Title: Advancing Ecosystems and Disaster Risk Reduction in Policy, Planning, Implementation, and Management

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Recently, several major global agreements have ushered a new era recognizing the role ecosystems can play directly and indirectly in terms of development, namely: the Sustainable Development Goals [1], the Sendai Framework for Disaster Risk Reduction [2,3], the United Nations Framework Convention on Climate Change and Paris Agreement [4], and the Ramsar Convention on Wetlands 12th Conference of the Parties (CoP)/Resolution XII.13 [5]. In addition, the Convention on Biological Diversity's 12th CoP in October 2014 passed Decision XII/20 [6], explicitly linking biodiversity to disaster risk reduction (DRR) and climate change adaptation (CCA). All these major global agreements and commitments recognize the role of ecosystems and natural infrastructure as key to helping achieve DRR, CCA and sustainable development. Consequently, there is now stronger global interest and demand than ever before, coming from national and local governments, communities, as well as the private sector, to apply ecosystem-based approaches and natural or green infrastructure solutions for building resilience to disasters and climate change.

Healthy, well-managed ecosystems serve as natural infrastructure that contribute to protecting people and livelihoods against many types of hazard events and climate extremes. The level of protection will depend upon a number of factors, from the magnitude of the hazard event, to the health and integrity of the ecosystems themselves. Increasingly, hybrid approaches that optimize both ecosystem services/functions and engineering solutions are being designed and implemented to mitigate hazard impacts or serve as protective barriers and safety nets. Generally, ecosystem-based approaches using natural infrastructure, which may include hybrid "green-grey" solutions, provide other social and environmental benefits, including support to local livelihoods, biodiversity conservation and carbon sequestration.

Despite the growing international support for ecosystem-based disaster risk reduction (Eco-DRR) approaches, they have not yet been mainstreamed as part of standard disaster risk management policy and practice in most countries. Conventional engineering approaches, such as the use of raised embankments, retaining walls and groins, are often the preferred options for enhancing protection and managing disaster and climate risks, yet these do not provide the multiple social and environmental benefits of natural infrastructure listed above.

One of the main constraints to mainstreaming and scaling up Eco-DRR approaches is the lack of standardized, technical guidelines for designing and using ecosystem-based measures for reducing disaster risks, which constrains the engineering community from further replicating and implementing such measures. Although guidance for implementing Eco-DRR measures have become much more available over the past decade, much of the guidance has not yet been subject to rigorous testing and standardization, nor is it readily available or implementable for all types of ecosystems and hazards. There are very few widely-accepted, technical, implementation guidelines, for instance in the case of establishing and managing "protection forests" – known as the NaiS guidelines - in Switzerland and used by other Alpine countries, to reduce risks from mountain hazards [7]. Therefore, engaging with engineers, engineering institutions and associations, is a critical step towards advancing Eco-DRR practices and more generally, taking forward the 2030 Agenda for sustainable development. A concomitant critical step is to provide similar clarity on the governance, policy, and economics of Eco-DRR.

The Partnership for Environment and Disaster Risk Reduction (PEDRR) hosted its Third International Science-Policy Workshop on 14-16 June 2016, at the United Nations University Institute for Environment and Human Security located in Bonn, Germany. This event brought together the environmental, engineering, and policy communities to establish a path towards promoting Eco-DRR approaches in the context of disaster risk management, resilient development policy and planning. This event capitalized on ongoing collaborations with policy makers, academia and engineering companies in order to develop and improve Eco-DRR measures based on integrated, ecological-engineering standards (Eco-Engineering). The workshop provided an unprecedented opportunity to coalesce current knowledge and practice of applying Eco-DRR measures, with the aim of further mainstreaming and scaling up Eco-DRR in development policies, plans and programs.

This special issue reflects and catalogues the principal goal of the PEDRR workshop - to accelerate and scale-up implementation of ecosystem-based approaches to disaster risk reduction in a variety of critical communities including engineering, academia, and policy-making. The participants collaborated to generate papers that cover the full range of issues explored at the workshop including engineering, design, science, policy, governance, economics, funding frameworks, and current innovative approaches. Specifically, the workshop and resulting special issue capture the core objectives of the PEDRR International Science-Policy Workshop including (1) convene and facilitate an interactive dialogue between engineering and Eco-DRR communities, and explore areas of convergence and divergence, (2) define the current knowledge base (and gaps) and available technical guidelines/standards on ecological engineering as well as hybrid ecosystem management and engineering approaches to DRR, (3) identify types of standards or criteria needed that would support consideration of Eco-DRR measures as one of the solutions for risk reduction and risk management, (4) enhance the economic case for promoting ecological-engineering approaches to DRR, (5) document and synthesis the current state of knowledge on ecosystems and disaster risk reduction in policy, planning, implementation, and management, and (6) identify opportunities and obstacles to advancing the combined fields referred to as Eco-Engineering [8]. This special issue is designed to provide the reader with a comprehensive grasp of the current status and future potential of Eco-Engineering by first providing governance, policy, and economic approach examinations followed by foundational descriptions of Eco-DRR and Eco-Engineering reinforced with a series of case studies across a diverse suite of hazards and socio-economic and environmental circumstances. Collectively, this compilation will help stimulate more engagement from the scientific, policy, and practitioner communities across the globe.

Of the 11 papers in this special issue, two distinct studies examine the governance frameworks and policies enabling or hindering Eco-DRR applications. First, Faivre et al. demonstrate how Eco-DRR is increasingly being promoted and mainstreamed through European Union programmes and policies that contribute to implementing the Sendai Framework for Disaster Risk Reduction. This paper further highlights how engagement with the research community via various European Commission programmes, centres, and user groups is demonstrating the cost-effective, added value of Eco-DRR, which further influences the integration into governance, policy, and funding at local and national levels. This paper provides an example for governance and policy uptake of Eco-DRR at national and multi-national scales. Second, Triyanti and Chu offer an assessment of the importance of governance practices and cross-sector, interdisciplinary interactions and dependence on the integration and use of Eco-DRR across the globe. The authors provide a synthesis of governance gaps and opportunities designed to highlight future research needs that include the governance and political dimensions of Eco-DRR.

As highlighted by Hinzpeter and Sandholz, recovery discussions and operations immediately after a disaster provide a window of opportunity to advance the implementation of Eco-DRR across diverse sectors. Unfortunately, tools such as the Post Disaster Needs Assessment (PDNA) as discussed in this paper, fail to address and incorporate environmental aspects of recovery in the overall process. An analysis of prior PDNA reports and surveys is provided along with resulting recommendations to help increase the application of Eco-DRR in post-disaster recovery efforts globally.

While economics is a consistent consideration throughout all papers in this special issue, Onuma and Tsuge provide a theoretical approach to help underpin the cost-benefit of natural infrastructure (i.e. "green") and "grey" or built infrastructure in the context of Eco-DRR. By examining various parameters including probability of hazard occurrence, exposure, vulnerability, population size, and cost-benefit (green vs. grey), the authors suggest a condition under which the use of natural infrastructure becomes more desirable then grey infrastructure as an engineered alternative to disaster risk reduction. By applying the results to various case studies, this paper helps to inform policy and economic decisions regarding the conditions for use of green versus grey infrastructure with estimated parameter values.

Alongside governance, policy, and economics, several other global Eco-DRR considerations were identified during the PEDRR workshop including the need to clarify the science regarding risk reduction effectiveness, develop principles, standards, and designs, reduce legal and regulatory obstacles to implementation, and grow a demonstration site network responsive to circumstances faced by communities around the globe. Whelchel et al. offer a foundational review of these consideration and an integration of science, designs, and policy via the emerging field of Eco-engineering. The authors use supportive coastal, river, and urban examples from around the world as well as global resource management processes (IWRM, ICZM) to illustrate the current state of knowledge, model science, design, and policy integration, identify initial "benchmark sites", and define guiding Eco-Engineering principles and standards. Other papers further document the state of knowledge on Eco-DRR as well as identify an initial network of demonstration sites. McVittie et al. provide an assessment of lessons learned from implementing Eco-DRR across a wide range of land uses (e.g. agriculture, forestry, coastal, urban, freshwater ecosystems) in Europe. The results provide evidence that Eco-DRR is cost-effective and achievable at different scales which includes the provision of important co-benefits. The authors suggest that these co-benefits are critical to ensuring both stakeholder support and funding allocation for Eco-DRR. The engagement of stakeholders throughout the design and implementation was identified as key to successful initial and final acceptance of Eco-DRR projects in Europe.

Moos et al. provide several case studies from Switzerland that apply risk analysis to the design of Eco-DRR approaches using protection forests. By quantifying the rockfall risk on mountain slopes with and without trees, the authors demonstrate that current forest stands reduce risk by about 90% as compared to non-forested situations. This analysis allows for a risk and cost-benefit comparison of structural versus Eco-DRR applications in the form of protective forests in mountainous areas prone to rockfall and slides, globally. Sandholz et al. examine the implications of landslides in heavily urbanized parts of Rio de Janeiro, Brazil by looking at the municipal institutions' responsibility and the presence of Eco-DRR measures put in place to minimize risks. This paper explores the complexity of establishing and implementing Eco-DRR in an urban development on steep and degraded slopes prone to landslides during heavy precipitation events. The responsibility for risk management was found to be diffuse across many fragmented sectors with limited alignment with diverse risk reduction activities (e.g. urban forestry). The paper discusses strategies and approaches to improved cooperative and comprehensive governance and risk reduction approaches that utilize Eco-DRR in an urban setting. As discussed by Dhyani et al., in many fast-growing cities, such as Nagpur, India, much of the development is haphazardous and rapid without any comprehensive plan, resulting in urban sprawl that can compromise the risk reducing benefits of ecosystems (i.e. flood reduction, heat amelioration, declining water tables). This paper assesses the implications of unplanned urban growth and the feasibility and appropriateness of re-integrating Eco-DRR in one of India's fastest growing cities.

The paper by Furuta and Shimatani documents the historical and current change in disaster management practices during reconstruction following the Great East Japan Earthquake and subsequent tsunami. The paper reveals the integration of Eco-DRR approaches into engineering practices for river and coastal projects. In addition, the policies, technical guidance, and best practices adopted during recovery are reviewed along with a comparison with the recovery process after Hurricane Sandy in the United States. Through this comparison, the authors suggest that technical guidance must be linked to a robust participatory engagement/planning process to ensure mainstreaming of Eco-DRR and the development of more innovative risk reduction measures. The application of Eco-DRR approaches to alter former installations of dikes or embankments as a proactive form of reconstruction is described by Warner et al. in a comparison between Dutch and Bangladeshi delta systems over the last 10-20 years. The removal of dikes to restore flood dynamics and reduce flood disaster risk as a top-down governance directive triggered frictions between people representing a complex set of environmental, technological and socio-political needs and tradeoffs given the redistribution of costs and benefits amongst stakeholders.

The papers compiled in this special issue respond to the wide range and diversity of circumstances involved with linking and integrating ecosystems with disaster risk reduction via science, engineering, government, policy, and economics. These fields of Eco-DRR and Eco-engineering are rapidly advancing as evidenced by the material presented herein and will become even more dynamic in the future. While each paper provides perspectives unique to a geography, policy, or practice there are several reinforcing themes that become apparent and can be coalesced into statements regarding current and future direction for Eco-DRR and Eco-Engineering as follows:

- Eco-DRR and Eco-Engineering approaches provide sustainable, equitable, regenerative, cost-effective solutions (as compared to traditional structural interventions) to reduce the magnitude of disasters and climate change and therefore directly contribute to global conventions, frameworks, and goals;
- These approaches offer co-benefits that also strengthen local and global economies and improve social stability;
- The integration of these approaches into national policies, governance practices, and international agreements is critical to ensure risk reduction and co-benefits are realized and shared;
- The design, planning, implementation, and uptake of these approaches should incorporate social realities of disaster risk management in partnership with local authorities and stakeholders;
- The implementation and success of these approaches depends on adaptation to local historic/current/future context, governance, and gradients: urban-rural landscapes, coastal-inland, disadvantaged-wealthy populations;
- While technical criteria, standards, incentives, and guidelines are needed at various scales and geographies, participatory, interactive community resilience building across sectors, professions, and populations is also crucial for successful implementation of these approaches.

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