SUNRAISE

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SUNRAISE: Sustainable Natural Resource Use in Arctic and High Mountainous Areas

Report on:

Lecture Material

Ecosystem Approach for Disaster Risk Reduction

Partner number: P12

Jawaharlal Nehru University, New Delhi

India

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Ecosystem Approach for Disaster Risk Reduction

Semester -I: July – December

Coordinator	Prof P K Joshi
Credits	**4 Credits**
Lecturers	Prof P K Joshi
Level	M.A.
Host institution	Special Centre for Disaster Research (SCDR), Jawaharlal Nehru University, New Delhi
Course duration	One Semester [July - December] Started in July 2020

Summary

This one full semester elective course provides the Master level students of Disaster Studies the basic understanding of ecosystem approach for disaster risk reduction. Besides, it will also introduce students to concepts, tools, methods for disaster risk reduction, specifically for climate and water related disasters. The course will touch upon frameworks at international, national and sub-national contest. The course includes individual assignments.

Target Student Audiences

Semester - III Students of M.A.

Prerequisites

- Nil

Aims and Objectives

This course has been designed with a view to help students in developing a comprehensive understanding and knowledge of importance of integrating ecosystem-based disaster risk reduction into development planning. It would emphasize on the need and preparedness for ecosystem management, disaster risk reduction, climate change and development. The main objectives of the course are: (i) to help students in understanding disaster typology, risk, and their impacts; (ii) to comprehend approaches and measured for disaster risk reduction; and (iii) to enumerate possible pathways, and options for disaster risk reduction and sustainable development.

General Learning Outcomes:

By the end of the course, students will successfully:

- Understand the disaster risk related factors and their impacts,
- Learn and appreciate importance of ecosystem based disaster risk reduction and planning,
- Identify and visualize the entry points for integration ecosystem based approaches in disaster risk reduction across sectors.

Overview of Sessions and Teaching Methods

The course will make most of interactive and self-reflective methods of teaching and learning including mainly lectures and presentations. It will start with an overview of disaster-risk reduction concepts and related concepts. Subsequently it will build the science and practice of assessment methods and integration of geospatial approaches. The sessions will be take help of blended teaching and learning approaches for interaction lecturing on different course components.

Course Workload

The table below summarizes course workload distribution:

Activities	Learning outcomes	Assessment	Estimated workload (hours)
In-class activities			
Lectures and Presentations	Introduction to the course work Basics and interconnections of ecology, environment and ecosystem. Introduction to EcoDRR, Natural resources management and traditional environmental wisdom and disasters.	Mid Semester Examination	06
Lectures and Presentations	Introduction to fundamentals of disaster risk reduction, Disaster typology and linkages of environment, development and disasters Revisiting the concepts of hazard, risk, vulnerability, disaster, mitigation, risk reduction and its evolution Disaster risk management (emergency, response, relief; resilience, reconstruction, recovery)	Mid Semester Examination	08
Lectures and Presentations	Disaster risk mitigation - evolution in the concept and framework from 'Response and Relief' to 'Mitigation and Preparedness'. Approaches in disaster management–engineering based solutions; community based solutions; ecosystem approach; and externality based response and relief approach, etc Risk reduction, climate change adaptation and environment	Mid Semester Examination	06
Lectures and Presentations	Disaster risk management - UN-PEDRR (Partnership for Environment and Disaster Risk Reduction), Strategic Environmental Assessment (SEA) and its linkages with ecosystem approach to disaster risk reduction (EcoDRR). Legislations, Codes & Standards, Risk sensitive land use planning, Safety auditing in disaster risk planning, reduction and management	End Semester Examination	08
Lectures and Presentations	Tools and approaches for EcoDRR and CCA Millennium Ecosystem Assessment and the importance of the ecosystem services		06

	(provisioning, regulating, supporting and cultural) and human well being		
Lectures and Presentations	Ecological approaches for mountain hazards: landslides, debris flow, rock fall and avalanches; coastal hazards: storms, flooding, rising sea level; urbanization: heat island effect, flooding, urban resilience; forest: fires, health and pest management, agriculture and water resources management and climate change. Integrated ecosystem management, water resources management, coastal zone management, fire management, protected area management and community based ecosystem and disaster risk management	End Semester Examination	06
Lectures and Presentations	Geospaital tools for ecosystem based disaster risk reduction (decision tools). Cost Benefit Analysis for Ecosystem-Based Disaster Risk Reduction Interventions	End Semester Examination	06
Independent work			
Individual Assignments	Ability to interpret data, and to use the concepts, tools, and methods for communicating information	Individual Presentations	10
Total			***56***

Grading

The students' performance will be based on the following:

- Quizzes/Surprise Test – 10%
- Mid Semester Examination – 30%
- End Semester Examination – 50%
- Individual Assignments – 10%

Course Schedule: **Semester-III: July - December 2020**

Course Assignments

The Structure of Individual Assignments will be as follows:

- Conducting Interviews in the fied.
- Review of research articles and working paper with given objectives.

Literature

- Buyck, C., Miththapala, S., Monty, F., and Murti, R. (2017). Ecosystems protecting infrastructure and communities: lessons learned and guidelines for implementation. IUCN
- Estrella M and N Saalismaa (2013) Ecosystem-based disaster risk reduction (Eco-DRR): An overview. In: Renaud FG, Sudmeier-Rieux K, Estrella M (eds) The role of ecosystems in disaster risk reduction. UNU Press, Tokyo, pp 26-54.
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Reading List Used

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DOI 10.1007/s11069-015-1795-6

ORIGINAL PAPER

Ecosystem approach for natural hazard mitigation of volcanic tephra in Iceland: building resilience and sustainability

Anna María Ágústsdóttir[1]

Received: 19 June 2014 / Accepted: 6 May 2015 / Published online: 22 May 2015

Abstract Living in Iceland, a highly volcanically active island with a historical eruption frequency of 20–25 events per 100 years, involves risks from lava, pyroclastic flows, tephra-fall, and floods from glacier/snow-covered volcanoes. Volcanic eruptions can have detrimental effects on human health, societies, and ecosystems. Eruptions in 2010–2011 proved the value of pre-event planning for some natural hazards. An additional focus is needed on pre-disaster mitigation responses for the effects of tephra-fall on vegetation: As outlined under the UNISDR Hyogo/Sendai Framework for Action, healthy ecosystems and environmental management are key actions in disaster risk reduction (DRR). Iceland's most serious environmental problem is the degraded state of common rangeland in the highlands, where tephra-fall has been catastrophic. Tephra (airborne volcanic material) affects hydrology, air quality, and ecosystems by direct burial or post-eruptive transport, extending its influence far beyond the initial eruption area. Resilience to tephra-related disturbances depends on an ecosystem's overall health. Tall, vigorous vegetation has greater endurance; its initial survival is more likely, while sheltering minimizes secondary transport and hastens recovery. Areas that are sparsely vegetated and already stressed are more vulnerable; there, tephra remains unstable and can cause further damage. Reclaiming vulnerable land and building healthy ecosystems, as represented by the Hekluskógar project, improve the ability of these areas to endure tephra-fall, increasing their resilience and reducing the associated costs to society. Successful DRR for tephra-fall, through the revegetation of degraded land, will require effective governance, multi-sector coordination, and the alignment of policies on land use, agriculture, natural resource management, and climate change mitigation.

Keywords Disaster risk reduction · Resilience · Volcanic tephra · Governance · Policy · Sustainability analysis · Threshold · Volcanic ash · Restoration ecology · Recovery · Hazard · Communities · Wind erosion · Air quality · Human health · Ash storm ·

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Agriculture · Ecosystem services · Environmental degradation · Ecosystem resilience for mitigation of natural disasters · Ecosystem restoration · Hyogo framework of action · Sendai framework for disaster risk reduction · Ecosystem stressors · Mitigation

1 Introduction

Ecosystems in Iceland are at risk both from natural hazards and from unsustainable human activities. In terms of natural hazards, Icelanders have, since 1967 (Act nr. 30/1967), developed responses to volcanic eruptions, earthquakes, oceanic floods, snow avalanches, weather, wildfires, and glacier outburst floods (jökulhlaups) (NCIP-DCPEM 2005a). Risk management in Iceland is currently based on the "Hyogo Framework for Action, Building the Resilience of Nations and Communities to Disasters" of the UN International Strategy for Disaster Risk Reduction (UNISDR) (2013); this framework incorporates assessment, prevention, mitigation, monitoring, early warning, and preparedness. In 2005, the Civil Protection and Emergency Management team of the Icelandic National Commissioner of Police completed hazard assessment, risk analysis, and response plans regarding volcanic eruptions and associated glacier outburst floods in South Iceland (NCIP-DCPEM 2005b); these plans were followed, in 2006, by a public awareness campaign incorporating evacuation drills for all the inhabitants of potentially threatened areas. During the next eruption (Eyjafjallajökull 2010), the response plan was successful, with respect to evacuations and all other planned mitigation measures. However, responses to the dispersal of volcanic ash, or of tephra in general, had not been included in the plan, and Iceland, along with all of Europe, was unprepared for the resulting extensive closure of airspace and the associated global economic effects. The local, regional, and global effects of tephra, defined as airborne volcanic material of any size, proved to be an important aspect of volcanic hazards left out of the otherwise successful pre-event risk management plan.

During a disaster, attention is understandably focused on direct impacts, relief, and recovery operations. Major events like the 2010 eruption of Eyjafjallajökull, however, can potentially act as thresholds, changing dominant ways of thinking and acting by placing tradition—in this case, traditional land-use patterns—under critical review (Birkmann et al. 2008). In Iceland, the 2010 tephra-fall event may create a paradigm shift toward embracing concepts of sustainability. By exploring the consequences of decisions that affect human and ecosystem integrity (Sidle et al. 2013), the potential for an ecosystem role in disaster risk reduction (DRR) for tephra-fall is revealed.

While ecosystem management is not a new concept, research is needed to maximize its benefits for DRR and to ease its uptake by communities, disaster management practitioners, policy makers, and decision makers (PEDRR 2010). Ecosystem-based DRR has been suggested for various hazards, such as landslides, flooding, avalanches, storm surges, wildfires, drought, and climate change (ProAct Network 2008; Sudmeier-Rieux and Ash 2009; World Bank 2010). With regard to volcanic eruptions, however, DRR measures have focused primarily on direct impacts, such as land-use planning in at-risk areas or effective emergency plans for the evacuation of people (EEA 2010). To reduce the indirect impacts, for example, on ecosystems, human health, or global temperature, requires measures at a supranational level. This is a more challenging issue because, as yet, there have been no quantitative evaluations of these indirect effects (EEA 2010). There exists a knowledge gap regarding ecosystem-based approaches of DRR for volcanic hazards. This article helps close that gap by presenting for the first time a unique approach to reducing the effects of remobilized tephra, increasing the initial survival of vegetation, and improving both social and ecosystem resilience to future tephra-fall events.

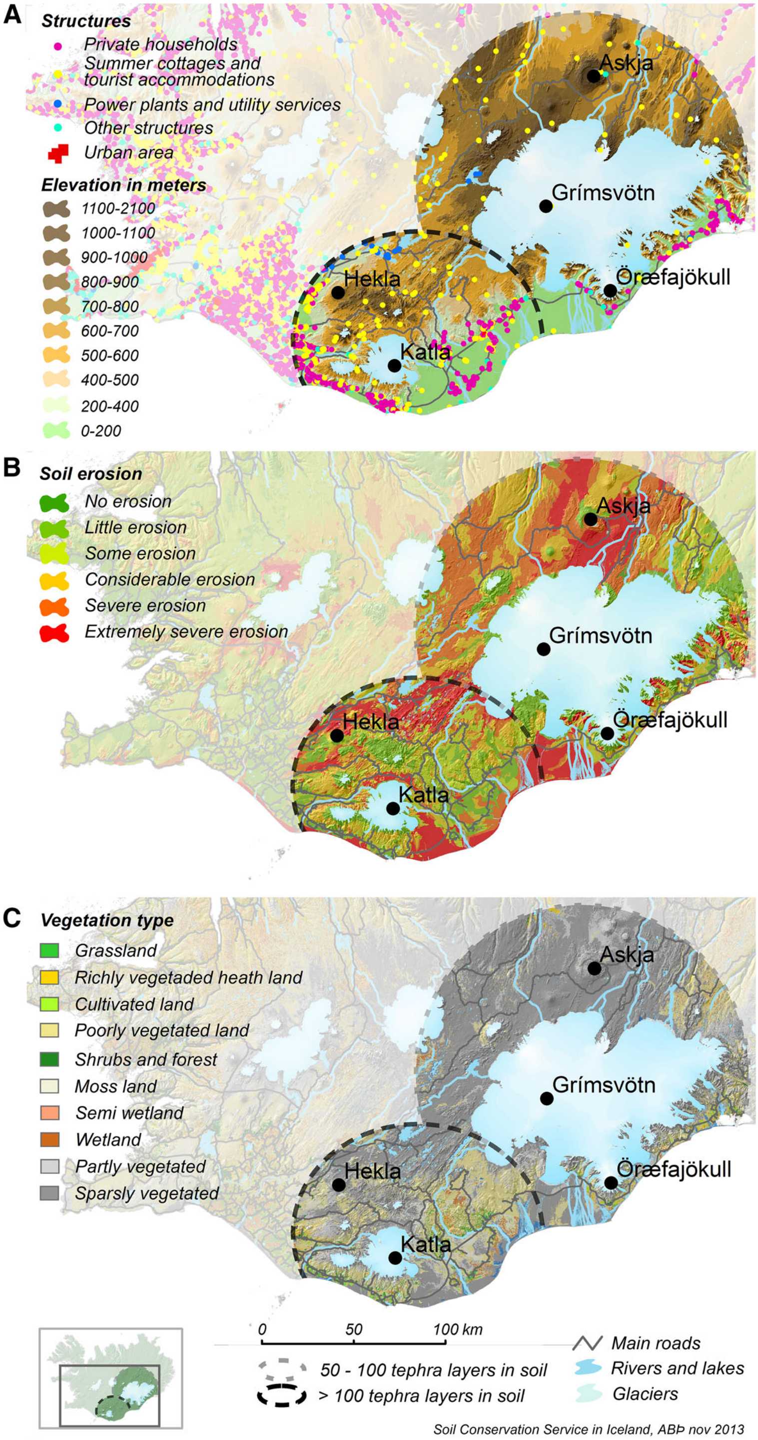
2 Natural systems, disruptions, and resilience

Change is a constant of natural systems. Abrupt events, such as earthquakes, severe weather, or volcanic eruptions, whether singular or repeated, often cause the largest damage to a natural system, as there is limited time for the system to adapt. Disruptions often last longer than the original event itself, initiating chain reactions that lead to further damage. This fact is well known from Iceland's eruptive history, as secondary effects have led to changes in climate, crop failure, and famine, either locally or on a larger scale; it is also known from global climate history, as abrupt events have led to the socioeconomic collapse of societies (Alley 2000; Hodell et al. 1995; Steingrímsson 1998; Thordarson and Self 2003).

A natural hazard is defined by the United Nations (UNISDR 2009) as a "Natural process or phenomenon that may cause loss of life, injury, or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage." A disaster is a serious disruption in the functioning of a community or a society, causing widespread human, economic, or environmental losses that exceed the ability of the affected community or society to cope using its own resources (UNISDR 2009). Disaster risk reduction is important to lessen these effects through reduced exposure, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events (Birkmann et al. 2013; UNISDR 2009).

The effects of a natural hazard depend not only on its magnitude, but also on the society's vulnerability, its culture, and its state before each event (Birkmann et al. 2013). The society's dependence upon land use in the affected areas, the distribution of the population, governance, risk perception, prior experience, and even luck can all play a role. The key to having a resilient society is the ability to absorb shocks, bounce back, learn, and adapt. Resilience has been defined by the UNISDR (2009) as: "The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions."

Mitigation of natural hazards is vital to meet the long-term aims and multiple objectives of sustainability, i.e., safeguarding the environment as well as human living conditions, while meeting the needs of both current and future generations (El-Masri and Tipple 2002). Ecosystems contribute to reducing the risk of natural hazards in multiple ways. The extent of buffering depends on the ecosystem's health and on the intensity of the event (Bignami et al. 2012; Boyd et al. 2005; Dugmore et al. 2007). Ecosystems sustain human livelihoods and contribute to the ability of communities to withstand and recover from disasters (Millennium Ecosystem Assessment 2005). Ecosystem health is thus closely linked to the idea of sustainability, which implies the ability of the system to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience) (Costanza 1992, 2012). The term "sustainable ecosystem" implies also that resource use, or the demand for ecosystem services, does not exceed the supply for both present and future generations (Sudmeier-Rieux and Ash 2009). The state of ecosystems and their land-


A
Structures
Private households
Summer cottages and tourist accommodations
Power plants and utility services
Other structures
Urban area
Elevation in meters
1100-2100
1000-1100
900-1000
800-900
700-800
600-700
500-600
400-500
200-400
0-200
Askja
Grímsvötn
Hekla
Katla
Öræfajökull
B
Soil erosion
No erosion
Little erosion
Some erosion
Considerable erosion
Severe erosion
Extremely severe erosion
Askja
Grímsvötn
Hekla
Katla
Öræfajökull
C
Vegetation type
Grassland
Richly vegetaded heath land
Cultivated land
Poorly vegetated land
Shrubs and forest
Moss land
Semi wetland
Wetland
Partly vegetated
Sparsly vegetated
Askja
Grímsvötn
Hekla
Katla
Öræfajökull
0 50 100 km
50 - 100 tephra layers in soil
> 100 tephra layers in soil
Main roads
Rivers and lakes
Glaciers
Soil Conservation Service in Iceland, ABÞ nov 2013

◀**Fig. 1** Potential mitigation in S and SE Iceland in areas most likely to experience tephra events, based on location of most active volcanoes, frequency of tephra layers in soil (Larsen and Gíslason 2013), and prevailing wind patterns (Jónsson 1990, 2010). *Circles* indicate frequency of tephra layers in soil (Larsen and Gíslason 2013); **a** land elevation, main roads, and structures (Map Viewer 2013), **b** soil erosion (Arnalds et al. 2001), **c** vegetation (Agricultural University of Iceland 2013)

use history contribute to their resilience to tephra-fall disturbances, as the following examples from Mexico and Iceland show. The Paricutin eruption in Mexico in 1943–1953 demonstrates the effects of prior land use: In areas affected by tephra-fall, successional progress still differs according to the pre-eruptive ecosystem state 50 years after the eruption ceased. In areas with prior intense land use, such as bare agricultural fields and other barren areas, plant cover remains low (<10 %) and succession proceeds at a slower pace than in areas that were covered by forests at the time of the eruption (Lindig-Cisneros et al. 2006). An example of the effect of post-eruptive land use comes from Iceland (Dugmore et al. 2007): After the tephra-fall from an eruption of Hekla in 1104 AD, the recovery of vegetation was reduced due to continued grazing pressure, thus limiting the natural succession of the degraded ecosystem. This geomorphic instability persisted in some areas until 1300 AD. However, after the deposition of new tephra from an eruption of Hekla in 1300 AD, a change in the human impact on the area (perhaps the complete removal of grazing pressure) allowed the landscape to stabilize.

3 Volcanic activity in Iceland

Volcanism is prevalent in Iceland due to the island's location on the Mid-Atlantic Ridge. Active volcanic regions cover 30 % of the island, with a historical (the last 1100 years) eruption frequency of 20–25 events per 100 years, or 1 every 5 years, on average (Thordarson and Larsen 2007). Risk of tephra-fall in Iceland is therefore considerable, as 78 % of all historical eruptions were explosive, with tephra making up >95 % of the eruptive material (Thordarson and Larsen 2007).

Large eruptions cause widespread dispersal of tephra: Icelandic tephra is found in the N Atlantic Ocean, in the Norwegian Sea, and in Europe (Haflidason et al. 2000). NW European lake and peat sediments of the past 1000 years show that tephra from Iceland reached N Europe with a mean return interval of 56 ± 9 years, suggesting that, for any 10-year period in the last millennium, there is a 16 % probability of a tephra event leaving detectable deposits in N Europe (Swindles et al. 2011). The probability in Iceland is much higher, as the effects of smaller eruptions are more localized.

Explosive eruptions are more common than effusive ones, and the frequency of explosive silicic eruptions in Iceland is high, or 1 every 200–300 years. Eruptions that emit 1–10 km^3 of tephra occur on average once every 1000 years, and larger events (>10 km^3 tephra) occur roughly once in 100,000 years (Thordarson and Larsen 2007). In terms of the Volcanic Explosivity Index (VEI), there is one VEI 5 event every 100–200 years and one VEI 6 event every 500–1000 years (Gudmundsson et al. 2008). These large events are likely to deposit tephra over most of Iceland, with the greatest damage to vegetation expected within the 20-cm isopach or 70–80 km from the volcano; severe damage could also occur at tephra thicknesses of less than 20 cm. The probability of a tephra-fall event with a thickness of >20 cm has been estimated as being highest in S Iceland, in the areas near Vík í Mýrdal (1/50), Landeyjar (1/200), Vestmannaeyjar (1/250), and Hornafjörður (1/1000) (Viðlagatrygging Íslands 2011).

The most active volcanic centers in Iceland are Grímsvötn, Hekla, and Katla (Fig. 1). Grímsvötn leads with 70 historical eruptions; the tephra volume per event is 0.01 to >0.5 km^3 (Thordarson and Larsen 2007). The 1783–1784 Laki (or Laki-Grímsvötn) eruption caused significant environmental and climatic effects, when 14.7 km^3 of lava covered 565 km^2 of land and 0.4 km^3 of tephra covered 7,200 km^2 within the 0.5 cm isopach; fine ash affected the entire island, over 100,000 km^2 (Thordarson and Self 1993, 2003). Sulfur release (120 Tg of SO_2) to the atmosphere caused vegetation damage across Iceland and the death of 60 % of the grazing livestock, mainly due to chronic fluorosis. Widespread famine caused the death of 25 % of the Icelandic population within 2 years (Snævar 1993; Steingrímsson 1998; Thordarson and Self 1993). Laki was a catastrophic disruption, especially for an isolated peripheral region, as Iceland was at the time. Similar, but less severe, impacts of this eruption were observed elsewhere in the N hemisphere (Thordarson and Self 2003). Eruptions such as Laki are low-probability, high-impact events. If such an event were to occur today, it would constitute a major European health hazard and likely cause an excess mortality in Europe of 29,000 in the first year and 142,000 due to long-term exposure to particles smaller than 2.5 μm in diameter (Schmidt et al. 2011).

The volcano Hekla historically produced 1–2 eruptions per century until 1947 (Thorarinsson 1967), with tephra volumes of 0.01–2 km^3 per event (Thordarson and Larsen 2007). The largest historical event, in 1104 AD, caused complete destruction within 70 km; tephra blanketed half the country, with 55,000 km^2 within the 0.2-cm isopach (Gudmundsson et al. 2008; Thorarinsson 1979).

The historical eruption frequency of the third most active volcano in Iceland, Katla, has been 1–3 per century, with tephra volumes of ~0.01 to >1 km^3 per event; all these eruptions have been associated with major glacial outburst floods (Thorarinsson 1975). The total volume of erupted magma is 25 km^3, making Katla (until the eruption of Bárðarbunga-Grímsvötn in 2014–2015) the most productive system in historical time (Larsen 2000; Thordarson and Larsen 2007). The largest event associated with Katla was the Eldgjá eruption of 934 AD, producing a minimum of 4 km^3 of basaltic tephra (Larsen 2000).

Other examples of large explosive eruptions include the 1875 event in Askja (SE Iceland), which caused abandonment of farms within 60–70 km distance when 1.83 km^3 of tephra erupted in 17 h (Carey et al. 2010; Thorarinsson 1944). The VEI 6-level eruption of Öræfajökull in 1362, the largest plinian event of the last millennium, deposited 10 km^3 of tephra, causing long-term devastation of large areas in SE Iceland (Thorarinsson 1958).

Changes in volcanic activity are expected in the near future. Volcanism in Iceland has a marked periodicity; this, combined with climatic change and the correspondingly reduced surface pressure from melting glaciers, suggests that the cyclic behavior of volcanic activity is about to enter its next active phase (Larsen et al. 1998; Sigmundsson et al. 2010). There is an increased probability of activity in the E Iceland volcanic zone, where 80 % of all historical eruptions have occurred and the four most active volcanoes are located (Thordarson and Larsen 2007). An eruption can be expected every 2–7 years at Grímsvötn, with parallel activity in nearby Bárðarbunga (Larsen et al. 1998; Óladóttir et al. 2011). Geophysical monitoring suggests the entry of magma beneath Hekla and the W Vatnajökull area in recent years, while for the last few decades an impending Katla eruption has been expected (IMO 2011). In 2006, the probability of a Katla eruption was estimated to be 20 % within the next 10 years (Eliasson et al. 2006). The latest event is the

2014–2015 non-explosive fissure eruption from the Bárðarbunga system (Gudmundsson et al. 2014; Sigmundsson et al. 2015). The largest effusive eruption in Iceland since the Laki eruption in 1783–1784 AD, it produced more than 1 km^3 of lava, covering 85 km^2 area north of Vatnajökull, and released up to 11.2 Mt SO_2 into the atmosphere (IMO 2014).

4 Effects of volcanic tephra

Volcanic eruptions cause a wide range of hazards, of which tephra is by far the most widespread. Distal impacts over large regions occur due to exposure to tephra, gases, aerosols, and volcanically modified precipitation, and the additional impacts on climate and weather (Lacasse 2001; Self 2006). The scale of influence on the environment and human society can be varied and complicated, due to the nature of the hazard dispersal; the effects are always local, but they can also be regional or even global.

Large explosive eruptions in Iceland have induced significant and long-lasting local impacts, e.g., as shown by the multi-decadal or multi-centennial response of biological proxies after tephra damages the vegetation cover, causing increased soil erosion, increased sedimentation rates, and pronounced landscape destabilization (Larsen et al. 2011, 2012). Tephra-fall can damage vegetation, soil life, and overall ecosystem function. The most drastic tephra events leave behind a barren surface of sterile substrates that require decades or even centuries of natural primary succession to restore (Fridriksson 1981; Thorarinsson 1979).

Tephra can damage vegetation by direct burial, heat, or breakage. Volatiles can adhere to tephra particles and, through dry or wet deposition, can cause lesions, defoliation, or plant death, as seen in the Laki eruption of 1783–1784 (Steingrímsson 1998). Stresses to ecosystems caused by tephra include the inhibition of photosynthesis, changes in the water budget (drought, surface flow, or waterlogging), and changes to predation and disease vulnerability; these may all result in structural changes in the plant community (Antos and Zobel 1985; Cook et al. 1981; Zobel and Antos 1987). Post-eruptive transport of tephra (by water or wind) can be severe (Arnalds et al. 2013), leading to further damage or burial in new areas. Wind erosion with tephra-laden air causes abrasion and desiccation and uncovers plant roots, as well as reducing the soil depth (Hagen and Casada 2013). Tephra in an open landscape can be blown back and forth, becoming a source of dust storms for decades.

Volcanic eruptions can have a wide range of impacts on human health; arguably, these impacts are more varied than for any other kind of natural hazard (Hansell et al. 2006; Horwell and Baxter 2006). Tephra-fall modifies hydrology and lowers air quality, affecting human health both directly, through inhalation or the abrasion of skin and eyes, and indirectly through impacts on terrestrial and aquatic environments (Carlsen et al. 2012; Gudmundsson 2011; Thorsteinsson et al. 2012). Resuspended tephra particles prolong these health hazards. Aerosolization experiments on tephra, using the recent Eyjafjallajökull (2010) and Grímsvötn (2011) eruptions, show the ease of re-dispersal to the air; resuspension also caused a substantial increase in the concentration of respirable airborne ash particles, increasing the potential health hazard (Lähde et al. 2013).

Post-eruptive processes extend the area of influence of a volcanic eruption some distance from the initial deposition area and can last for years. In 2013, 2–3 years after the two 2010–2011 eruptions, resuspension of tephra by wind caused repeated episodes of poor air quality, with concentrations up to 1000–6000 μg/m^3 in Fljótshverfi, S Iceland (50–90 km away from the eruption sites) and up to 100–1100 μg/m^3 in Reykjavík (140–220 km away), which are well above the recommended limit of 50 μg/m^3 (EAI 2013). Post-eruptive resuspension of tephra has limited the quality of life in Iceland, as reported in the media as late as 2013, by causing reduced visibility, ground transportation hazards, property damage (such as sandblasted vehicles), and road closures. Similar effects were seen in Chile after the Mt. Hudson eruption of 1991, where remobilization of ash by wind was observed for at least 10 years after the eruption, causing significant problems in some areas and greatly hindering the re-establishment of agriculture (Bitschene 1995).

Tephra-fall is the only volcanic process that shows a damage gradient. In contrast to lava flows and pyroclastic flows, which cause the total devastation of the affected arable land and vegetation (Bignami et al. 2012), the severity of tephra-fall on agriculture generally increases progressively with tephra thickness, although its effects are linked to those due to social resilience and economic and political factors. In Iceland, tephra-fall has often caused farms to be abandoned. In the lowlands, a tephra thickness of 8–10 cm has led to farm abandonment for a year or less and 15 cm to abandonment for 1–5 years, while 30–50 cm of tephra has caused farms to be abandoned for a minimum of decades. In the highlands, a 20-cm-thick tephra-fall caused permanent abandonment (Ágústsdóttir 2013; Thorarinsson 1979). Similar effects on society have been observed in other countries, the key determinant of the re-occupation of farms being recovery of the vegetation (Wilson et al. 2010). Damage to agricultural land or water resources can also have significant impacts on the society's long-term economic growth (Mitchell et al. 2013).

5 Costs of natural hazards

The costs to society of even a moderate volcanic eruption can be substantial, as shown by the two Icelandic eruptions of 2010–2011. Both were moderate size events, with VEI indices of 3–4 (Gudmundsson et al. 2012). The prolonged 2010 Eyjafjallajökull eruption (lasting 39 days), combined with persistent NW winds, dispersed low concentrations of fine ash over a large part of Europe. This ash caused an unprecedented, large disruption to air traffic, with the cancelation of 108,000 flights, interrupting the travel of 10.5 million passengers and costing the airline industry in excess of $1.7 billion in lost revenue (Eurocontrol 2010). Although there was hardly any direct damage from this eruption, it revealed the vulnerability of modern society's interconnected economies. The consequences of interruptions in supplies of goods to industrial firms worldwide meant that gradually more and more economic sectors were affected by the volcano, in addition to other subsequent negative effects on the global economy.

Comparing this eruption to that, a year later, of Grímsvötn, we can see how the circumstances at the time of an eruption can affect the amount of global economic damage. In 2011, Grímsvötn (at least VEI 4) produced more European tephra fallout in the first 24 h than occurred during the entire 2010 Eyjafjallajökull eruption, with the bulk volume of tephra 2–3 times greater (Gudmundsson et al. 2012). However, the short duration of the eruption and the absence of strong upper atmospheric winds prevented the dispersal of tephra at the scale observed in 2010 (Marzano et al. 2013); thus, the larger eruption had a lesser effect on global society.

In Iceland, the costs to society of natural hazards are generally high regardless of the circumstances. The effects of tephra-fall, being immediate, long-term, and widespread, lead to persistent costs for years afterward. The economic cost of recovery constitutes a major burden on Icelandic society. Tephra-fall and the repeated floods due to the 2010–2011 events led to damages in transportation, agriculture, and tourism. Costs to the Icelandic government for urgent tasks in the affected areas were 11.3 million USD in May 2012 (Prime Minister's Office 2011). Additional costs were covered by the annual budget provisions of various government institutes. Damage to insured property, by the end of 2011, was 3.43 million USD (Viðlagatrygging Íslands 2011). Damage to uninsured property, such as machinery, fields, drainage systems, home power stations, emergency responses, and cleanup, has not been accounted for. Various other indirect and secondary losses, such as social or environmental issues (including damage to ecosystems) and loss of production are unquantifiable in monetary value.

A 2011 European study showed that if DRR initiatives can reduce the cost of damages by less than 1 %, then from an economic standpoint such DRR actions can be justified using cost–benefit analyses (European Commission 2011). Cost–benefit analyses are, however, only a decision-making tool. It is rare that all costs and all benefits are assessed and included in a quantitative assessment, while the assessment of risk, the study found, is politicized in all DRR decisions (European Commission 2011). Investing in ecological restoration should be considered, instead, as a high-yielding investment (De Groot et al. 2013). Studies have shown that healthy and resilient ecosystems contribute to climate change adaptation, as well as to disaster risk reduction (CBD 2009; Doswald et al. 2014; Munang et al. 2013; Renaud et al. 2013; World Bank 2010). Investing in preventive measures, including maintaining healthy ecosystems, can be more cost-effective than simply bearing the costs incurred by natural hazards (through inaction) or paying the costs (including construction and maintenance) of engineered solutions to DRR (Jones et al. 2012; PEDRR 2010; UNISDR 2011; World Bank 2010).

6 Vulnerability of Icelandic ecosystems

Iceland's climate is humid and cool-to-temperate. Iceland is near the boundary between the midlatitude westerlies and the polar easterlies; cyclones pass frequently, and shifts between frost and thaw are common. The mean annual range of precipitation is 400–2000 mm. The mean annual range of temperature is 2–6 °C, with the mean July range being 6–10 °C (Einarsson 1976). Cool summers considerably limit the yield and growing potential for a range of plants. The growing season is short, i.e., days above 4 °C range from 89 to 144 day/year (Fridriksson and Sigurðsson 1983). Natural succession is slow, and revegetation (with minimal human input) generally requires a long recovery time (decades) to turn degraded land into healthy ecosystems.

Iceland's most serious environmental problem is the degraded state of common rangeland in the highlands. Andosols, the main soil type in Iceland, are characterized by a general lack of cohesion (Arnalds 2004) and are vulnerable to degradation and erosion if the vegetation cover is weakened. At the time of settlement, c. 871 AD, 60 % of Iceland was vegetated and some 25–40 % covered by forest (Arnalds 1987). The current state of Icelandic ecosystems is often far from the expected climax vegetation for the climate. Birch woodland is the natural climax vegetation in Iceland, and lowland areas up to about 300 m.a.s.l. are within the subalpine vegetation zone. Above this limit, and in the outermost coastal districts in the northwest, north, and northeast, arctic-alpine vegetation dominates (Hallsdóttir and Caseldine 2005). At present, after 1100 years of added stress from unsustainable land use, about 95 % of the forest has been lost; only 27 % of the country remains vegetated, and natural forests cover ~1.2 % of the total area (Arnalds 1987; Gunnarsson et al. 2005). Surveys show that 40 % of the country is "considerably," "severely," or "extremely" eroded (Arnalds et al. 2001).

7 Disaster risk reduction and natural hazards

The risk of volcanic eruptions cannot be avoided in Iceland, as the area of possible impact for the largest events covers the whole island. The Icelanders' only option is to live with the risk and to aim to minimize it through DRR action, lessening the cost society has to bear (Ágústsdóttir 2013; Kelman and Mather 2008). The value of a DRR effort is threefold: in disaster preparedness, quicker recovery, and cost reduction.

By building up healthy ecosystems, DRR increases the resilience of both society and ecosystems to future volcanic events, improving their ability to survive tephra-fall and/or minimizing the disruption (Ágústsdóttir 2013). An ecosystem's resilience to the deposition of tephra depends on several factors: the depth of burial, the species' capability to regenerate when buried, the diversity of responses, seasonality, water availability, and the toxicity of the tephra. Vigorous ecosystems generally have greater endurance and shorter recovery times. Already stressed ecosystems are more vulnerable to the additional stress of tephra-fall. Research on stability domains indicates that efforts to reduce the risk of unwanted state shifts due to disturbances should address the gradual changes that affect resilience, rather than merely controlling the fluctuations caused by the disturbance (Folke et al. 2004; Scheffer et al. 2001). Stability domains, for ecosystems, typically depend on slowly changing processes that affect land use, nutrient stocks, soil properties, and the biomass of long-lived organisms (Scheffer et al. 2001). However, once degraded, ecosystems need human input to reverse these processes and to cross thresholds of energy, nutrients, and the availability of seeds, before it is possible to transition to a more productive state. Such actions have more than a century-long history in Iceland. The methods traditionally used for revegetation in Iceland, i.e., fertilization and/or seeding and planting, are also applicable to emergency revegetation after tephra-fall. DRR strategies that improve the overall health of ecosystems, on the other hand, would be preventive, and the experience gained could aid in planning post-eruptive recovery.

Vegetation is one of the main factors affecting dust emission and dust storm frequency (Engelstaedter et al. 2003; Shinoda et al. 2011; Tegen et al. 2002). Taller vegetation has higher surface roughness, resulting in less dust emission. When visibility data were used to develop a global map of annual dust storm frequency (Engelstaedter et al. 2003), a comparison with vegetation cover revealed an inverse correlation with the leaf area index (an index of vegetation density) and net primary productivity; the highest storm frequency was found in desert/bare ground environments, while a magnitude lower storm frequency occurred in areas with dense vegetation cover. This underscores the importance of vegetation in dust retention.

Vegetation acts as a bioshield reducing wind erosion (Aubault et al. 2015; Breshears et al. 2009; Webb and Strong 2011). The standing biomass modifies the near surface wind profile and alters soil and atmospheric characteristics (soil structure, surface stability, and air moisture). Vegetation controls wind erosion through various processes: (1) by sheltering the ground surface from erosive forces, reducing the friction velocity under the biomass to lower levels at the soil surface, creating wakes of reduced mean wind velocity, and covering a portion of the ground, thereby limiting the erodible area; (2) through momentum extraction from the wind, by absorbing a part of the total shear stress of the wind and thereby decreasing the shear stress acting on the ground and on the downstream plants; and (3) by trapping and intercepting windborne particles to further reduce their transport capacity (Hagen and Casada 2013; Shao 2000; Wolfe and Nickling 1993). Stronger winds are required to initiate erosion in vegetated areas. The threshold velocities required to initiate the saltation effect of wind erosion generally increase with both leaf area index and canopy height (Hagen and Casada 2013). Standing biomass reduces the surface loss from abrasion by the saltating sand grains an average of 35 % (Hagen and Casada 2013).

Land cover in Iceland is characterized by seminatural surfaces (95.2 %), while agriculture areas cover only 2.4 %, according to the Corine land classification system (National Land Survey of Iceland 2009). Plowing to remove tephra is only possible on a very limited part of these agricultural areas. Removal of tephra and recovery of an ecosystem thus depend mainly on natural processes. Recovery via extant vegetation and re-colonization will likely play a role in the post-eruptive natural revegetation and succession processes. Efficient post-event buildup of ecosystems depends on natural regeneration ability of the site, through species, microsite, and successional patterns (Titus and Tsuyuzaki 2003). Tephra-induced changes exert strong selective pressures, by filtering intolerant species out of the community (Maun 2004). A species' response to disturbance is typically classified into three processes: tolerance, avoidance, and regeneration (Burylo et al. 2012; Lavorel and Garnier 2002). Tolerance to tephra-fall is very dependent on the vegetation's height, as partial burial is easier to withstand than complete burial (Burylo et al. 2012). Experience from volcanoes in Japan shows that a species' survival following an eruption occurs either via a seed bank or through vegetative recovery, provided that disturbance gradients such as the thickness of the tephra-fall and/or the ground surface stability do not exceed the species' tolerance (Tsuyuzaki 2009; Tsuyuzaki and Hase 2005). Post-eruptive erosion can also be beneficial if buried plants are uncovered in time to aid in the recovery.

Healthy ecosystems bounce back more quickly after tephra-fall. Surface stabilization is achieved, as the tephra is removed into the soil more quickly via root action and by adding new organic material onto the surface. Surviving vegetation provides a local source of seeds, while the shelter provided by vegetation both living and dead reduces secondary transport. In areas with little or no vegetation, on the other hand, the fallen tephra is unstable and easily moved repeatedly by erosion, causing further abrasive damage. This effect was clearly observed in S Iceland after the recent eruptions. Research on the Hekla eruption of 1104 AD indicates a rapid surface stabilization of areas with deep vegetation cover, due to the vegetation subsequently growing through 35 cm of tephra. Other areas, by contrast, were affected by erosion cutting into the underlying sediments and experienced prolonged phases of instability, with discrete episodes of surface transport; such processes continued until 1300 AD (Dugmore et al. 2007). History thus suggests that DRR actions to produce healthy ecosystems can lessen post-eruptive tephra transport, producing fewer incidents of low air quality, less disruption, and reduced cleanup, resulting in less cost to society and better human and ecosystem health.

The degraded common rangelands in the highlands of Iceland are especially vulnerable to tephra-fall events. Eroded surfaces like these, which are barren or have a partial vegetation cover of sparse and low-growing plants, are easily disrupted. The resilience of this rangeland to catastrophic events can be drastically improved by reclamation efforts, as well as by reducing the grazing intensity. Diminished dependence on land use in certain high-risk areas would lower the country-wide risk of societal disturbance by tephra-fall events. Improved overall ecosystem status could also provide future options for changed post-eruptive land use, initiated as emergency short-term solutions or as a permanent land-use change. Risk reduction actions have additional positive spin-offs, including decreased erosion, increased soil fertility and water-holding capacity, and preservation or enhancement of carbon stocks, biodiversity, and wildlife habitat, providing health and recreational benefits.

8 Effective governance and policies

Land-use practices affect ecological processes in several vital ways, causing changes to the composition, structure, and function of ecosystems. Environmental laws and agricultural incentives both influence land use, but policy changes or new incentives are often needed to implement management practices aiming for long-term environmental goals. Effective governance of DRR requires an alignment of policies, including those pertaining to agriculture, land-use planning/zoning, natural resource management, climate change mitigation through revegetation, and restoration of native forests. Coherent legislation, cross-sector integration, and effective knowledge sharing are all needed to make ecosystem-based DRR approaches successful and to maximize their potential benefits. In Iceland, the following policies need to be taken into consideration when designing DRR approaches to tephra-fall.

8.1 Agricultural policies

Agricultural areas in Iceland are mainly in the lowlands, below 200 m.a.s.l., and cover <1.2 % of the country's total land area, whereas potentially they could cover an estimated <6 % (Snæbjörnsson et al. 2010). Traditional agriculture is based on rangeland grazing and on haymaking for indoor feeding during winter.

Agricultural subsidies have put pressure on Iceland's ecosystems. From the 1950s to the early 1980s, subsidies rewarded production, leading to an increased number of sheep until production limitation quotas were set in 1978 and revised in 1985. Positive changes were brought about through the work of the Soil Conservation Service of Iceland, which has battled land degradation since 1907 (Olgeirsson 2007). In recent decades, two voluntary land restoration incentive programs, "The Farmers Heal the Land" (since 1990) and "The Land Improvement Fund" (since 2003), have led to farmland improvement, moving the initiative and responsibility from the state to the local authorities and land users. A policy change in 2000 encouraged sustainability, as the Icelandic government signed a contract with sheep farmers on partial cross-compliance agricultural support. Participation is voluntary; farmers meeting the land-use quality criteria get up to 22.5 % more in subsidies. Under this program, grazing should be sustainable on land in acceptable condition. However, from an environmental perspective, the criteria are not stringent enough, and continued land use is allowed if improvement plans are made. Furthermore, the definition of "sustainable land use" is not scientific, but instead based on criteria agreed upon between the sheep farmers and the government. Sanctions against overexploitation are limited. Laws to control grazing on degraded land exist in theory (for example, Act. 6/1986, 17/1964), but in practice any attempts to enforce them have not led to real grazing control.

A global comparison of case studies suggests that, in seven out of eight cases, the economic consequences of land degradation are much higher than the costs of related inaction, even when the costs of degradation are defined only in terms of decreased crop yields (Nkonya et al. 2011). Reasons for failing to take action against land degradation are often based on policy (Braun et al. 2012). Improved land health and the improved economy of rural areas could be obtained if agricultural policies had less emphasis on production and more of a focus on environmental values. This finding is in line with a recent synthesis by OECD (2010) on the linkage of agriculture policy and rural development, suggesting that, faced with heterogeneity in rural areas, the continued shift from a sectoral emphasis toward place-based policies is likely to lead to increasingly effective policies.

8.2 Land-use planning and wilderness protection in the central highlands

Iceland's interior highlands are uninhabited, yet they are influenced by land-use planning and socioeconomic pressures. They are important as common grazing areas for lowland sheep-farming communities. Each municipality manages its adjacent areas, which extend toward the center of the country. Legislation passed in 1998 (Act. 58/1998) to clarify the ownership of the highlands provided a legal basis for the Icelandic state to own both the land and the land rights that are not subject to private ownership. This act led to an ongoing legal procedure disputing private and governmental claims. Stakeholders are diverse, with conflicting economic interests. Farmers, landowners, municipalities, power companies, various types of tourism, recreational users, and nature conservationists all have divergent visions of nature and land use. New legislation on planning (Act 123 of 2010) is intended to provide a coordination platform for sectoral plans regarding these central highlands. Land-use intensification generally leads to reduction in both response diversity and functional redundancy, thereby reducing an ecosystem's resilience to future disturbances (Laliberte et al. 2010). Successful resource management should aid in ecosystem buildup, not add to the chronic stress that makes the effects of the disturbances permanent (Mori et al. 2013).

8.3 Rural policies

Rural development often involves areas with declining income, declining employment, and a falling population; it is concerned with stimulating economic growth, creating new sources of income, and preventing the further decline of rural populations (OECD 2009). Iceland is no exception: More than half of the population lives in the city of Reykjavík, after persistent urbanization and depopulation of rural areas during the last century. About 7 % of the nation lives in areas with small local population clusters, where diverse employment and services cannot be maintained (Bjarnason 2010). Remote marginal lands face the possibility of being withdrawn from production; they experience high transport costs and are only marginally profitable. They are also more likely to be linked with adverse environmental effects, such as erosion due to mismanagement. Agriculture and rural development in these sites could benefit from a diversification of policies.

8.4 Climate change mitigation through revegetation

Increasing carbon sequestration in the soil and in vegetation through reclamation of degraded or desertified land is an important part of Iceland's climate change actions for the

UNFCCC (Art. 3.4 of the Kyoto Protocol). In Iceland, revegetation on 83.21 kha removed 167 Gg CO_2 eq. (Net—Net accounting) in 2010, compared to 1990 (Environment Agency of Iceland 2012). Revegetation is also a part of ten major tasks of an Icelandic governmental action plan from 2010 to curb greenhouse gas emissions. This strategy aims for a 50–75 % overall reduction by 2050, compared to 1990, yet the trend from 1990 to 2010 suggests a 30 % increase in these emissions (Environment Agency of Iceland 2012). The effectiveness of this policy goes hand in hand with the funding provided: Since 2003, funds to the Soil Conservation Service of Iceland have decreased by 30 %. To reach the emission reduction target, more effort should be put into the removal of carbon through revegetation. Early action accumulates more carbon with more climate benefits.

9 Reclaiming vulnerable land and building healthy ecosystems

National strategies for the restoration of native Icelandic woodlands, set forth in 2007, aim to increase forest cover to 10 % of the island in the future (Ministry for the Environment 2007). Various projects contribute to this effort, such as revegetation by the Soil Conservation Service of Iceland and regional afforestation programs. Birch (*Betula pubescens*) has been the only forest-forming tree species in Iceland since the Holocene. Birch and willow species (*Salix spp*.) have good potential for natural regeneration, often being early colonizers in natural succession and key species in ecosystem development. On severely degraded land, land reclamation is often necessary prior to afforestation to stabilize the surface, halt soil erosion, restore ecosystem functioning, and provide sites for seeds.

Restoration strategies for Iceland's native forests are well presented in the Hekluskógar project (Hekluskógar 2015). This 900 km^2 woodland restoration of native birch and willows near Hekla volcano, S Iceland, aims to reduce the potential damage from future Hekla eruptions by increasing ecosystem resilience and limiting the secondary distribution of tephra to nearby regions. When the project began in 2005, Hekluskógar was mostly comprised of desertified land at a fairly low elevation. Forest remnants, historical accounts, and place names, however, suggested that forests had grown there in the past which, in the post-settlement period, were degraded over time as human land use and tephra-fall events led to severe erosion.

Ecosystem functioning in Hekluskógar now remains hampered by nutrient-limited soil, low water-holding capacity, unstable surfaces, and extensive frost heaving, which together limit its natural recovery and the establishment of seedlings. Revegetation through fertilization and seeding helps to overcome these ecological thresholds, stimulating a natural succession of local flora and aiding ecosystem development. The extent of the area and the input needed, however, place practical limits on this otherwise very successful woodland restoration attempt. Self-seeding is promoted by strategic placement of tree seedlings, which in the future will act as sources for seed dispersal and further colonization by wind-dispersed species.

The success of the startup at Hekluskógar is credited to the fact that planning and management is a joint effort of various stakeholders: landowners, governmental officials, scientists, and extension officers. It represents an alignment of policies toward a united goal of sustainability and DRR. A similar buy-in by all stakeholders will be necessary to expand the Hekluskógar concept to areas near other active Icelandic volcanoes. This expansion will first, however, require a determination of which areas will see most benefit from the Hekluskógar approach; such areas may not be those that are most at risk from a tephra-fall event. Predictions of volcanic impact zones are in general a difficult task that often constrains DRR action (Bignami et al. 2012), since in Iceland, as stated above, the whole island can endure damage in the largest eruptions. Areas of influence for smaller to medium eruptions, however, are usually regional, with a directional extent. In these regional focus areas, a new risk assessment for volcanic hazards, currently in progress, will provide the information needed to plan a more detailed, long-term DRR action.

Identifying high-risk zones, based either on the expected frequency of volcanic eruptions or on their degree of impact, can aid in directing DRR actions, as well as improving their ease of execution and increasing their expected social value. Areas that face multiple natural hazard risks (e.g., of different frequency or magnitude, as well as possibly interacting risks) could arrive at effective multi-risk approaches through a cost/benefit analysis of DRR actions. Actions such as those represented by the Hekluskógar project are likely to be most successful outside of the zone of extreme impacts, from areas of medium impact toward the edge of the impact zone. In zones where extreme impacts are likely, any preventive DRR action is likely to have limited value. There, only post-eruptive revegetation can stimulate natural succession on fresh volcanic deposits.

Preliminary results, based on the location of Iceland's most active volcanoes, the frequency of tephra layers in the soil (Larsen and Gíslason 2013), and the prevailing wind patterns (Jónsson 1990, 2010), suggest that areas in S and SE Iceland are the most likely to experience tephra-fall events (Fig. 1).This region of expected tephra-fall, stretching 270 km along the southeast coast, is also considered "fragile" in the sense of rural development, with negative trends regarding population, age structure, and employment (Bjarnason 2010). The population in this area has fallen by 13 % during the last decade (Bjarnason 2010). Cultural and behavioral barriers have to be addressed. Rural communities in S and SE Iceland, for instance, may be unwilling to change their traditional land-use patterns and thereby affect rural cultural events, such as the autumn sheep gathering from communal areas. There may also be uncertainty about whether property rights based on tradition will be lost, if this type of land use is discontinued. Information could overcome these barriers, so that resistance to change does not limit progress toward sustainable land use. Changes through regulatory governance and involving local stakeholders can guide these rural communities toward a more sustainable use of natural resources.

Natural systems have large absorption capacities; yet once tipping points are reached, they can suddenly crash, with devastating consequences for other economic and social systems (United Nations ESCAP 2013). Ecosystems at risk should receive priority for management interventions to enhance their resilience or restore the desired stability domain. Building resilience will mean addressing a nexus of converging threats. One key is to understand how land use exacerbates episodic disturbances that can reshape systems. Effective land-use planning can be applied as DRR, diminishing existing stress by building up healthy ecosystems, thereby enhancing the ecosystems' resilience and reducing societal vulnerability to natural hazards (EEA 2010). Land-use planning does, however, have unresolved challenges. Few disaster risk management systems have been able to employ land-use planning or to influence investment policies to encourage effective disaster risk management (Johnson 2011; UNISDR 2011).

Planning for recovery after a disaster is likewise missing in most countries, with a few exceptions such as China, Canada, and New Zealand, where disaster recovery is linked to broader projects of governance (Mitchell 2006). Iceland could benefit from forming a recovery plan for ecosystems that have endured tephra-fall, following New Zealand's example of making sustainability the guiding principle of all public actions taken during the recovery phase of disasters (Mitchell 2006).

The state of an ecosystem determines its tolerance to disturbances and affects its recovery time (Grandy et al. 2012; Lindig-Cisneros et al. 2006). The extensive ecosystem degradation in Iceland, coupled with the island's short growing season, ensures that post-eruptive ecosystem recovery is a long-term process. A preventive DRR approach through healthier ecosystems, combined with a post-event approach of planning for sustainability, could speed up this recovery. Positive tipping points may occur in the recovery process, when human interventions in degraded ecosystems allow their processes and populations to recover (Olgeirsson 2007; Westley et al. 2011). Ecosystem functioning and the traits that lead to enhanced ecosystem resilience and succession in Iceland need to be explored while planning this ecosystem recovery process. It is within this context that the Hekluskógar concept is most successful. With its effective stakeholder participation, alignment of policies, use of local flora, and heterogeneous solutions tailored to fit the local environment, the concept can be transferred to other regions that are likely to be at risk of tephra-fall.

10 Conclusions

As volcanic activity in Iceland is expected to rise in the future, increased natural hazard risks can be anticipated. Eruptions in 2010–2011 proved the value of pre-disaster planning for some volcanic hazards, but a new focus is needed on pre-disaster mitigation responses for the effects of tephra-fall on vegetation. As outlined in the UNISDR Hyogo Framework, healthy ecosystems and environmental management are key actions in disaster risk reduction (DRR). The Hyogo Framework further recommends that policymakers take six steps toward DRR: assessment, prevention, mitigation, monitoring, early warning, and preparedness (UN-ISDR 2013). The assessment here of the tephra-fall problem has shown that vulnerability exists due to current land use in Iceland and that the underlying risk factors could be reduced. Prevention of tephra-fall events is impossible, but improved ecosystem health could prevent further degradation and move systems away from negative ecosystem tipping points (Sidle et al. 2013). Mitigation has been shown to improve ecosystem resilience. Monitoring improves knowledge on ecosystem status, detects subtle signs of resilience loss (Sidle et al. 2013), and suggests improvements. Such monitoring is important to set up in Iceland. Early warning immediately prior to events is irrelevant here, as ecosystem processes operate on long-time scales. Preparedness can be obtained from studying past events and through sustainable practices. Societal DRR benefits will include the economic and human health benefits of healthy ecosystems and their services prior to an eruption, while, afterward, those ecosystems that survive tephra-fall will reduce the secondary transport of tephra. Post-eruptive benefits to society will be faster recovery for the economy, transport, and agriculture, and, first and foremost, better air quality.

The Hyogo Framework is due to expire in 2015, and a wide consultation process is currently shaping its successor, the post-2015 framework for disaster risk reduction. The new Sendai DRR framework was endorsed at the Third UN World Conference for Disaster Risk Reduction in Sendai, Japan on March 14–18, 2015 (UNISDR 2015). At its core are four priorities for action: (1) understanding disaster risk, (2) strengthening disaster risk governance to manage disaster risk, (3) investing in disaster risk reduction for resilience, and 4) enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction. These priorities are directly aligned with our approach here: (1) we have strengthened the evidence base for an ecosystem approach to

DRR for volcanic tephra-fall; (2) we have pointed out governance issues in Iceland that need to be strengthened for effective DRR; (3) we have suggested an alignment of various policies regarding land-use, land degradation, and rural development in order to strengthen the sustainable land-use management of ecosystems and form an integrated natural resource management approach that incorporates DRR; and (4) we have suggested that heightened ecosystem resilience is the key to disaster preparedness and to efficient recovery.

Vulnerability to tephra-fall is dynamic, changing in both space and time, and depends on a complex relationship between nature and society. Societal changes in governance, the understanding of hazards, technology, coping mechanisms (before, during, and after), and the resources available to DRR or post-event response actions all fluctuate over time. Consider, for instance, the difference in vulnerability between the pre-industrial subsistence farming community, where the effects of major eruptions could lead to nationwide crisis, depression, and famine (Thordarson and Self 2003), and the modern society that can follow online the real-time measurements of activity during an ongoing volcanic eruption. All communities need the skills, capacity, and experience to cope and adapt. Among these, an awareness of risk and vulnerability can enable informed decision making. We have linked here volcanic eruptions to ecosystem-based disaster risk reduction and the need for sustainable land-use management, although the use of ecosystems as "bioshields" is not a panacea and should be accompanied by other measures, e.g., early warning systems, disaster preparedness, and emergency actions, to decrease people's vulnerability to natural hazards (Feagin et al. 2010). However, if Iceland's currently unsustainable land-use practices are continued, the country's vulnerability to tephra-fall will increase; the minimum benefit of DRR would be to limit that increase in vulnerability. Alternately, a weak framework of legislation and policy, poor land-use planning, and inertia to change are some of the economic, political, scientific, and social components contributing the most to environmental degradation.

Ecosystem services are essential for sustainable livelihoods, both immediately and in the long term. The restored habitats of an ecosystem-based DRR effort will improve the capacity of both ecosystems and people to withstand future extreme natural hazards. Investments in sustainable land management can offer cost-effective solutions (De Groot et al. 2013) to reducing a community's vulnerability to natural hazards such as volcanic eruptions. It costs less (in economic, social, and political terms) to prevent or mitigate hazards than it does to clean up and fund recovery after a disaster (Anderson 1990). Ecosystem-based DRR in Iceland could also merge the goals of sustainable and rural development. Combining ecosystem restoration in degraded areas with long-term views of rural development, nature protection, agriculture, and resource management leads to a proactive, cost-effective alternative to the reactive, emergency-response expenses, while pooling limited resources for rural, agriculture, and ecological development provides more leverage toward sustainability and resilience. In the long term, DRR investments have a high rate of return and contribute to sustainable economic development (European Commission 2013). But investing in prevention, versus only reacting to disasters, requires political will, resources, and an adherence to long-term political strategies that recognize the value of ecosystems and the need for DRR solutions.

The key messages presented in this article are not only relevant for DRR in Iceland but are also valid for other regions, especially in other volcanic areas where people depend strongly on natural resources, where environmental conditions are degraded, and where the growth of vegetation is limited by harsh environmental conditions. The innovative approach suggested here aims to reduce environmental vulnerabilities in order to reduce the primary and secondary effects of volcanic tephra on ecosystems and human health. The opportunities that effective ecosystem management provides for DRR, in terms of decreasing the vulnerability of both people and ecosystems to future extreme events, should be given high priority in disaster management planning. Encouraging the sustainable use and appropriate management of fragile ecosystems now has an additional aim: to reduce risk and vulnerabilities to natural hazards.

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SHORT ARTICLE

Convergent Agency: Encouraging Transdisciplinary Approaches for Effective Climate Change Adaptation and Disaster Risk Reduction

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Abstract Three recent global agreements have been established to facilitate the implementation of global-level responsibilities to deal with disaster risk reduction (DRR), human development, and climate change adaptation (CCA) respectively. While these agreements have a common goal of reducing social, economic, and environmental vulnerability, they have been developed by largely independent communities of practice. This has limited cross-fertilization despite the inherent multidimensional nature of global challenges and the considerable thematic overlap. We argue that developing a transdisciplinary strategy that effectively integrates disciplines, approaches, and knowledge systems will lead to greater and more sustainable impacts, together with a more efficient use of financial resources. Hybrid approaches should be encouraged during planning of future development efforts so that risk reduction is conducted simultaneously with CCA. Transdisciplinary processes are central to generating context-sensitive knowledge to support decisions on CCA and DRR options that minimize trade-offs and maximize synergies and complementarities required to guide sustainable development trajectories. Finally, building codes together with climate and risk-smart research, education, and awareness raising, are identified as priority entry points to materialize the blending of DRR and CCA approaches and effectively reduce risk while mitigating and adapting to climate change.

Keywords Building codes · Climate change adaptation · Disaster risk reduction · Sustainable development goals · Transdisciplinary knowledge

1 Introduction

For more than 25 years, the scientific community has been anticipating important global changes in the fields of climate change adaptation (CCA) and disaster risk reduction (DRR) following the release of the first assessment report of the Intergovernmental Panel on Climate Change (IPCC 1990). Since then a number of major global agreements and guidelines have taken place to address these issues (Fig. 1).

In 2015, three key global agreements were established to facilitate the implementation of global-level responsibilities to deal with DRR, human development, and CCA respectively (Fig. 1). In March, the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) (UNISDR 2015) replaced the Hyogo Framework for Action 2005–2015 (HFA) (UNISDR 2005). The SFDRR was designed to guide the international community in its collective support of regions and countries in strengthening their resilience to disasters. In September, the Millennium Development Goals (MDGs) were replaced by the Sustainable Development Goals (SDGs) (UN 2015), where DRR was addressed by goals linked to poverty eradication, food security, infrastructure, cities and human settlements, climate change, and ecosystems. Finally, in December, at the 21st Session of the Conference of the Parties (COP 21) of the United Nations Framework Convention on Climate

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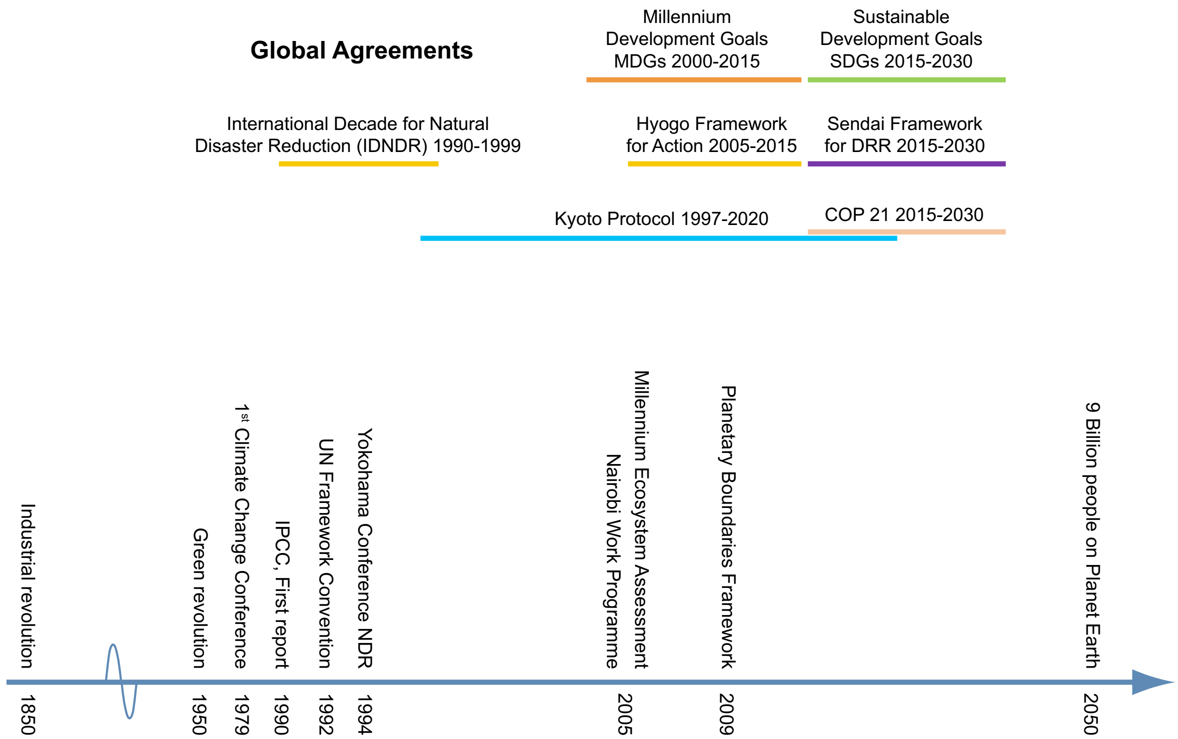

Fig. 1 Global initiatives in response to contemporary challenges on Planet Earth

Change (UNFCCC 2015), the draft of the Paris Agreement was adopted to address the immense challenges of climate change, hence facilitating government actions that encourage including risk reduction as part of efforts addressing CCA.

It is increasingly clear that these global efforts have overlapping goals. Developing a transdisciplinary strategy that effectively integrates disciplines, approaches, and knowledge systems will lead to greater and more sustainable impacts, together with a more efficient use of financial resources. This article briefly outlines areas of overlap, identifies priority entry points for collaborative engagement between the respective communities of practice, and proposes steps to guide the integration of DRR and CCA efforts to reduce vulnerability and increase their contribution to the SDGs.

2 Transdisciplinary Knowledge Contributes to more Effective DRR and CCA Actions

Developing transdisciplinary knowledge requires crossing multiple disciplinary boundaries, engaging scientific and nonscientific sources or practices, and using methodological tools that encourage collective learning (Barrios et al. 2012) from different disciplines to generate holistic understanding of global phenomena (Parkes et al. 2005; Stock and Burton 2011). In this section, we suggest a transdisciplinary process aimed at minimizing trade-offs, and maximizing synergies and complementarities between DRR and CCA efforts.

While efforts to reduce disaster risks and climate change risks have long coexisted, there is increasing recognition of the opportunities for blending CCA and DRR efforts because the types of actions required for both approaches are often similar (Doswald and Estrella 2015). Recognizing that climate change is a key hazard driver (Kelman 2015), for example, highlights the opportunity to explicitly incorporate the gradual effects of climate change when planning to reduce disaster risks.

When planning for DRR, traditional engineering options through structural approaches (reservoirs, dykes, seawalls, and dams), based on codes that do not take into account climate change, are normally the options considered. But when trying to adapt to climate change, ecosystem-based adaptation options are often considered, particularly in rural landscapes (Geneletti and Zardo 2016). We argue that both approaches should be strategically combined during planning of future development efforts so that adaptation to climate change is conducted simultaneously while reducing risks. The Dutch “Room for the River” program,[1] established in response to the devastating 1993 and 1995 Rhine delta floods in the Netherlands, is a good example of combining DRR and CCA approaches that aims to give rivers

[1] https://www.ruimtevoorderivier.nl/english/.

space to flood safely in order to protect vulnerable urban and rural areas. The success of convergent agency, however, is dependent on the full recognition of the advantages and disadvantages of both approaches, over different temporal and spatial scales, in order to develop a transdisciplinary knowledge that minimizes trade-offs and maximizes synergies and complementarities. Encouraging a gradual and open process of cross-fertilization would foster convergence, limit the risk that results of one approach negatively affect the results of the other, and more importantly ensure that the resulting development actions will help to reduce, and not exacerbate, vulnerability.

The lack of transdisciplinary knowledge to support recovery plans to face disaster events misses a great opportunity for reducing vulnerability to hazards and increasing adaptation capacity in the longer term. In El Salvador, for example, people who lost their homes to Hurricane Mitch in 1998 were still living in temporary shelters when an earthquake struck in 2001, thus leaving them even more vulnerable than before (Wisner 2001). The wrong location of provisional settlements following a disaster can also lead to unplanned environmental problems (for example, deforestation) that could limit the contribution of natural ecosystems to CCA (Parker et al. 1995).

Similarly, while mangrove forests normally occupy the costal intertidal zones and have been shown to reduce the impact of tsunami events (Danielsen et al. 2005; EEA 2015), their replacement with unsuitable vegetation to presumably provide the same protective function may actually lead to greater damage. For example, the planting of pine forests to prepare for coastal natural events along Japan's coast exacerbated damage during the tsunami caused by the Great East Japan Earthquake in 2011. Pine trees are inadequate for such protective function given their characteristic shallow rooting pattern, are uprooted more easily, and become the first debris to hit and damage houses and other buildings (Renaud and Murti 2013). The replacement of mangrove forests would also have an impact on the functionality of aquatic ecosystems given their important role as breeding grounds for fish and nursery habitat for their juveniles (Kathiresan and Bingham 2001). The failure to blend relevant scientific knowledge and local knowledge and experience has been highlighted as a common limitation to matching tree-based interventions to variations in social-ecological context (Coe et al. 2014).

In contrast, The Nature Conservancy has used transdisciplinary knowledge to guide DRR actions in the case of 1-in-100 year storm events in New York City, and concludes that hybrid options offer the best protection from these storms, while also providing significant environmental benefits (Nature Conservancy 2015). Hybrid options combine biodiversity conservation with engineering options tailored for key habitats (dunes, mangroves, coral reefs, wetlands, and forests). They benefit from and do not disrupt the natural features of these habitats, thus lowering vulnerability by reducing wave energy, absorbing floodwaters, and helping defend against storms. Hybrid options can also be used in urban settings to help cope with the effects of increasing mean temperature associated with climate change. For example, increasing tree cover in cities by encouraging tree planting along streets, in parks and backyards, together with the naturalization of lands that surround water and water facilities, can play an important role in buffering temperature through shading and maintaining moist environments (Bowler et al. 2010). While hybrid options have shown significant potential, there is still limited practical evidence of their success in simultaneously addressing the impacts of DRR and CCA. This is likely the result of difficulties encountered in the attempt to fully embrace transdisciplinarity during knowledge sharing and integration processes across different disciplines, sectors, and scales relevant for ecosystem management and DRR (Scholz and Steiner 2015).

3 The Strategic Role of Building Codes as an Entry Point to Reduce the Gap between CCA and DRR

Building codes create uniform regulatory standards that hold design professionals and contractors responsible to a set of principles aimed to protect families, communities, and society at large in the event of a natural hazard (FEMA 2013). The absence of building codes, outdated building codes, and the failure to enforce existing codes, all represent a fundamental vulnerability issue in urban and rural areas. The importance of building codes was highlighted by the dramatic contrast between the impacts of recent earthquakes in Haiti, Chile, and Japan. While the Haiti 2010 earthquake generated considerable human and structural losses because of the lack of building codes, the reduced impact observed after the Chile 2010 and Japan 2011 earthquakes was the result of the successful implementation of building codes that reduced human and economic losses. While the Chile earthquake released nearly 1000 times more energy than the earthquake in Haiti, both in densely populated areas, it resulted in 1000 times fewer victims (Bendito and Gutiérrez 2015). It is worrisome that following the West Java, Indonesia 2009 earthquake, new building reconstruction efforts did not follow the existing building codes (EERI 2009), thus increasing vulnerability by neglecting the Sendai Framework's Priority 4 that emphasizes the need of "building back better to prevent creating new risks" (UNISDR 2015).

Building code challenges go beyond urban settings and can directly influence food security. Postharvest losses are recognized as one of the largest sources of inefficiency in agricultural production (IFAD 2013; CCAFS 2015). In Rwanda, for example, none of the postharvest facilities evaluated were designed with consideration of the emerging environmental and climate change challenges, nor were they constructed following building codes (Bendito and Twomlow 2014). While it is not viable to prevent self-construction, simple guidelines that include design, construction materials, and maintenance issues (Bendito and Twomlow 2014) can provide a significant contribution to transdisciplinary knowledge development processes that optimize hazard-resistance and ecosystem services in the self-constructed buildings.

Building codes should move from a passive to a proactive stance in order to maintain their relevance on a rapidly changing planet (Bendito and Gutiérrez 2015). Existing and new infrastructures should be better adapted to the current and expected future impacts of climate change. Building codes should therefore include, among other features, hazard maps developed for different events (multihazard maps) and for different engineering design levels (for example, differing return periods) (Bendito et al. 2014). Return period is the mean time between the occurrence of two specific hazards. Given the existing trend of increased frequency and intensity of climatic events, the current return periods (the probability of the most severe hazard event occurring in a 100-year period) used to develop hazard maps need to be revised to include shorter and multiple return periods.

Updated multihazard maps, data on exposure (building inventory, population size and distribution, soil types, and so on), ecosystem services (assessment of the degradation status of key habitats), Geographic Information Systems (GIS), and local knowledge (for example, early warning indicators) become critical components of risk maps as useful boundary objects during the development of transdisciplinary knowledge. Boundary objects are defined as collaborative products that can incorporate different points of view and still retain acceptable levels of robustness (Clark et al. 2011). Risk maps facilitate the communication of the spatial and temporal impacts of disasters on people, infrastructure, and ecosystem services by showing areas at high, medium, and low risk. Risk maps help to guide the development of mitigation and adaptation measures at different scales (for example, community, district, and national levels).

4 Transdisciplinary Knowledge to Reduce Gaps between DRR and CCA

The way in which findings are communicated in the global development arena can significantly influence outcomes because "words used are constructors of reality" (Mires 2015). If we continue to refer to human-made disasters as "natural disasters" people will continue to think that these disasters are acts of God and not caused by the increased vulnerability to hazards resulting from human actions. It is necessary to shift the perspective from natural disasters to "natural hazards" (Briceño 2015). We also have to make sure that these concepts exist globally in all cultures. In some African languages, for example, the term ''risk'' does not exist (Manyena 2016).

Developing transdisciplinary concepts that cut across the divides that mark traditional disciplinary boundaries can facilitate knowledge sharing and unification (Stock and Burton 2011). The Eco-Disaster Risk Reduction/Climate Change Adaptation (Eco-DRR/CCA) approach (Renaud et al. 2016) could be considered an effort to develop transdisciplinary knowledge. The Eco-DRR/CCA approach encourages the development of hybrid options by fostering the holistic thinking required to address complex problems synthesized in the SDGs. For example, when SDG 13 (Target 13.1) "strengthening resilience and adaptive capacity to climate-related hazards" is tackled using the Eco-DRR/CCA approach, Target 11.5 "reducing losses caused by disasters" and Target 6.6 "protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes" would also be directly influenced. Similarly, implementation of climate-smart postharvest projects as part of Eco DRR/CCA actions can simultaneously contribute to SDG 2 concerned with food security and improved nutrition, and SDG 9 concerned with building resilient infrastructure to foster sustainable development.

5 Conclusion

It is argued that DRR and CCA should be strategically combined during planning of future development efforts so that risk reduction is conducted simultaneously with adaptation to climate change. The ability of society to deal sensibly with risk and climate change, which largely occur together in time and space, would be strengthened with greater understanding of interactions between both phenomena. The value of transdisciplinary processes is shown to be central to research that generates context-sensitive knowledge to support decisions on CCA and DRR options that minimize trade-offs and maximize synergies and complementarities required to guide sustainable development trajectories.

Building codes are identified as a priority entry point to integrating DRR and CCA approaches. Climate- and risk-smart education and awareness raising should also be a fundamental component of the strategy to face our increasingly unpredictable and challenging future. Universities need to improve undergraduate education teaching students to act locally while thinking globally, encouraging respect for diversity and the value of "deeper digging" through dialog and consensus building to fully benefit from processes of cross-fertilization. New engineering curricula need to seriously incorporate ecological knowledge as a resource rather than a burden, highlighting, for example, the strategic value of key habitats that act as natural solutions to reducing risk and vulnerability. Engineers would greatly benefit from a better understanding of the role of ecosystems and the multiple benefits they provide to society (ecosystem services) as great opportunities for convergent agency.

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Last Page

The appended material is based on course developed under the SUNRAISE Project.

The course is being offered at the Jawaharlal Nehru University. The teaching is carried out using the published research material. As the course is multi-disciplinary, finding a text book is challenging. The appended notes are using the material available as Open Access, which is distributed under the terms and conditions of the Creative Commons Attribution license.

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