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Ecosystem-based Disaster Risk Reduction:

Bridging mitigation and adaptation for community resilience

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Abstract

Ecosystem-based disaster risk reduction (eco-DRR) is emerging as an approach to disaster risk reduction which bridges mitigation and adaptation, protecting communities from the impacts of disasters in the short term while building long term resilience by addressing both hazards and vulnerability to them. Wide-ranging experience of implementing eco-DRR initiatives in different contexts and to address different hazards highlights the importance of key considerations on which there is extensive consensus across the literature.

Firstly, eco-DRR must be appropriate to the context, necessitating knowledge about the ecosystem, the capacity of the community to sustain it, and the role of hybrid solutions combining eco-DRR with grey engineering solutions.

Secondly, meaningful community engagement is vital to the success of eco-DRR. Working with the communities involved is of key importance to ensure the eco-DRR initiative is appropriate, sustainable, and strengthened by local knowledge and expertise.

Finally, the benefits of eco-DRR initiatives may take considerable time to be visible. Commitment to long term programming and funding, and ensuring that short-term benefits are realised by the community while the longer term benefits accrue, are essential.

These considerations provide useful guidance to the design and delivery of eco-DRR. The literature also highlights priority gaps in the global body of knowledge which future research and learning should work to address: firstly, a need to develop a base of evidence as well as evidence-based standard of practice and guidance, and secondly, a need to understand the relationship between eco-DRR and gender and social inclusion, which is a major gap in the current body of knowledge.

Keyword: Ecosystem-based Disaster Risk Reduction, Community Resilience, Mitigation, Adaptation

1. Introduction

Ecosystem-based disaster risk reduction (eco-DRR) is emerging as an approach to disaster risk reduction which bridges mitigation and adaptation, protecting communities from the impacts of disasters in the short term while building long term resilience by addressing both hazards and vulnerability to them. Although a relatively new field, researchers and practitioners have generated a wealth of experience and knowledge about what eco-DRR is, the benefits it offers, and the factors needed for it to be effective, as well as guiding principles and learning about gaps and limitations.

This paper reviews a wide selection of academic and grey literature to synthesise this knowledge and provide an overview of the current state of the art in relation to eco-DRR, the evidence supporting it, current agreed good practice, and the gaps, challenges, and limitations of the field.

2. Understanding ecosystem-based Disaster Risk Reduction

Eco-DRR refers to the use of ecosystem-based approaches in order to reduce disaster risk (Estrella, M. and Saalismaa 2013; DasGupta and Shaw, 2018). Effective disaster risk reduction addresses the underlying causes and drivers of disaster risk and prevents new risks from arising (Sebesvari et al., 2019) by building the adaptive capacities of stakeholders at individual, community, and institutional levels (Murti and Buyck, 2014).

Traditional approaches to DRR which focus on engineering ("grey") solutions, such as embankments, levees, or drainage systems address the need to protect people and societies from the impacts of disasters, but cannot address these underlying causes and drivers of hazards, vulnerabilities, and exposure (Sudmeier-Rieux et al., 2019; Sebesvari et al., 2019).

Eco-DRR promotes the maintenance and enhancement of ecosystems and their services to reduce vulnerability and exposure, and mitigate hazards and their impacts (Gupta and Nair, 2012). This is increasingly important in a context of growing pressures on ecosystems due to population and economic growth which reduces the ability of ecosystems to provide functions and services, including protection from hazard events – which are themselves increasing in frequency and severity (Sudmeier-Rieux et al., 2019).

The Millennium Ecosystem Assessment 2005 identifies four major categories of ecosystem services: provisioning services, such as food, water, and fuel; cultural services, such as recreational, spiritual, and aesthetic services; supporting services, such as soil formation, photosynthesis, and nutrient recycling processes; and regulating services, such as water purification and moderation of extreme weather events (Gupta and Nair, 2012).

Eco-DRR also reflects the key paradigmatic shifts in the DRR field away from reactive humanitarian response to proactive, anticipatory action taken before disasters occur to reduce their impacts (Gupta and Nair, 2012), and away from addressing single concerns towards more holistic approaches that address the different components of risk and resilience (Faivre et al., 2017).

3. Terminology and definitions

Eco-DRR can be usefully defined as "the sustainable management, conservation, and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development." (Monty et al., 2017).

Eco-DRR is linked to, and can support, ecosystem-based adaptation (EbA), which is defined as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change" (CBD, 2019).

Eco-DRR and EbA are both examples of Nature-based Solutions (NbS), which refers to "Actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016).

Resilience has been defined as "the ability of a system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite costs and risks" (Haimes 2009), and described using the R4 Framework as being based on robustness, redundancy, resourcefulness, and rapidity (Tierney and Bruneau 2007). However, the limitations of understanding resilience as maintenance of a status quo which fosters risk are highlighted in a shift towards a more transformative definition of resilience as "the ability to bounce forward following a disaster" (Manyena et. Al, 2011), emphasising a focus on preventing disasters and reducing vulnerabilities (Table 1)

Table 1 Ecosystems and their disaster risk reduction services

Type of Ecosystem	Examples	Hazards	Hazard Mitigation Functions	Risk Reduction Co-benefits
Coastal	Mangroves, saltmarshes, coral reefs, barrier islands, sea grass beds, estuaries, peat swamps, sand dunes	Floods Flash floods Debris and mud floods Tropical cyclones Storm surges Torrential rains Wind storms Tsunami Coastal erosion Harmful algal blooms Sub-marine mudslides Sea level rise Sea surface temperature rise	Continuum of natural buffer systems Protect against hurricanes, storm surges, flooding Absorb and dissipate low magnitude wave energy Reduce wave heights Reduce erosion from storms and high tides Hold flood waters Buffer against saltwater intrusion Particularly effective when more than one ecosystem is combined	Provision of subsistence, livelihood options and safety nets CO2 absorption Provision of habitats for plants and animals
Drylands	Trees, grasses and shrubs conserve soil, shelterbelts, greenbelts	Drought Desertification Wind erosion Sand storms	Retain moisture to mitigate the effects of drought Conserve soil Control desertification Provide barriers against wind erosion and sand storms	Provision of subsistence, livelihood options and safety nets CO2 absorption Provision of habitats for plants and animals
Forests, Mountainside vegetation cover	Mountain forests, vegetation on hillsides, vegetation cover, root structures, catchment forests	Landslides Avalanches Rock falls Soil erosion Floods Droughts	Protect against landslides and avalanches Protect against erosion Protect against floods Safeguard against drought	Water recharge and purification Drought mitigation Water supply
Wetlands	Marsh, fen, peatland, water, floodplains, wet grasslands, tidal flats, deltas, estuaries	Storm surge Coastal flood Tropical cyclones Tsunami Coastal erosion Seal level rise Glacial melt	Attenuate flood magnitude by retaining water Increasing soil level Reduce height and speed of storm surges and tidal waves Stabilise shoreline Control erosion	Water purification Water storage Provision of subsistence, livelihood options and safety nets CO2 absorption

Notes: Table compiled and adapted from CNRD-PEDRR, 2013; Sudmeier-Rieux et al., 2019; Gupta and Nair, 2012; Monty et al., 2017; UNDRR, 2020a

4. Evidence

4.1 Hazard and Exposure

Eco-DRR approaches can mitigate the impacts of hazard events themselves, for example wetlands attenuating the magnitude of a flood by retaining water and regulating water flow (Sebesvari et al., 2019), forest and vegetation cover preventing soil erosion which increases the risk of floods and landslides, as well as reducing heat stress linked to droughts (Walz et al., 2021).

Coastal vegetation was found to mitigate the impacts of the 2011 tsunami in Japan, catching large debris such as boats. Coral reefs and salt marshes have been found to reduce wave heights by 70%, and to do so more cost-effectively than "grey" engineered structures (Narayan et al., 2016).

In Sri Lanka, the impact of the 2004 Indian Ocean tsunami was found to be greatly reduced in Yala National Park, where the protection of sand dunes limited the wave height to 5 cm, compared with a nearby resort where sand dunes had been removed, and the wave reached a height of 7 metres, causing the loss of 27 lives (Sudmeier-Rieux et al., 2019). Post-disaster damage assessments found that damage to lives and livelihoods was significantly greater in areas where ecosystems including sand dunes, mangroves, and coral reefs, had been disturbed or degraded (Gupta and Nair, 2012).

Sustainable agriculture has also been found to reduce the impact of drought in the Sahel by conserving soil moisture and maintaining food supply for communities. This example also points to the importance of ecosystems as a vital resource for communities in disaster recovery in meeting needs for food, water, and shelter (Gupta and Nair, 2012).

The literature also emphasises that while well-managed ecosystems can provide protection from the impacts of hazards, there are limitations linked to the composition and health of the ecosystem, as well as the type and intensity of the hazard itself and that grey infrastructure is an important part of this protection (Gupta and Nair, 2012;Sudmeier-Rieux et al., 2019).

4.2 Vulnerability

Eco-DRR can play an effective role in reducing vulnerabilities by supporting and increasing the capacity of populations to cope with and adapt to hazards, for example by providing vital provisioning services, and materials to prepare for hazard events (Walz et al., 2021).

Additionally, eco-DRR can protect livelihoods, both from the immediate impacts of sudden onset hazard events and from longer-term degradation of the provisioning services, as well as cultural services in areas where tourism is a significant employer. A case study in India found that mangrove buffer zones protected rice croplands from the impact of cyclones, enabling continuity of this major source of income as well as food security (Murti and Buyck, 2014).

4.3 Co-Benefits

In addition to addressing the hazard, exposure, and vulnerability components of disaster risk, eco-DRR can deliver co-benefits which support ecosystem services, environmental conservation and climate change mitigation, livelihoods, and human wellbeing (Sudmeier-Rieux et al., 2019).

4.4 Ecosystem services

Ecosystems provide populations with a range of vital services such as clean drinking water (Sebesvari et al., 2019), food, fuel, building materials, and waste recycling in addition to attenuating the impacts of hazards (DasGupta and Shaw, 2018; Gupta and Nair, 2012). Eco-DRR initiatives which protect or restore the health of these ecosystems therefore maintain the delivery of these essential ecosystem services in ways that "grey" engineering does not (UNDRR, 2020b).

4.5 Climate change mitigation

Eco-DRR also mitigates against climate change by conserving and restoring ecosystems which are vital in carbon sequestration, such as forests, coastal vegetation, and peatlands, and limits greenhouse gas emissions caused by deforestation and land degradation (Duarte et al., 2013; DasGupta and Shaw, 2018; Gupta and Nair, 2012).

The restoration of mangroves is an example of eco-DRR which protects coastlines while also providing or increasing natural habitats for marine life, and contributing to carbon storage, supporting the conservation of natural resources and restoring biodiversity alongside reducing disaster risk (CBD, 2019). Reforestation activities also deliver carbon sequestration (UNEP, 2021), with a project in Ethiopia which is working to regenerate 2,728 hectares of native forests aiming to remove approximately 870,000 tonnes of carbon dioxide equivalent greenhouse gases by 2036 (Brown et al., 2011).

The environmental benefits of eco-DRR are contrasted with the costs incurred by grey infrastructural development which deteriorates and damages landscapes and ecosystems (Onuma, 2018).

Economic

Eco-DRR has been found to be highly cost-effective (Sudmeier-Rieux, 2012), with cost-benefit analyses finding that eco-DRR activities deliver higher returns on investment than hard infrastructure solutions (Gupta and Nair, 2012). The cost of maintaining and conserving ecosystems can be significantly lower than maintaining or enhancing more expensive infrastructure investments (DasGupta and Shaw, 2018; CBD, 2019), particularly over the longer term (Gupta and Nair, 2012; Sudmeier-Rieux et al., 2019).

A case study in Vietnam found that mangrove rehabilitation generated 23.million USD over 20 years in risk reduction and natural resource utilisation benefits, compared with 0.5 million USD generated by constructing dykes (CBD, 2019).

There is also potential for investment in eco-DRR to reduce the costs of post-disaster relief, with initiatives such as beach nourishment in Barbados avoiding 30% of expected losses (CBD, 2019).

Social

Finally, eco-DRR activities provide numerous valuable social benefits, with the protection of ecosystems or generation of urban green spaces improving the quality of life, and mental and physical health, for populations (Kabisch et al., 2016, cited in CBD, 2019).

5. Principles

CBD (2019) lay out twelve key principles for eco-DRR across four main themes: building resilience and enhancing adaptive capacity; ensuring inclusivity and equity in planning and implementation; achieving EbA and eco-DRR on multiple scales; and effectiveness and efficiency (Table 2).

Table 2 Guiding Principles for eco-DRR

Building resilience and enhancing adaptive capacity	Eco-DRR should: Result in enhanced resilience and decreased vulnerability of people and ecosystems to climate change and disaster risk Respond to current and future impacts of climate change and disaster risk, contributing to incremental and transformative adaptation and disaster risk reduction; Use biodiversity, ecosystem services and landscapes without harming their functioning; Generate societal benefits and ideally enhance biodiversity, contributing to sustainable development using equitable, transparent and participatory approaches Eco-DRR initiatives should consider a full range of ecosystem-based approaches to enhance resilience of socio-ecological systems as a part of overall adaptation and disaster risk reduction strategies Use disaster response as an opportunity to build back better for enhancing adaptive capacity and resilience and integrate ecosystem considerations throughout all stages of disaster management. Consider the precautionary approach in planning and implementing interventions1.
Ensuring inclusivity and equity in planning and implementation	Eco-DRR interventions must be fully participatory, particularly ensuring participation of indigenous peoples and local communities, and transparency and accountability throughout all stages of planning and implementation. Interventions should be prioritised and targeted to prevent and avoid the disproportionate impacts of climate change and disaster risk on vulnerable groups, indigenous peoples and local communities, and ecosystems.
Achieving eco-DRR on multiple scales	Interventions should be designed at the appropriate spatial and temporal scales, recognizing that benefits are only apparent at larger temporal and spatial scales. Ensure that eco-DRR is sectorally cross-cutting and involves collaboration, coordination, and co-operation of stakeholders and rights holders.
Effectiveness and efficiency	Ensure that interventions are evidenced-based and supported by the best available science, research, data and practical experience, and diverse knowledge systems including traditional knowledge of indigenous peoples and local communities. Incorporate mechanisms that facilitate adaptive management and active learning into Eco-DRR, including continuous monitoring and evaluation at all stages of planning and implementation. Identify and assess limitations and minimize potential trade-offs of interventions. Maximize synergies in achieving multiple benefits, including for biodiversity, conservation, sustainable development, gender equality, adaptation, and risk reduction.

[1]The precautionary approach is stated in the preamble of the Convention on Biological Diversity: "Where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat." - CBD, 2019

6. Conditioning factors

6.1 Collaboration and community participation

It is vital for eco-DRR initiatives to be based on trusting relationships with the communities, and to build local adaptive capacities and community ownership, so that relevant approaches based on the knowledge and needs of communities, can be delivered and sustained (Murti and Buyck, 2014; Sudmeier-Rieux et al., 2019; CBD, 2019; UNDRR, 2020b; Hou-Jones et al., 2021).

Communities involved in eco-DRR represent both those who are most affected by disasters (Murti and Buyck, 2014; CBD, 2019), and those whose activities directly impact ecosystems (IUCN, 2014; Sudmeier-Rieux et al., 2019. Embedding eco-DRR approaches in participatory ways which build on existing community leadership, community life, and community structures is central to ensuring community ownership and the implementation of locally relevant and effective initiatives (Hou-Jones et al., 2021).

The literature also emphasises that community participation must be inclusive of the diversity within those communities, and must consider existing differences, conflicting and competing interests and priorities, and facilitate dialogue and cooperation to avoid unintended consequences (Sudmeier-Rieux et al., 2019; Salvaterra et al., 2016; UNDRR, 2020b).

6.2 Scale of implementation

Eco-DRR is found to be most effective when it is implemented at local scales, where the target population is smaller (Onuma, 2018; DasGupta and Shaw, 2018). However, solutions which are implemented at landscape scales, using integrated landscape approaches which are based on a holistic understanding of the different ecosystems and elements co-existing in the area, are found to be effective while also facilitating cooperation with different stakeholder groups (Hou-Jones et al., 2021).

In terms of time, eco-DRR engagement should be long-term, enabling meaningful collaboration with communities, and adaptation and refinement of approaches in line with changing needs of the context as well as learning from the implementation itself. Eco-DRR is not a quick-fix solution and cannot be effectively designed or delivered in a short-term timescale, but may require more than a decade of continuous work (Hou-Jones et al., 2021).

7. Gaps, challenges and limitations

7.1 Limited effectiveness

As with structural protection measures and solutions, there are limits to the physical protection provided by eco-DRR, depending on the type of hazard, its intensity, and the type and condition of the ecosystem (Sudmeier-Rieux et al., 2019; Gupta and Nair, 2012).
For example, although slope vegetation generally reduces the risk of landslides by protecting against erosion, trees that are very old or heavy can trigger landslides. Mangroves are effective in absorbing wave energy, but are less effective in providing protection for coastal storms which are less frequent and more severe "one in 100 year" storm events (Sudmeier-Rieux et al., 2019).

Additionally, it can take a comparatively long time for eco-DRR measures to become effective, and this occurs in a context of ongoing impacts to ecosystems caused by climate change, which may limit their ability to provide protective and other services. These limitations underline the consensus in the literature that hybrid solutions, which combine eco-DRR with structural approaches, can provide effective disaster protection and mitigation while being cost-effective and generating co-benefits associated with eco-DRR (Sudmeier-Rieux et al., 2019).

7.2 Taking Eco-DRR to scale

The literature highlights the need to develop systemic knowledge and agreed best practices to guide the implementation of eco-DRR measures in practice (Welchel et al., 2018; CNRD-PEDRR, 2013).

Alongside a call for agreed and standardised guidelines for the implementation of eco-DRR measures is the recognition of the locally specific characteristics and services of different ecosystems. This presents a challenge in scaling up eco-DRR measures which are successful at local levels, where the effectiveness of the solutions may not be possible to replicate (Sudmeier-Rieux et al., 2019; DasGupta and Shaw, 2018).

7.3 Increased risk and opportunity costs

There are also unintended consequences of eco-DRR to consider. Coastal forests may create additional risks, for example by increasing the height of a tsunami, strengthening currents by creating a channelling effect, or increasing dangerous floating debris from broken trees (Sebesvari et al., 2019).Without proper consultation and planning, there is also a risk of eco-DRR interventions disrupting or damaging other ecosystem services, such as cultural services (CBD, 2019). Additionally, in contexts of poverty where socio-economic inequality worsens vulnerability to disaster impacts, the opportunity costs involved with changes to the use of land or water resources may negatively impact communities affected by disaster risk (McVittie et al., 2017).

7.4 Gender and social inclusion

There is little evidence in the literature regarding gender and inclusion in eco-DRR planning and implementation. More research is required to understand the how eco-DRR solutions impact women and other marginalised populations, and how the roles of marginalised groups interact with eco-DRR design and delivery (Sudmeier-Rieux et al., 2019). Disaster risk reduction which does not explicitly consider gender and social inclusion risks further entrenching existing inequalities, worsening the vulnerabilities of already vulnerable people, and weakening the effectiveness of the intervention itself by not including the knowledge, skills, and experience of the whole population (Brown et al., 2019).

7.5 Policy landscape and political will

The impacts of climate change, including disasters, are felt across administrative and political boundaries, necessitating cross-sectoral coordination between government authorities at all levels (Andrade Pérez et al., 2010). This requires political commitment, as well as coherence: policies and objectives across different ministries must be aligned, enabling the mobilisation of resources, and the inclusion of eco-DRR planning, implementation, and coordination within departmental mandates (Murti and Buyck, 2014; Sudmeier-Rieux et al., 2019; Hou-Jones et al., 2021).

8. Concluding remarks

The cyclical relationship between disasters and poverty which cumulatively erode resilience, adaptive capacity, and development gains are well understood in the literature. The loss and instability of livelihoods caused by hazard events, as well as damage to the ecosystems which provide so many resources for income generation, greatly compound vulnerability to subsequent disasters, worsening their impacts, widening inequalities, and impeding sustainable development.

Eco-DRR presents a range of opportunities to address these critical challenges holistically, protecting communities from the impacts of disasters while also building their multi-faceted resilience in the longer term by reducing the risk presented by a hazard as well as socio-economic vulnerability to it.

The cost-effectiveness of eco-DRR approaches is particularly relevant in a context of the increasing frequency and severity of humanitarian crises, and the widening humanitarian funding gap. Reducing the costs of the preparation for disasters, and the costliness of their impacts through effective risk reduction and mitigation, can reduce pressure on the limited funds available to the humanitarian community to respond to disasters and recover from them.

Wide-ranging experience of implementing eco-DRR initiatives in different contexts and to address different hazards highlights the importance of key considerations on which there is extensive consensus across the literature.

Firstly, eco-DRR must be appropriate to the context: this requires knowledge about the ecosystem in question, the species of vegetation, for example, and its impact on other local plant, animal, and human life, the opportunity costs to the community, and sustainability within the socio-economic context, such as the feasibility of irrigating trees planted to restore a forest ecosystem. It may also be more appropriate to combine eco-DRR with engineering solutions to provide optimum protection from hazard impacts.

Secondly, meaningful community engagement is vital to the success of eco-DRR. Working with the communities involved is of key importance to ensure the eco-DRR initiative is appropriate to the needs and capacities of the context, to build knowledge, trust, and ownership of the initiative so that it is maintained sustainably, and to strengthen eco-DRR with the diverse knowledge and experiences of different stakeholder groups.

Finally, eco-DRR is a long-term undertaking. The benefits of initiatives may take considerable time to be visible. This necessitates two approaches: committing to long term programming and funding, and ensuring that short-term benefits are realised by the community while the longer term benefits accrue, to maintain trust, buy-in, and acceptance of the initiative, and avoid an exploitative approach which demands the time and investment of a community without appropriate return.

These considerations provide useful guidance to the design and delivery of eco-DRR. The literature also highlights priority gaps in the global body of knowledge which future research and learning should work to address.

Firstly, there is a need to increase the technical and operational capacity of the eco-DRR community. This relates to the need for an evidence base, but also to the need for evidence-based standards of practice and guidance to synthesise and share learning on an ongoing basis and continually improve the effectiveness of eco-DRR approaches.

Secondly, a major gap in current knowledge relates to the relationship between eco-DRR and gender and social inclusion. There is a need to explore and understand how eco-DRR works for vulnerable and marginalised populations, and how eco-DRR can support the commitment to leave no one behind.

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