Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Slow-onset events: a review of the evidence from the IPCC Special Reports on Land, Oceans and Cryosphere

Kees van der Geest and Romy van den Berg

This paper reviews the evidence on slow-onset events presented in the Special Report on Climate Change and Land (SRCCL) and the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), both published in 2019. It analyses how the reports, and recent literature cited in them, deal with the eight types of slow-onset events, specified by the UNFCCC: increasing temperatures, sea level rise, salinization, ocean acidification, glacial retreat, land degradation, desertification and loss of biodiversity. The authors used qualitative data analysis software to analyse the reports, and for each of the SOEs, they coded and analysed information about the state, rate of change, timescale, geography, drivers, impacts, management responses, adaptation limits and residual losses and damages. The paper provides an overview of the state of the art on SOEs and helps to identify gaps and challenges in understanding the nature of SOEs, their impact and effective management approaches.

Address
United Nations University Institute for Environment and Human Security (UNU-EHS), Platz der Vereinten Nationen 1, 53113 Bonn, Germany

Corresponding author: van der Geest, Kees (geest@ehs.unu.edu)

Current Opinion in Environmental Sustainability 2021, **50**:109–120

This review comes from a themed issue on **Slow onset events related to climate change**

Edited by **Susana Adamo**, **Riyanti Djalante**, **Prabodh GD Chakrabarti**, **Fabrice Renaud**, **Amsalu Woldie Yalew**, **Doreen Stabinsky**, and **Zinta Zommers**

Received: 02 February 2021; Accepted: 17 March 2021

https://doi.org/10.1016/j.cosust.2021.03.008

Introduction

Article 8 of the Paris Agreement states that 'Parties recognize the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events' [1]. However, in the emerging body of research on losses and damages from climate change, there has been significantly more attention for sudden-onset extreme weather events than for slow-onset events [2•]. A reason can be that hazards with a slow onset are often ignored, while sudden-onset disasters tend to receive more attention as their effects are more visible [3••].

The publication of the IPCC special reports on Climate Change and Land [4] and on the Ocean and Cryosphere in a Changing Climate [5] presents a unique opportunity to review the evidence on slow-onset events. While the reports hardly use the term 'slow-onset events' as such, they discuss a large body of evidence on the processes that the UNFCCC Cancun Agreement labels as slow-onset events: increasing temperatures, sea level rise, salinization, ocean acidification, glacial retreat, land degradation, desertification and loss of biodiversity [6]. The two reports were selected for analysis because they cover impacts of climate change in on land, oceans and cryosphere and they had recently been published. A finding from the analysis, however, was that the reports do not cover the full spectrum of slow-onset events in the same depth. Loss of biodiversity and salinization, for example, receive less attention and may be covered in more depth in other studies and reports.

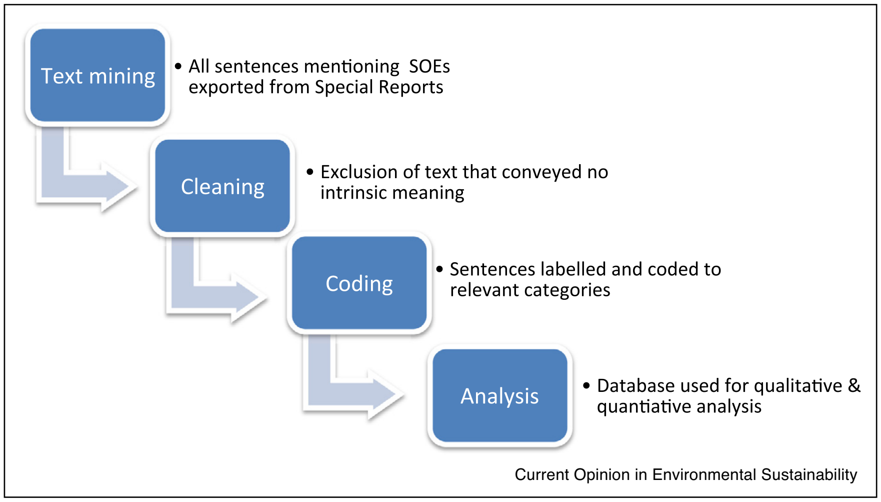
A reason that the two special reports do not tend to use the term 'slow-onset events' may be that the term itself is not accurate. Slow-onset events actually unfold gradually over time and in that sense, it would be more accurate to speak of slow-onset changes or slow-onset processes than of 'events' [7,8]. Alternative labels that are used in the literature are slow-onset hazards, disasters and climate impacts [9•,10••,11•,3••,12,13•].[1]

While some publications, for instance on climate-induced human mobility [14,15•], do distinguish and compare the effects of sudden-onset and slow-onset events, so far, no scientific publications have attempted to provide an overview of the evidence on the different SOEs collectively. This paper addresses this gap with a systemic analysis of the state of the art on slow-onset events,[2] presented in

[1] Despite this critical note on the term 'slow-onset events', the current paper does use the term as it has become the common label in UNFCCC processes and the emerging literature on this topic.

[2] In Section 'Quantitative analysis' we explain that the two Special Reports have separate chapters on four of the eight SOEs identified by the UNFCCC: desertification, land degradation, sea level rise and glacial retreat. While the report also presents evidence on the other four SOEs, the authors recommend further research to analyse other assessment reports such as IPBES [70] for loss of biodiversity and the forthcoming IPCC 6th Assessment Report for increasing temperatures, salinization and ocean acidification.

Figure 1



Step-wise work flow of the database preparation.

IPCC SRCCL and SROCC, including the state, rate of change, timescale, geography, drivers, impacts, management responses, adaptation limits and constraints and residual losses and damages.

The paper is structured as follows: we first discuss the methods used to analyse the reports, followed by a quantitative and qualitative analysis of the evidence on SOEs. The quantitative analysis shows the level of attention for the different SOEs; compares the nature of the evidence in terms of causes and consequences; and looks at the emphasis on human versus environmental drivers and impacts. In the qualitative analysis, we review the evidence on each SOE separately, describing the nature, drivers, impacts, responses and residual losses and damages. Lastly, in the discussion and conclusions section, we reflect on the findings.

Materials and methods

This section describes the methods used to construct and analyse a database with information about slow-onset events in the two special reports. Figure 1 shows a graphic summery of the steps taken to prepare and analyse the database.

Qualitative data analysis software (MaxQDA) was used to extract sentences in the reports that mention SOEs. Such sentences were identified with QDA search strings that were broader than the exact labels of the SOEs. For example, to identify sentences discussing sea level rise, the software did not only look for sentences with the exact term 'sea level rise', but also sentences that include word combinations like 'rising seas', 'increasing sea level' and 'higher sea surface'. Hits in references, headers, titles, figures, and other instances where the word(s) conveyed no intrinsic meaning were excluded.

The 5003 valid sentences were exported to a spreadsheet. Table 1 shows the number of relevant sentences per SOE and per special report. In the spreadsheet all sentences were coded to the categories in which they carried relevant information. The categories are:

- Nature: Information about the state, rate of change, timescale and geography;
- Driver: Information about the natural and anthropogenic causes;
- Impact: Information about the societal and environmental impact(s);
- Management response: Information about solutions, policy options and actions, such as such as mitigation and adaptation, to address SOEs and deal with their impacts;

Table 1

Number of sentences coded by SOE and Special Report

SOE	SRCCL	SROCC	Total
Increasing temperatures	616	858	1474
Sea level rise	48	800	848
Salinization	71	54	125
Ocean acidification	2	186	188
Glacial retreat	4	428	432
Land and forest degradation	1223	37	1260
Desertification	555	0	555
Loss of biodiversity	91	30	121
Total	2610	2393	5003

- Loss and damage/limits to adaptation: Information about situations in which observed or future impacts of climate change relative to available response options[3] translate into losses and damages to nature and society.

Within these five categories, labels were assigned to sentences to allow further cataloguing of the database. The category 'nature', for instance, included labels for the timescale (past–present–future) and geography (local–regional–national–continental–global), and the category 'impacts' included labels that distinguish different types of impacts on human and natural systems, such as impacts on livelihoods, displacement and ecosystem services.

The resulting database serves two purposes. Firstly, it can be used for quantitative analysis, for instance to compare the number of instances in which the reports convey information about anthropogenic and natural drivers of SOEs. The second purpose of the database is to facilitate qualitative analysis. In the spreadsheet, users can filter columns to only display text from the reports that convey information about a specific topic. To find information about the impacts of observed temperature increase in Africa, for example, the user selects 'increasing temperatures' in the SOE column; 'past' and 'present' in the timescale column; 'impacts' in the category column; and 'Africa' in the geography column.

Results

Quantitative analysis

As Table 1 shows, the two IPCC Special Reports show significant differences in the level of attention for the eight SOEs. For example, SRCCL had separate chapters on land degradation and desertification, and SROCC had a separate chapter on sea level rise. Also in SROCC, the chapter on high mountain areas has detailed information on glacial retreat. By contrast, the other 4 SOEs — increasing temperatures, salinization, ocean acidification and loss of biodiversity — were cross-cutting issues in the reports and evidence on these SOEs is much more scattered across the chapters.

Figure 2 shows, for each SOE, the percentage of coded sentences that convey information about the nature, drivers, impacts, responses and loss and damage. The numbers do not add up to 100% because one sentence could be coded in different categories. The figure reveals significant differences between the SOEs. In the case of loss of biodiversity, for example, the reports include much more information about drivers than about impacts. The contrary is the case for glacial retreat and ocean acidification, where much more emphasis is on the impacts than on the causes. Another key finding of Figure 2 is that the reports include significantly less information on responses and losses and damages than on impacts and drivers. The exceptions are land and forest degradation and desertification. For these SOEs, and to a lesser extent also sea level rise, the reports put more emphasis on management responses, such as prevention and adaptation.

Figure 3 shows differences between SOEs in terms of attention for natural and human or anthropogenic drivers and environmental and societal impacts. The reports discuss human drivers more often in the case of increasing temperatures, land and forest degradation, desertification and loss of biodiversity. Natural drivers receive more attention in the case of glacial retreat, sea level rise, ocean acidification and salinization. The third category (mixed drivers) involves text in which a combination of human and natural drivers is discussed, which was most frequent in the case of land and forest degradation, desertification and salinization.

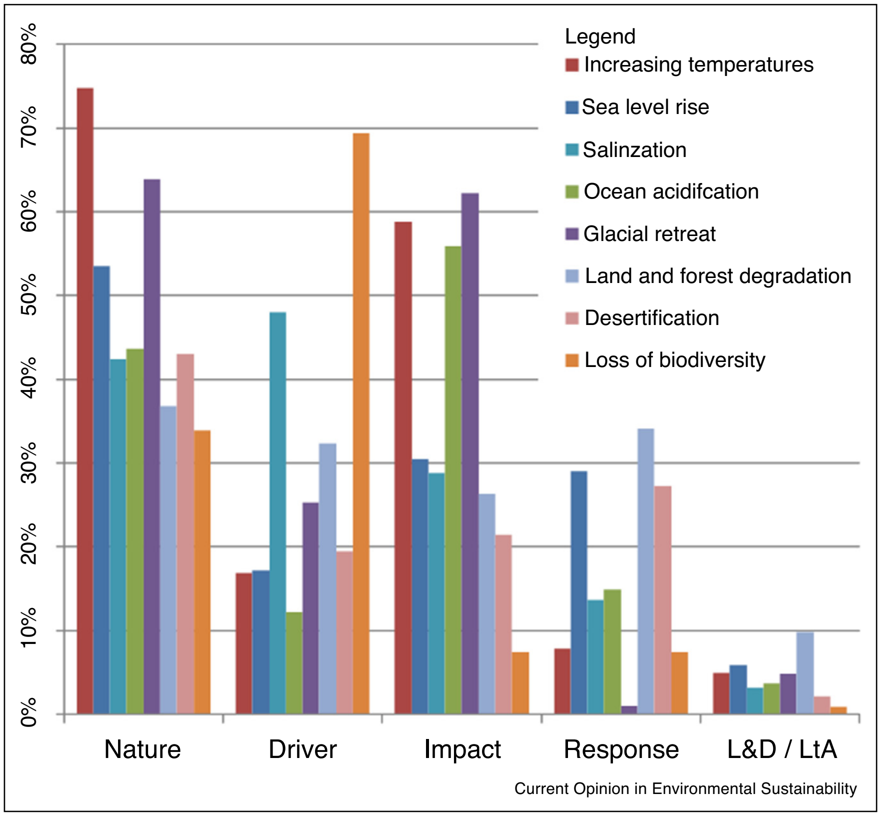
For increasing temperatures, glacial retreat, ocean acidification and loss of biodiversity, the focus is more on environmental than on societal impacts. By contrast, for land degradation, desertification, sea level rise and salinization, there is more attention for societal impacts. The third category consists of text in the report that discuss how impacts of SOEs drive changes in other SOEs, which was most frequently the case for increasing temperatures, sea level rise and land and forest degradation. Examples include increasing temperatures causing sea level rise; sea level rise causing salinization; and land and forest degradation causing loss of biodiversity.

Qualitative analysis

In this section, we review, for each SOE, key findings from the special reports. We describe the nature of the

[3] There is no official, universally accepted definition of losses and damage [95••]. Some definitions do not clearly distinguish L&D from impacts of climate change [96••]. UNFCCC [97], for example, describes loss and damage as 'the actual and/or potential manifestation of impacts associated with climate change in developing countries that negatively affect human and natural systems'. Similarly, in the SROCC Glossary, losses and damages are broadly described as 'harm from (observed) impacts and (projected) risks'. From an analytical perspective, however, there is no added value in using a new term/concept (loss and damage) if it does not differ sufficiently from an existing term/concept (impacts). Therefore, most definitions of loss and damage used be researchers emphasize that losses and damages refer to impacts relative to available response options [96••]. Zommers *et al.* [8], for example, define losses and damages as adverse effects that 'cannot be or have not been avoided through mitigation or managed through adaptation efforts'. In the coding process for the present analysis, we categorized text under 'loss and damage' when it conveyed information about limited response options to avoid impacts and when the terms loss and damage were used literally.

Figure 2



The percentage of coded sentences by SOE and code category.
Note: The category 'Nature' includes information on the definition, geography, timescale, state and rate of change of the SOE.

SOEs and the drivers, impacts, responses, adaptation limits and constraints, and residual losses and damage. The level of detail varies between SOEs, according to the attention given to each in the special reports.

Increasing temperatures

The special reports discuss increasing temperatures at different temporal and spatial scales: observed and projected; terrestrial and marine; global, regional and local. Since the pre-industrial time (1850–1900), the global mean surface temperature has increased by 0.87°. The rise in temperature has been even more pronounced over land: 1.53° (SRCCL: 7). In the Arctic, temperatures have increased more than double the global average over the past two decades [16,17]. The main drivers of increasing temperatures are greenhouse gas emissions and land use change, including albedo effects [18,19]. An important effect of the gradual increase of temperatures is that the frequency of extreme heat events also rises. For instance, SRCCL cites research by O'Neill *et al.* [20] who find that in 2035 daily temperature maxima exceed the 90th percentile of 1961–1990 temperatures on more than 25% of days. The impact of increasing temperatures is discussed extensively, and there is ample attention for environmental impacts, including changes in ecosystem functioning and biome shift due to warmer temperatures, particularly at higher latitudes. The reports describe how specific species react to this in terms of productivity and behaviour [21,22]. Response options, discussed in the SRs, mostly involve reducing global warming by cutting GHG emissions (SROCC p. 115, SRCCL p.136). Terminology used often is that warming should be limited to well below 1.5°C or 2°C. Most future scenarios that aim to achieve this rely on bioenergy, carbon capture and afforestation [23]. The reports are critical about the use of bioenergy, which would require conversion of large areas of land to bioenergy crops, which could lead to short-term carbon losses. Another set of response options involves adaptation to higher temperatures. Tree planting is one such option [24,25]. To deal with extreme heat events in Melbourne (Australia), for instance, a 10% increase in vegetation cover helps to reduce temperatures by one

Figure 3

Sentences conveying information about environmental and human drivers and impacts.
Note: The scales of the vertical axes vary according to the total number of coded sentences per SOE.

degree [26]. The reports also describe situations where adaptation limits are encountered. In some drylands of the Mediterranean and North Africa, for example, Haddeland *et al.* [27] find that a 2.5°C–3.5°C temperature increase may lead to a situation in which migration becomes the only adaptation option for people. For corals, limits to adapt to ocean warming and acidification may already be reached this century (SROCC: 325). SRCCL further states that delaying climate action can result in temperature increases that would cause irreversible losses and damage to ecosystems (SRCCL: 34).

Sea level rise

In its definition of sea level rise, the IPCC refers to four distinct causal processes, which operate at different spatial and temporal scales. The first two relate to changes in ocean water volume due to (1) glacier and ice sheet melt, and (2) expansion of ocean volume due to higher water temperature (thermal expansion). Besides changes in

water volume, sea level change can also be caused by changes in the shape of the ocean basins and changes in the Earth's gravitational and rotational fields. And lastly, local subsidence increases relative sea level (SROCC: 696). According to SROCC, the first process makes the largest contribution to contemporary global SLR (SROCC: 323). Three of these four causal processes have underlying human causes, particularly anthropogenic global warming and local land and groundwater extraction [28,29]. Over the past century, sea level rise amounted to 1−2 mm per year in most regions, but has now accelerated to 3−4 mm per year (SROCC: p. 327). Projections of future SLR usually refer to Representative Concentration Pathways (RCPs). Globally, SLR is projected to amount to 4−9 mm per year under RCP2.6 and 10−20 mm per year under RCP8.5 by the end of the 21th century (OCC: 327).

An adverse effect of sea level rise is that it compounds impacts of sudden-onset events, such as cyclones and coastal inundation [30,31]. Geographically, most attention goes to impacts of SLR on small islands states and densely populated coastal areas, particularly in Asia, Europe and North America. SROCC discusses several adaptation options, including ecosystem-based adaptation and coastal protection. It is acknowledged that coastal ecosystems have a medium capacity to naturally adapt to sea level rise, when the onset is not too sudden [32]. The report also documents cases of maladaptation when ecosystem-based adaptation and coastal protection have adverse effects [33,34]. According to SROCC, the limits to adaptation are mostly societal (economic, financial, social barriers) rather than technical, which poses important governance questions [20]. Graham *et al.* [35] identify five types of social values at risk from sea level rise: health, feeling of safety, attachment to places and people, self-esteem and self-actualization. These categories are also relevant for discussions on non-economic loss and damage due to other climatic stressors, including slow-onset events.

Salinization

Salinization is the process by which a non-saline soil becomes saline. The SRCCL glossary defines saline soils as 'soils with levels of soluble salts (..) high enough to negatively affect plant growth'. The report cites research by Wicke *et al.* [36] who suggest that globally, approximately 11 million square kilometres of land (7.4%) is affected by salt. Much of the research that the reports discuss looks at salinization in Asia. The principal drivers of salinization are sea level rise and irrigation (SROCC: 378; SRCCL, 347). Impacts of salinization include land degradation and desertification, biodiversity loss, and adverse effects on agricultural production, livelihoods, freshwater resources and health [37–39]. Two types of responses to salinization are discussed: prevention and adaptation. As preventive measures, the reports often mention the use of more effective irrigation techniques, managing groundwater and installing proper drainage in irrigated fields [40–42]. Adaptation strategies include switching to salt-tolerant crops or in extreme cases switching livelihood systems from agriculture to aquaculture [43,44].

Ocean acidification

In the process of ocean acidification, CO_2 dissolves in seawater. As a consequence, the pH decreases, which has negative consequences for marine life and causes coral bleaching [45]. In the past three decades, 20–30% of anthropogenic CO_2 emissions were absorbed by oceans, leading to a pH decline of 0.017–0.027 per decade (SROCC: 469). Over the 21st century ocean acidity is projected to increase at even higher rates, up to 71–91% under RCP8.5 [46]. The impact of ocean acidification is discussed mainly in relation to loss of biodiversity. It causes calcification of organisms and affects fish species, invertebrates and corals. Limits to adaptation will be reached this century under all emission scenarios for certain species [47], particularly corals [48,49]. SROCC pays less attention to the human impacts of ocean acidification, but there is some evidence that it will cause a decline in catch for the fisheries sector [50,51]. Research by Ekstrom *et al.* [52], for example, estimates that ocean acidification generated revenue losses of 110 USD to the oyster industry in the Pacific.

Glacial retreat

Glacial retreat occurs when the snow and ice mass of glaciers melt at a faster rate than they accumulate. As a result, the end of the glacial tongue ends at a higher elevation. When the mass of snow and ice reduces, this alters the flow of meltwater rivers, with adverse effects on water availability for irrigation (e.g. Refs. [53,54]). SROCC reports that it is *very likely* that the main driver of glacial retreat is atmospheric warming [55,56]. Geographically, evidence of glacial retreat is given primarily for the polar regions (particularly the Greenland Ice Sheet and Antarctic Ice Sheet) and high mountain areas in the Andes, Himalaya and Alps. Jointly, for the period 2006–2015, the average annual mass loss is estimated at 653 Gt, which translates to 1.81 mm sea level rise each year (calculated from SROCC: 6). Projections of glacier mass losses up to 2100 amount to 18% under RCP2.6 and 36% under RCP8.5. The rate of change will be much faster in mountain areas with relatively small glaciers, compared to the larger land ice masses in the polar regions. The contribution of small glacier shrinkage to global sea level rise is modest, but local and regional impacts on streamflow, ecosystems and agricultural livelihoods can be severe. In the short term, streamflow temporarily increases when glaciers melt faster, but in the long term, it

produces a more permanent decrease [57,58]. Glacier retreat also affects stability of mountain slopes and increases the risk of Glacier Lake Outburst Floods (GLOFs) [59]. The tourism sector, and particularly ski resorts, will experience severe economic impacts from glacial retreat. Under RCP 8.5, for example, it is projected that by the end of the 21st century, snow reliability will be too low for most ski resorts in the US and Europe to be viable [60,61]. One economic sector that may benefit from glacial retreat is the mining industry as snow and ice melt can increase accessibility of potential mining areas [62]. As halting glacial retreat in the short to medium term is impossible, SROCC mainly discusses reactive response options. In agriculture, for example, these include the adoption of new irrigation technologies and water conservation measures, improving water storage infrastructure and changing cropping patterns [63•]. In the case of glacial retreat, SROCC discusses adaptation limits and constraints in relation to habitability, human migration and displacement [64••]. It documents evidence of communities who were forced to leave their homes because irrigated agriculture was no longer viable or because of increased risk of natural hazards, such as GLOFs and landslides [65–67]. While the report notes the paucity of empirical evidence on loss and damage in high mountain areas, it does highlight the cultural values that people place on mountain landscape environments, which may be altered irreversibly as a result of glacial retreat [68].

Land and forest degradation

SRCCL defines land degradation as 'a negative trend in land condition (..), expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans' (SRCCL: 817). Forest degradation is land degradation in forested areas. Global rates, severity and extent of land degradation are hard to quantify. The SRCCL cites a review by Gibbs and Salmon [69] who found that 10–60 million km^2 (8%–45%) of ice-free land has been degraded worldwide. According to IPBES [70], 3.2 billion people worldwide are affected by land degradation. Land degradation in Asia, Africa and South America is discussed more than in other continents. The drivers of land degradation most often considered in SRCCL are human-induced processes including anthropogenic climate change. Other human drivers include the expansion of agriculture into unfit soils, growing food demand and unsustainable land and forest management practices. The impact of land and forest degradation is discussed thoroughly, with effects on society and the natural environment receiving similar levels of attention. Environmental impacts are frequently discussed in relation to the ecosystem services they provide to humanity [71,72]. A response to land and forest degradation is formulated under SDG15 and its objective to 'protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and halt biodiversity loss' (SRCCL: 388). Land degradation neutrality (LDN) and sustainable land management (SLM) are central concepts in this effort. Concrete land management measures include growing green manure crops and cover crops, crop residue retention, zero tillage, use of locally adapted varieties, inter-cropping, crop rotations, and maintenance of ground cover through improved grazing management [73]. There is consensus that preventing degradation is preferable over restoring degraded land [74]. SRCCL notes that there is still a lack of knowledge on adaptation limits, but does give a few examples where land degradation exceeds such limits, such as in the case of coastal erosion exacerbated by sea level rise and thawing of permafrost. When the report discusses losses and damages, the focus is predominantly on economic losses, but loss of indigenous knowledge, cultural identity and emotional wellbeing also receive some attention (e.g. Refs. [75,76]). SRCCL further states that delayed action on land degradation can lead to irreversible biophysical and human outcomes.

Desertification

Desertification is land degradation in arid, semi-arid and dry subhumid areas as defined in the Global Land Outlook of UNCCD. The lack of a 'non-desertified' reference state [77] and the complexity of interactions between social, economic, and environmental systems [78] makes it hard to quantify and map desertification. Evidence of desertification is given most prominently for Asia and Africa, where 70% of the worlds' drylands are located (SRCCL: 253). When expressed as a reduction of biomass productivity in dryland areas, research by Le *et al.* [79] suggests that 9.2% of global drylands has experienced desertification between the 1980s and 2000s. Historically, desertification was considered as a purely human-driven process (SRCCL: 258). Currently there is a better understanding of how different human and environmental processes interact to drive desertification [80,81]. The impacts of desertification are mostly discussed in relation to the decline in ecosystem services it entails, and the implications for the livelihoods of natural resource-dependent populations [82]. Response measures to combat desertification include avoiding, reducing and reversing it. When this is not successful, the next response is to adapt to it. As in the case of land degradation, sustainable land management (SLM) is a key concept in combatting desertification [83]. Prevention is preferable as it is less costly and difficult than restoring degraded land, and it reduces the risk of maladaptation [74]. However, efforts to avoid desertification are often hampered by biophysical constraints, such as water availability, and social, economic and institutional constraints. When

desertification cannot be or has not been avoided, common adaptation options are migration and livelihood diversification [84,85]. These options can increase people's resilience and improve their food and livelihoodsecurity, but entail the risk of cultural losses in terms of the possibly irreversible disappearance of a 'way of life' [86••].

Loss of biodiversity

The two IPCC Special Reports define biodiversity as 'the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (SROCC: 806; SRCCL: 679). Loss of biodiversity occurs when this variability reduces. The reports do not provide much detail about current and future rates of biodiversity loss at global or regional levels, but SRCCL does cite research that shows that current losses are already far above historical rates [22,87,88] and that climate warming will further accelerate losses of species diversity [89]. The impact of climate change on biodiversity loss is not a new topic. In 2005, the Millennium Ecosystem Assessment already stated that 'climate change is likely to become one of the most significant drivers of biodiversity loss by the end of the century' Other drivers commonly mentioned in the reports are land degradation and desertification, which destroy species' habitats [90,91]. Both SRs focus much more on the causes of biodiversity loss than on the consequences and management options. One impact of biodiversity loss that the reports do emphasize is declined functionality of ecosystem services, for instance in carbon sequestration [92], provisioning services [93] and the capacity to adapt to further climate change [94]. The special reports mostly discuss biodiversity loss in relation to other SOEs, usually as an outcome of these processes, but sometimes also as a trade-off or co-benefit of responses to the other SOEs. For instance, growing biofuel crops to reduce GHG emissions and global warming can have adverse effects on biodiversity. By contrast, ecosystem restoration and reforestation to combat desertification can have positive effects for biodiversity.

Conclusion

This paper reviewed the evidence on slow-onset events in the Special Report on Climate Change and Land (SRCCL) and the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC). For each of the eight SOEs that the UNFCCC distinguishes, it analysed information about the state, rate of change, timescale, geography, drivers, impacts, management responses, adaptation barriers and losses and damages. The review found significant differences in the level of attention for the eight SOEs, and the emphasis on drivers, impacts, responses and residual losses and damages.

Many of these differences are understandable and justifiable and do not necessarily imply knowledge gaps. For example, it makes sense that the IPCC discusses more evidence on sea level rise than on biodiversity loss because the former was a key focus of SROCC while the latter is the main focus of another intergovernmental body, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which was not included in this analysis. Another difference identified in the results section is that SRCCL looks more at human drivers of SOEs while SROCC pays more attention to natural drivers. In our view, this is understandable because localized human activities on land, such as agricultural expansion and extraction of water for irrigation, have significant impacts on land and forest degradation, desertification and salinization. For the SOEs that SROCC primarily focuses on — sea level rise, glacial retreat and ocean acidification — human activities play a more indirect role, by causing global warming.

An important finding from this paper is that the reports primarily discuss the nature, drivers and impacts of SOEs, while significantly less attention goes to management responses to avert, minimise and address the adverse consequences of SOEs. To inform policy and action on climate change and its impacts, research evaluating the effectiveness of different management options and responses is essential and needs to be developed further.

There is even more paucity of information about the limits and constraints to adaptation and residual losses and damages resulting from slow-onset events. The research on loss and damage is still emerging and some of the potential losses and damages from climate change have not yet been assessed and categorized. Particularly loss and damage from slow-onset processes is an emerging topic with a lot of knowledge gaps. This is something the IPCC itself also acknowledges. SROCC states for example: 'More work is required to explore the range of activities available for responding to L&D resulting from slow onset processes' (SROCC: 630). It is now up to the research community and funding agencies to take up this important work.

Funding information

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest statement

Nothing declared.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. UNFCCC: **Adoption of the Paris agreement**. *United Nations Framework Convention on Climate Change, Twenty-First Session of Conference of the Parties* 2015 https://unfccc.int/resource/docs/2015/cop21/eng/l09r.pdf.

2. • van der Geest K, Warner K: **Loss and damage in the IPCC Fifth Assessment Report (Working Group II): a text-mining analysis**. *Clim Policy* 2020, **20**:729-742 http://dx.doi.org/10.1080/14693062.2019.1704678.

This paper uses qualitative data analysis software to analyse what the Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC WGII AR5) has to say about the topic of 'losses and damages from climate change'. The study reveals that the report primarily associates loss and damage with extreme weather events and economic impacts, and treats it primarily as a future risk. Present-day losses and damages from slow-onset processes and non-economic losses receive much less attention.

3. •• Staupe-Delgado R: **Progress, traditions and future directions in research on disasters involving slow-onset hazards**. *Disaster Prev Manag* 2019, **28**:623-635 http://dx.doi.org/10.1108/DPM-11-2018-0358.

This semi-structured review of the literature about slow-onset hazards in disaster studies shows that the majority of publications that mention slow-onset hazards do so only by means of delimitation. More theoretical and empirical work on onset and manifestation speed of disasters is needed. While slow-onset hazards, such as sea level rise and desertification, are a great concern, the authors find that, in theory, they are easier to manage and proactively respond to than sudden-onset hazards, primarily because there is more lead time. The problem with 'creeping disasters' and having more lead time, however, is that warnings often go unheard and response is put on hold until severe losses and damages occur and impacts become unnecessarily costly to reverse.

4. IPCC: *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva: Intergovernmental Panel on Climate Change; 2019.

5. IPCC: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Geneva: Intergovernmental Panel on Climate Change; 2019.

6. UNFCCC: *Slow-Onset Events: Technical Paper FCCC/TP/2012/7*. 2012 https://unfccc.int/resource/docs/2012/tp/07.pdf.

7. Siegele L: **Loss and damage: the theme of slow-onset impact**. *The Loss and Damage in Vulnerable Countries Initiative*. 2012.

8. Zommers Z, van der Geest K, de Sherbinin A, Kienberger S, Roberts E, Harootunian G, Sitati A, James R: *Loss and Damage: The Role of Ecosystem Services*. Nairobi: UNEP; 2016.

9. • Rigaud KK, Jones B, Bergmann J, Clement V, Ober K, Schewe J, Adamo S, McCusker B, Heuser S, Midgley A: *Groundswell: Preparing for Internal Climate Migration*. Washington, DC: World Bank; 2018.

The World Bank's Groundswell Report uses a gravity model to project population mobility, resulting from climate change and related impacts, particularly those with a slow onset. It looks at countries in three world regions: Sub-Saharan Africa, South Asia and Latin America, and projects internal population movements until 2050 and for the period beyond. Sea level rise, storm surges, low water availability and low agricultural productivity are found to be key drivers of migration. Cutting greenhouse gases and embedding climate migration in development planning can reduce the number of people forced from their homes, which in the case of inaction would accelerate after 2050.

10. •• Thomas A, Benjamin L: **Management of loss and damage in small island developing states: implications for a 1.5°C or warmer world**. *Reg Environ Change* 2018, **18**:2369-2378.

Based on interviews with UNFCCC climate change negotiators from Small Island Developing States (SIDS) and analysis of Intended Nationally Determined Contributions (INDC), the authors evaluate the ability of SIDS to monitor and respond to loss and damage from climate change. The paper identifies three areas of concern for SIDS: lack of data relating to loss and damage, gaps in financial assessments of loss and damage, and a lack of policies or mechanisms targeted at loss and damage. The authors add that these issues appear to be most acute in relation to slow onset impacts.

11. • Broberg M, Martinez Romera B: **Loss and damage after Paris: more bark than bite?** *Clim Policy* 2020, **20**:661-668.

This editorial introduction to a special issue on loss and damage from climate change provides a historical context to the inclusion of loss and damage in the UN climate change treaty regime and assesses the current state of affairs. It concludes that the inclusion of loss and damage in the Paris Agreement in 2015 has provided 'the bones' for a more effective policy framework to address loss and damage, but that there is still a clear need to put flesh to these bones.

12. Boston J, Panda A, Surminski S: **Designing a funding framework for the slow-onset impacts of climate change: insights from recent experiences with coastal retreat**. *Working Paper No. 373*. Leeds and London: Centre for Climate Change Economics and Policy; 2020.

13. • Nordlander L, Pill M, Martinez Romera B: **Insurance schemes for loss and damage: fools' gold?** *Clim Policy* 2020, **20**:704-714.

Nordlander and co-authors review the use of insurance schemes as finance mechanism to address climate change-induced loss and damage. The paper concludes that, despite their popularity among policy makers, insurance schemes seem ill-suited to address the full range of loss and damage. It advices policy makers to consider how to overcome the apparent challenges in order to 'insure the uninsurable'.

14. Missirian A, Schlenker W: **Asylum applications and migration flows**. *Am Econ Rev* 2017, **107**:436-440.

15. • Zickgraf C: **'The fish migrate and so must we': the relationship between international and internal environmental mobility in a Senegalese fishing community**. *J Int Relat* 2018, **16**:5-21.

This Senegalese case study is based on qualitative fieldwork in a coastal neighbourhood of Saint Louis where people's main source of livelihood is fishing. Sea level rise, coastal erosion and other environmental pressures put this neighbourhood and its livelihood system at risk. The author's use of a flexible methodology and non-strict definition of migration enabled her to uncover intricate relations between different environmental stressors and mobility outcomes. Long-distance, cross-border migration in search of a better fish catch in Mauretania, for example, was connected (through migrant savings and remittances) to short-distance, more permanent movements of houses away from the encroaching sea onto the safer mainland.

16. Notz D, Stroeve J: **Observed Arctic sea-ice loss directly follows anthropogenic CO_2 emission**. *Science* 2016, **354**:747-750 http://dx.doi.org/10.1126/science.aag2345.

17. Richter-Menge J, Overland JE, Mathis JT, Osborne EE: *Arctic Report Card 2017*. 2017www.arctic.noaa.gov/Report-Card.

18. De Noblet-Ducoudré N *et al.*: **Determining robust impacts of land use-induced land cover changes on surface climate over North America and Eurasia: results from the first set of LUCID experiments**. *J Clim* 2012, **25**:3261-3281 http://dx.doi.org/10.1175/JCLI-D-11-00338.1.

19. Devaraju N, de Noblet-Ducoudré N, Quesada B, Bala G: **Quantifying the relative importance of direct and indirect biophysical effects of deforestation on surface temperature and teleconnections**. *J Clim* 2018, **31**:3811-3829 http://dx.doi.org/10.1175/JCLI-D-17-0563.1.

20. O'Neill BC *et al.*: **IPCC reasons for concern regarding climate change risks**. *Nat Clim Change* 2017, **7**:28-37 http://dx.doi.org/10.1038/nclimate3179.

21. Kjesbu OS *et al.*: **Synergies between climate and management for Atlantic cod fisheries at high latitudes**. *Proc Natl Acad Sci U S A* 2014, **111**:3478-3483 http://dx.doi.org/10.1073/pnas.1316342111.

22. Pimm SL *et al.*: **The biodiversity of species and their rates of extinction, distribution, and protection**. *Science* 2014, **344**:1246752 http://dx.doi.org/10.1126/science.1246752.

23. IPCC: *Global Warming of 1.5°C*. Geneva: Intergovernmental Panel on Climate Change; 2018.

24. Findell KL *et al.*: **The impact of anthropogenic land use and land cover change on regional climate extremes**. *Nat Commun* 2017, **8**:989 http://dx.doi.org/10.1038/s41467-017-01038-w.

25. Sonntag S, Pongratz J, Reick CH, Schmidt H: **Reforestation in a high-CO_2 world—higher mitigation potential than expected, lower adaptation potential than hoped for**. *Geophys Res Lett* 2016, **43**:6546-6553 http://dx.doi.org/10.1002/2016GL068824.

26. Coutts A, Harris R: *A Multi-Scale Assessment of Urban Heating in Melbourne During an Extreme Heat Event and Policy Approaches for Adaptation*. Victoria, Australia: Victorian Centre for Climate Change Adaption Research; 2013. 64 pp.

27. Haddeland I *et al.*: **Global water resources affected by human interventions and climate change**. *Proc Natl Acad Sci U S A* 2014, **111**:3251-3256 http://dx.doi.org/10.1073/pnas.1222475110.

28. Slangen A *et al.*: **Anthropogenic forcing dominates global mean sea level rise since 1970**. *Nat Clim Change* 2016, **6**:701-705.

29. Stammer D, Cazenave A, Ponte RM, Tamisiea ME: **Causes for contemporary regional sea level changes**. *Annu Rev Mar Sci* 2013, **5**:21-46.

30. Little CM *et al.*: **Joint projections of US East Coast sea level and storm surge**. *Nat Clim Change* 2015, **5**:1114-1120 http://dx.doi.org/10.1038/nclimate2801.

31. Garner AJ *et al.*: **Impact of climate change on New York City's coastal flood hazard: increasing flood heights from the preindustrial to 2300 CE**. *Proc Natl Acad Sci U S A* 2017, **114**:11861-11866 http://dx.doi.org/10.1073/pnas.1703568114.

32. Duarte CM *et al.*: **The role of coastal plant communities for climate change mitigation and adaptation**. *Nat Clim Change* 2013, **3**:961.

33. Nguyen TP, Luom TT, Parnell KE: **Mangrove allocation for coastal protection and livelihood improvement in Kien Giang province, Vietnam: constraints and recommendations**. *Land Use Policy* 2017, **63**:401-407 http://dx.doi.org/10.1016/j.landusepol.2017.01.048.

34. Magnan A *et al.*: **Addressing the risk of maladaptation to climate change**. *WIREs Clim Change* 2016, **7**:646-665.

35. Graham S *et al.*: **The social values at risk from sea level rise**. *Environ Impact Assess Rev* 2021, **41**:45-52.

36. Wicke B *et al.*: **The global technical and economic potential of bioenergy from salt-affected soils**. *Energy Environ Sci* 2011, **4**:2669 http://dx.doi.org/10.1039/c1ee01029h.

37. Wilbers G-J, Becker M, Sebesvari Z, Renaud FG: **Spatial and temporal variability of surface water pollution in the Mekong Delta, Vietnam**. *Sci Total Environ* 2014, **485**:653-665.

38. Genua-Olmedo A, Alcaraz C, Caiola N, Ibanez C: **Sea level rise impacts on rice production: the Ebro Delta as an example**. *Sci Total Environ* 2016, **571**:1200-1210.

39. Dasgupta S *et al.*: **The impact of aquatic salinization on fish habitats and poor communities in a changing climate: evidence from southwest coastal Bangladesh**. *Ecol Econ* 2017, **139**:128-139 http://dx.doi.org/10.1016/j.ecolecon.2017.04.009.

40. Qadir M, Noble AD, Chartres C: **Adapting to climate change by improving water productivity of soils in dry areas**. *Land Degrad Dev* 2013, **24**:12-21 http://dx.doi.org/10.1002/ldr.1091.

41. UNCTAD: *Water for Food – Innovative Water Management Technologies for Food Security and Poverty Alleviation*. . 32 pp New York, USA, and Geneva, Switzerland: United Nations; 2011.

42. Dagar J, Sharma P, Sharma D, Singh A: *Innovative Saline Agriculture*. India, New Delhi: Springer; 2016, 1-519.

43. Smajgl A *et al.*: **Responding to rising sea levels in the Mekong Delta**. *Nat Clim Change* 2015, **5**:167-174.

44. Renaud FG *et al.*: **Resilience and shifts in agro-ecosystems facing increasing sea level rise and salinity intrusion in Ben Tre Province, Mekong Delta**. *Clim Change* 2015, **133**:69-84.

45. Lachkar Z: **Effects of upwelling increase on ocean acidification in the California and Canary Current systems**. *Geophys Res Lett* 2014, **41**:90-95 http://dx.doi.org/10.1002/2013GL058726.

46. Kwiatkowski L, Orr JC: **Diverging seasonal extremes for ocean acidification during the twenty45 first century**. *Nat Clim Change* 2018, **8**:141-145 http://dx.doi.org/10.1038/s41558-017-0054-0.

47. Thresher RE, Guinotte JM, Matear RJ, Hobday AJ: **Options for managing impacts of climate change on a deep sea community**. *Nat Clim Change* 2015, **5**:635-639 http://dx.doi.org/10.1038/nclimate2611.

48. Smith MD: **An ecological perspective on extreme climatic events: a synthetic definition and framework to guide future research**. *J Ecol* 2011, **99**:656-663 http://dx.doi.org/10.1111/j.1365-2745.2011.01798.x.

49. Hughes TP *et al.*: **Global warming and recurrent mass bleaching of corals**. *Nature* 2017, **543**:373-377 http://dx.doi.org/10.1038/nature21707.

50. Golden CD *et al.*: **Nutrition: fall in fish catch threatens human health**. *Nature* 2016, **534**:317-320 http://dx.doi.org/10.1038/534317a.

51. Hilmi N *et al.*: **Ocean acidification in the Middle East and North African region**. *Reg Dev* 2017, **46**:43-57 LEADm Universite du Sud – Toulo n Var.

52. Ekstrom JA *et al.*: **Vulnerability and adaptation of US shellfisheries to ocean acidification**. *Nat Clim Change* 2015, **5**:207 http://dx.doi.org/10.1038/nclimate2508.

53. Bury JT *et al.*: **Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru**. *Clim Change* 2011, **105**:179-206 http://dx.doi.org/10.1007/s10584-010-9870-1.

54. Nüsser M, Schmidt S: **Nanga Parbat revisited: evolution and dynamics of sociohydrological interactions in the northwestern Himalaya**. *Ann Am Assoc Geogr* 2017, **107**:403-415 http://dx.doi.org/10.1080/24694452.2016.1235495.

55. Marzeion B, Jarosch AH, Gregory JM: **Feedbacks and mechanisms affecting the global sensitivity of glaciers to climate change**. *Cryosphere* 2014, **8**:59-71 http://dx.doi.org/10.5194/tc-8-59-2014.

56. Vuille M *et al.*: **Rapid decline of snow and ice in the tropical Andes — impacts, uncertainties and challenges ahead**. *Earth-Sci Rev* 2018, **176**:195-213 http://dx.doi.org/10.1016/j.earscirev.2017.09.019.

57. Young G *et al.*: **Vulnerability and adaptation in a dryland community of the Elqui Valley, Chile**. *Clim Change* 2010, **98**:245-276 http://dx.doi.org/10.1007/s10584-009-9665-4.

58. Alata E, Fuentealba B, Recharte J, Fuentealba B, Recharte J: **El despoblamiento de la Puna: efectos del cambio climático y otros factores**. *Rev Kawsaypacha* 2018, **2**:49-69 http://dx.doi.org/10.18800/kawsaypacha.201802.003.

59. Rasul G: **The role of the Himalayan mountain systems in food security and agricultural sustainability in South Asia**. *Int J Rural Manag* 2010, **6**:95-116 http://dx.doi.org/10.1177/097300521100600105.

60. Steiger R *et al.*: **A critical review of climate change risk for ski tourism**. *Curr Issues Tour* 2017, **22**:1343-1379 http://dx.doi.org/10.1080/13683500.2017.1410110.

61. Wobus C *et al.*: **Projected climate change impacts on skiing and snowmobiling: a case study of the United States**. *Glob*

Environ Change 2017, **45**:1-14 http://dx.doi.org/10.1016/j.gloenvcha.2017.04.006.

62. Brenning A, Azócar GF: **Minería y glaciares rocosos: impactos ambientales, antecedentes políticos y legales, y perspectivas futuras**. *Rev Geogr Norte Gd* 2010, **47**:143-158 http://dx.doi.org/10.4067/S0718-34022010000300008.

63. • Rasul G, Pasakhala B, Mishra A, Pant S: **Adaptation to mountain cryosphere change: issues and challenges**. *Clim Dev* 2019, **12**:297-309 http://dx.doi.org/10.1080/17565529.2019.1617099.

This paper studies climate change adaptation and cryosphere change adaptation measures in five mountain systems around the world (the Andes, Alps, Pamir, Tien Shan and Himalaya). The adaptation measures include things that people do locally to do deal with glacial retreat and altered stream flows, but also what governmental and non-governmental organizations do to counter impacts of climate change in mountain areas. The paper identifies a common set of constraints in cryosphere change adaptation: the physical challenges of mountain terrain, low adaptive capacities, limited knowledge and high uncertainty about future risks.

64. •• Huggel C *et al.*: **Loss and damage in the mountain cryosphere**. *Reg Environ Change* 2019, **19**:1387-1399 http://dx.doi.org/10.1007/s10113-018-1385-8.

The emerging research community that studies losses and damages from climate change has done little to consider how loss and damage in the mountain cryosphere might be conceptualized, categorized, and assessed. Through a systematic literature review, the authors address this gap by making a categorization of losses and damages in the mountain cyrosphere, distinguishing between physical and societal impacts and primary and secondary impacts. The paper identifies seven types of loss and damage: to culture, livelihoods, revenue, natural resources, life and security.

65. Parveen S, Winiger M, Schmidt S, Nüsser M: **Irrigation in Upper Hunza: evolution of socio-hydrological interactions in the Karakoram, northern Pakistan**. *Erdkunde* 2015, **69**:69-85 http://dx.doi.org/10.3112/erdkunde.2015.01.05.

66. van der Geest K, Schindler M: **Brief communication: loss and damage from a catastrophic landslide in Nepal**. *Nat Hazard Earth Syst* 2016, **16**:2347-2350 http://dx.doi.org/10.5194/nhess-16-2347-2016.

67. Prasain S: **Climate change adaptation measure on agricultural communities of Dhye in Upper Mustang, Nepal**. *Clim Change* 2018, **148**:279-291 http://dx.doi.org/10.1007/s10584-018-2187-1.

68. Bosson J-B, Huss M, Osipova E: **Disappearing world heritage glaciers as a keystone of nature conservation in a changing climate**. *Earths Future* 2019, **7**:469-479 http://dx.doi.org/10.1029/2018ef001139.

69. Gibbs HK, Salmon JM: **Mapping the world's degraded lands**. *Appl Geogr* 2015, **57**:12-21 http://dx.doi.org/10.1016/J.APGEOG.2014.11.024.

70. IPBES: *The Assessment Report on Land Degradation and Restoration*. Bonn, Germany: IPBES Secretariat; 2018. 744 pp.

71. Mirzabaev A, Nkonya E, von Braun J: **Economics of sustainable land management**. *Curr Opin Environ Sustain* 2015, **15**:9-19 http://dx.doi.org/10.1016/j.cosust.2015.07.004.

72. Thomas R: **Opportunities to reduce the vulnerability of Dryland farmers in Central and West Asia and North Africa to climate change**. *Agric Ecosyst Environ* 2008, **126**:36-45 http://dx.doi.org/10.1016/j.agee.2008.01.011.

73. Henry B, Murphy B, Cowie A: *Sustainable Land Management for Environmental Benefits and Food Security. A synthesis report for the GEF*. 2013. Washington DC, USA, 127 pp.

74. Webb NP, Stokes CJ, Marshall NA: **Integrating biophysical and socio-economic evaluations to improve the efficacy of adaptation assessments for agriculture**. *Glob Environ Change* 2013, **23**:1164-1177 http://dx.doi.org/10.1016/j.gloenvcha.2013.04.007.

75. Suzuki R: *Linking Adaptation and Mitigation through Community Forestry: Case Studies from Asia*. Bangkok, Thailand: RECOFTC, The Center for People and Forests; 2012. 80 pp.

76. Oakes LE, Ardoin NM, Lambin EF: **'I know, therefore I adapt?' Complexities of individual adaptation to climate-induced forest dieback in Alaska**. *Ecol Soc* 2016, **21**:art40 http://dx.doi.org/10.5751/ES-08464-210240.

77. Bestelmeyer BT *et al.*: **Desertification, land use and the transformation of global drylands**. *Front Ecol Environ* 2015, **13**:28-36 http://dx.doi.org/10.1890/140162.

78. Cherlet M *et al.*: *World Atlas of Desertification*. Luxembourg: Publication Office of the European Union; 2018. 248 pp.

79. Le QB, Nkonya E, Mirzabaev A: **Biomass productivity-based mapping of global land degradation hotspots**. In *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*. Edited by Nkonya E, Mirzabaev A, von Braun J. Cham, Switzerland: Springer International Publishing; 2016:55-84.

80. Sterk G, Boardman J, Verdoodt A: **Desertification: history, causes and options for its control**. *Land Degrad Dev* 2016, **27**:1783-1787 http://dx.doi.org/10.1002/ldr.2525.

81. Yan X, Cai YL: **Multi-scale anthropogenic driving forces of Karst rocky desertification in south-west China**. *Land Degrad Dev* 2015, **26**:193-200 http://dx.doi.org/10.1002/ldr.2209.

82. Rosenzweig C *et al.*: **Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison**. *Proc Natl Acad Sci U S A* 2014, **111**:3268-3273 http://dx.doi.org/10.1073/pnas.1222463110.

83. Cowie AL *et al.*: **Land in balance: the scientific conceptual framework for land degradation neutrality**. *Environ Sci Policy* 2018, **79**:25-35.

84. Nawrotzki RJ, Runfola DM, Hunter LM, Riosmena F: **Domestic and international climate migration from rural Mexico**. *Hum Ecol* 2016, **44**:687-699 http://dx.doi.org/10.1007/s10745-016-9859-0.

85. Belay A, Recha JW, Woldeamanuel T, Morton JF: **Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia**. *Agric Food Secur* 2017, **6** http://dx.doi.org/10.1186/s40066-017-0100-1.

86. •• Heslin A, Deckard ND, Oakes R, Montero-Colbert A: **Displacement and resettlement: understanding the role of climate change in contemporary migration**. *Loss and Damage from Climate Change*. Cham: Springer; 2019, 237-258.

Heslin *et al.* outline challenges and debates in the literature about population displacement and resettlement in the context of climate change. Based on empirical examples from different parts of the Global South, the paper identifies a range of losses and damages incurred by populations in the process of displacement and resettlement and — importantly — in their new place of residence.

87. Ceballos G *et al.*: **Accelerated modern human-induced species losses: entering the sixth mass extinction**. *Sci Adv* 2015, **1**:e1400253 http://dx.doi.org/10.1126/sciadv.1400253.

88. De Vos JM, Joppa LN, Gittleman JL, Stephens PR, Pimm SL: **Estimating the normal background rate of species extinction**. *Conserv Biol* 2015, **29**:452-462 http://dx.doi.org/10.1111/cobi.12380.

89. Urban MC *et al.*: **Improving the forecast for biodiversity under climate change**. *Science* 2016, **353**:aad8466 http://dx.doi.org/10.1126/science.aad8466.

90. Pecl GT *et al.*: **Biodiversity redistribution under climate change: impacts on ecosystems and human well-being**. *Science* 2017, **355**:eaai9214 http://dx.doi.org/10.1126/science.aai9214.

91. Riahi K *et al.*: **The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview**. *Glob Environ Change* 2017, **42**:153-168 http://dx.doi.org/10.1016/j.gloenvcha.2016.05.009.

92. McLeod E *et al.*: **A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2**. *Front Ecol Environ* 2011, **9**:552-560 http://dx.doi.org/10.1890/110004.

93. Saintilan N *et al.*: **Climate change impacts on the coastal wetlands of Australia**. *Wetlands* 2019, **39**:1145-1154 http://dx.doi.org/10.1007/s13157-018-1016-7.

94. Pretty J, Bharucha ZP: **Integrated pest management for sustainable intensification of agriculture in Asia and Africa**. *Insects* 2015, **6**:152-182 http://dx.doi.org/10.3390/insects6010152.

95. •• Mechler R *et al.*: **Science for loss and damage. Findings and propositions: concepts, methods and policy options**. In *Loss and Damage from Climate Change.* Edited by Mechler R. Heidelberg: Springer; 2018:3-37.

This chapter introduces to a book about loss and damage from climate change, which gathers insights from research conducted across multiple disciplines, including climate science, political science, law, geography and anthropology. Its twenty-two chapters combine conceptual work and empirical case studies. Key findings of the book's chapters are summarized in this introduction and synthesized in five propositions about risk management, attribution science, adaptation limits, climate risk insurance and the need to transform the policy debate on Loss and Damage from a highly polarized discussion into a more inclusive one.

96. •• Boyd E *et al.*: **A typology of loss and damage perspectives**. *Nat Clim Change* 2017, **7**:723-729 http://dx.doi.org/10.1038/nclimate3389.

Based on interviews with 38 key actors in loss and damage research, practice and policy, this paper introduces a typology of four different perspectives on loss and damage: 1) The adaptation and mitigation perspective; 2) The risk management perspective; 3) The limits to adaptation perspective; and 4) Existential perspective. The four perspectives are arranged in ascending order on a scale that looks at the extent to which approaches to address L&D are distinct from, or go beyond, existing adaptation mechanisms.

97. UNFCCC: *A Literature Review on the Topics in the Context of Thematic Area 2 of the Work Programme on Loss and Damage: A Range of Approaches to Address Loss and Damage Associated with the Adverse Effects of Climate Change*. UNFCCC Subsidiary Body for Implementation (SBI); 2012 http://unfccc.int/resource/docs/2012/sbi/eng/inf14.pdf.