawl and poorer health outcomes (air pollution, obesity, traffic accidents) (Frumkin 2002; Lopez 2004; Freudenberg et al. 2005).	N/A	N/A	Urban sprawl is associated with higher levels of water pollution due to loss of filtering vegetation and increasing impervious surfaces (Romero and Ordenes 2004; Tu et al. 2007).	Sprawling or informal settlements often do not have access to electricity or other services, increasing chances that households rely on dirty fuels (Dhingra et al. 2008)	Sprawl is associated with rapid economic growth in some areas (Brueckner 2000). Reducing urban sprawl is part of many managed 'smart growth' plans, which may reduce overall economic growth in return for sustainability benefits (Godschalk 2003).	Urban sprawl often increases public infrastructure costs (Brueckner 2000), and densification and redevelopment can improve equality of access to infrastructure (Jenks and Burgess 2000).	Urban sprawl is associated with inequality (Jargowsky 2002)	Urban sprawl is associated with unsustainability, including increased transport and CO_2 emissions, lack of access to services, and loss of civic life (Kombe 2005; Andersson 2006). Sustainable cities include compactness, sustainable transport, density, mixed land uses, diversity, passive solar design, and greening (Chen et al. 2008; Jabareen 2006; Andersson 2006).	Reducing urban sprawl and promoting community gardens and periurban agriculture can contribute to more sustainable production in cities (Turner 2011)	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	There are debates over the role of urban sprawl in reducing social capital and weakening participatory governance in cities (Frumkin 2002; Nguyen 2010)	N/A

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Integrated response options based on risk management	GOAL 1: No Poverty	GOAL 2: Zero Hunger	GOAL 3: Good Health and Well-being	GOAL 4: Quality Education	GOAL 5: Gender Equality	GOAL 6: Clean Water and Sanitation	GOAL 7: Affordable and Clean Energy	GOAL 8: Decent Work and Economic Growth	GOAL 9: Industry, Innovation and Infrastructure	GOAL 10: Reduced Inequality	GOAL 11: Sustainable Cities and Communities	GOAL 12: Responsible Consumption and Production	GOAL 13: Climate Action	GOAL 14: Life Below Water	GOAL 15: Life on Land	GOAL 16: Peace and Justice Strong Institutions	GOAL 17: Partnerships to achieve the Goal
Livelihood diversification	Diversification is associated with increased welfare and incomes and decreased levels of poverty in several country studies (Arslan et al. 2018; Asfaw et al. 2018).	Diversification is associated with increased access to income and additional food sources for the household (Pretty 2003); likely some food security benefits but diversification can also lead to more purchased (unhealthy) foods (Niehof 2004; Barrett et al. 2001).	More diversified livelihoods have diversified diets which have better health outcomes (Block and Webb 2001; Kadiyala et al. 2014) particularly for women and children (Pretty 2003).	More diversified households tend to be more affluent, and have more disposal income for education (Ellis 1998; Estudillo and Otsuka 1999; Steward 2007), but diversification through migration may reduce educational outcomes for children (Gioli et al. 2014)	Women are participants in and benefit from livelihood diversification, such as having increased control over sources of household income (Smith 2014), although it can increase their labour requirements (Angeles and Hill 2009).	Lack of access to affordable water may inhibit livelihood diversification (Calow et al. 2010).	Access to clean energy can provide additional opportunities for livelihood diversification (Brew-Hammond 2010; Suckall et al. 2015).	Livelihood diversification by definition contributes to employment by providing additional work opportunities (Ellis 1998; Niehof 2004).	N/A	The relationship between livelihood diversification and inequality is inconclusive (Ellis 1998). In some cases, diversification reduces inequality (Adams 1994) while in others it increases it (Reardon et al. 2008).	One part of urban livelihoods in developing countries is the linkage between rural and urban areas through migration and remittances (Rakodi 1999; Rakodi and Lloyd-Jones 2002). This livelihood diversification can strengthen urban income (Ricci 2012).	Livelihood diversification does not always lead to sustainable production and consumption choices, but it can strengthen autonomy, potentially leading to better choices (Elmqvist and Olsson 2007; Schneider and Niederle 2010).	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	N/A	N/A
Use of local seeds	Many hundreds of millions of smallholders still rely on local seeds; without them they would have to find money to buy commercial seeds (Altieri et al. 2012; McGuire and Sperling 2016; Howard 2015).	Local seeds revive and strengthen local food systems (McMichael and Schneider 2011) and lead to more diverse and healthy food in areas with strong food sovereignty networks (Coomes et al. 2015; Bisht et al. 2018). However local seeds are often less productive than improved varieties.	Local seed use is associated with fewer pesticides (Altieri et al. 2012) loss of local seeds and substitution by commercial seeds is perceived by farmers to increase health risks (Mazzeo and Brenton 2013), although overall literature on links between food sovereignty and health is weak (Jones et al. 2015).	N/A	Women play important roles in preserving and using local seeds (Ngcoya and Kumarakulasingam 2017; Bezner Kerr 2013) and sovereignty movements paying more attention to gender needs (Park et al. 2015).	Local seeds often have lower water demands, as well as less use of pesticides that can contaminate water (Adhikari 2014).	N/A	Food sovereignty supporters believe that protecting smallholder agriculture provides more employment than commercial agriculture (Kloppenberg 2010).	N/A	Seed sovereignty advocates believe it will contribute to reduced inequality (Wittman 2011; Park et al. 2015) but there is inconclusive empirical evidence.	Seed sovereignty can help sustainable urban gardening (Demailly and Darly 2017) which can be part of a sustainable city by providing fresh, local food (Leitgeb et al. 2016).	Locally developed seeds can help protect local agrobiodiversity and can often be more climate resilient than generic commercial varieties, leading to more sustainable production (Coomes et al. 2015; Van Niekerk and Wynberg 2017).	See main text on climate mitigation and adaptation	N/A	See main text on desertification and degradation	Seed sovereignty is positively associated with strong local food movements, which contribute to social capital (McMichael and Schneider 2011; Coomes et al. 2015; Grey and Patel 2015).	Seed sovereignty could be seen as threat to free trade and imports of genetically modified seeds (Kloppenberg 2010; Howard 2015; Kloppenburg 2014).
Disaster risk management (DRM)	DRM can help prevent impoverishment as disasters are a major factor in poverty (Basher 2006; Fothergill and Peek 2004).	Famine early warning systems (EWS) have successfully prevent impending food shortages (Genesio et al. 2011; Hillbruner and Moloney 2012).	EWS is very important for public health to ensure that people can get shelter and medical care during disasters (Greenough et al. 2001; Ebi and Schmier 2005).	N/A	Women often disproportionately affected by disasters; gender-sensitive EWS can reduce their vulnerability (Enarson and Meyreles 2004; Mustafa et al. 2015)	Many EWS include water-monitoring components that contribute to access to clean water (Wilhite 2005; Iglesias et al. 2007). Some urban areas use water EWS successfully to monitor levels of contaminants (Hasan et al. 2009; Hou et al. 2013).	N/A	DRM can help minimise damage from disasters, which impacts on economic growth (Basher 2006).	DRM can help protect infrastructures from damage during disasters (Rogers and Tsirkunov 2011).	EWS can ensure that inequality is taken into account when making predictions of impacts (Khan et al. 1992).	EWS can be very effective in urban settings – for example, heat wave EWS and flooding EWS to minimise vulnerability (Parnell et al. 2007; Bambrick et al. 2011; Djordjević et al. 2011).	DRM can make sustainable production more possible by providing farmers with advance notice of environmental needs (Stigter et al. 2000; Parr et al. 2003).	See main text on climate mitigation and adaptation	EWS can play important role in marine management, for example, warnings of red tide, tsunami warnings for coastal communities (Lee et al. 2005; Lauterjung et al. 2010).	See main text on desertification and degradation	DRM can reduce risk of conflict (Meier et al. 2007), increase resilience of communities (Mathbor 2007) and strengthen trust in institutions (Altieri et al. 2012)	N/A
Risk-sharing instruments	Crop insurance reduces risks, which can improve poverty outcomes by avoiding catastrophic losses, but is often not used by poorest people (Platteau et al. 2017).	Availability of crop insurance has generally led to (modest) expansions in cultivated land area and increased food production (Claassen et al. 2011a; Goodwin et al. 2004).	General forms of social protection lead to better health outcomes; unclear how much crop insurance contributes (Tirivayi et al. 2016).	Households lacking insurance may withdraw children from school after crop shocks (Jacoby and Skoufias 1997; Bandara et al. 2015).	Women farmers vulnerable to crop shocks, but tend to be more risk-averse and sceptical of commercial insurance (Akter et al. 2016; Fletschner and Kenney 2014).	Crop insurance can be indexed to weather and water access and thereby increase adapation to water stress (Hoff and Bouwer 2003). Subsidised insurance can also be linked to reductions in pesticide use to reduce nonpoint source pollution, which has shown success in the USA and China (Luo et al. 2014)	N/A	Subsidised crop insurance contributes to economic growth in the USA (Atwood et al. 1996) but at considerable cost to the governance (Glauber 2004).	N/A	N/A	N/A	Crop insurance has been implicated as a driver of unsustainable production and disincentive to diversification (Bowman and Zilberman 2013), although community risk-sharing might increase diversification and production.	See main text on climate mitigation and adaptation	There is mixed evidence that crop insurance may encourage excess fertiliser use (Kramer et al. 1983; Wu 1999; Smith and Goodwin 1996), which contributes to ocean pollution; however, some governments are requiring reductions in nonpoint source pollution from farms, otherwise farmers lose crop insurance (Iho et al. 2015).	See main text on desertification and degradation	Community risk-sharing instruments can help strenthen resilience and institutions (Agrawal 2001).	Subsidised crop insurance can be seen as a subsidy and barrier to trade (Young and Westcott 2000).

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Supplementary information for Section 6.5.4

	IAM Study	Climate Change	Mitigation	Adaptation	Desertification	Land Degradation	Food Security	Other
Alexander et al. 2018	No			Yes				Yes
Baker et al. 2019	No		Yes					
Baldos and Hertel 2014	No						Yes	
Bauer et al. 2018	Yes		Yes					
Bertram et al. 2018	Yes		Yes				Yes	Yes
Ten Brink et al. 2018	Mixed				Yes	Yes	Yes	Yes
Calvin et al. 2013	Yes		Yes	Yes				
Calvin et al. 2014	Yes		Yes				Yes	Yes
Calvin et al. 2016a	Yes		Yes					
Calvin et al. 2016b	Yes		Yes					
Calvin et al. 2017	Yes		Yes				Yes	
Calvin et al. 2019	Yes		Yes					Yes
Chaturvedi et al. 2013	Yes		Yes					Yes
Clarke et al. 2014	Yes	Yes	Yes					Yes
Collins et al. 2013	No	Yes						
Daioglou et al. 2019	Yes		Yes					
Doelman et al. 2018	Yes		Yes				Yes	
Edmonds et al. 2013	Yes		Yes					
Favero and Massetti 2014	Yes	Yes	Yes					
Frank et al. 2015	IAM-land		Yes					
Frank et al. 2017	Yes		Yes				Yes	
Fricko et al. 2017	Yes		Yes					
Fujimori et al. 2017	Yes		Yes					
Fujimori et al. 2019	Yes		Yes				Yes	
Fujimori et al. 2019	Mixed		Yes				Yes	
Gao and Bryan 2017	No		Yes			Yes	Yes	Yes
Graham et al. 2018	Yes							Yes
Grubler et al. 2018	Yes		Yes				Yes	Yes
Hanasaki et al. 2013	Yes							Yes
Harrison et al. 2016	Yes							Yes
Hasegawa et al. 2015a	Yes						Yes	
Hasegawa et al. 2015b	Yes						Yes	
Hasegawa et al. 2018	Mixed			Yes			Yes	
Heck et al. 2018	Mixed	Yes	Yes					Yes
Hejazi et al. 2014b	Yes		Yes					Yes
Hejazi et al. 2015	Yes		Yes					Yes
Humpenöder et al. 2014	Yes		Yes					
Humpenöder et al. 2018	IAM-land		Yes				Yes	Yes
Iyer et al. 2018	Yes		Yes				Yes	Yes
Jones et al. 2013	Yes	Yes						
Jones et al. 2015	Yes		Yes					
Kim et al. 2016	Yes			Yes			Yes	Yes
Kraxner et al. 2013	No		Yes					Yes
Kreidenweis et al. 2016	Yes		Yes				Yes	
Kriegler et al. 2017	Yes		Yes				Yes	
Kriegler et al. 2018a	Mixed		Yes					
Kriegler et al. 2018b	Yes		Yes					
Kyle et al. 2014	Yes		Yes	Yes				
Lamontagne et al. 2018	Yes		Yes					

	IAM Study	Climate Change	Mitigation	Adaptation	Desertification	Land Degradation	Food Security	Other
Le Page et al. 2013	Yes		Yes					
Liu et al. 2017	No			Yes			Yes	
Lotze-Campen et al. 2013	Mixed			Yes			Yes	
Monier et al. 2018	Yes	Yes	Yes	Yes				Yes
Mouratiadou et al. 2016	Yes		Yes					Yes
Muratori et al. 2016	Yes		Yes				Yes	
Nelson et al. 2014	Mixed			Yes			Yes	
Newbold et al. 2015	Mixed							Yes
Obersteiner et al. 2016	IAM-land						Yes	Yes
Parkinson et al. 2019	Yes		Yes					Yes
Patrizio et al. 2018	No		Yes					Yes
Pedercini et al. 2018	No						Yes	Yes
Pikaar et al. 2018	IAM-land		Yes					Yes
Popp et al. 2014	Yes		Yes					
Popp et al. 2017	Yes		Yes				Yes	
Powers and Jetz 2019	No							Yes
Riahi et al. 2017	Yes		Yes				Yes	
Ringler et al. 2016	Yes			Yes			Yes	Yes
Rogelj et al. 2018b	Yes		Yes					
Springmann et al. 2018	No		Yes					Yes
Stehfest et al. 2019	Mixed							
Stevanovic et al. 2016	IAM-land			Yes				
Stevanović et al. 2017	IAM-land		Yes				Yes	
Tai et al. 2014	No						Yes	
Thornton et al. 2017	Yes	Yes	Yes	Yes			Yes	
UNCCD 2017	Mixed				Yes	Yes	Yes	Yes
Van Meijl et al. 2018	Mixed		Yes	Yes			Yes	
Van Vuuren et al. 2015	Yes		Yes				Yes	Yes
Van Vuuren et al. 2017a	Yes		Yes					
Van Vuuren et al. 2018	Yes		Yes					
Weindl et al. 2015	IAM-land			Yes			Yes	
Weindl et al. 2017	IAM-land		Yes					
Wiebe et al. 2015	Mixed			Yes			Yes	
Wolff et al. 2018	No				Yes	Yes		Yes
Wu et al. 2019	Yes							
Yamagata et al. 2018	No					Yes		Yes

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