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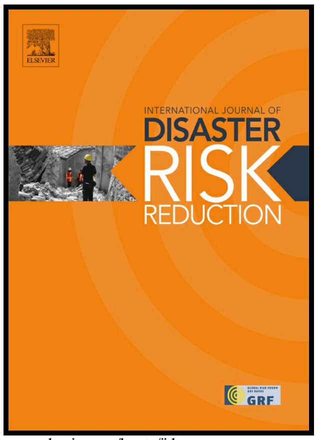

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A Survey of Governance Approaches to Ecosystem-based Disaster Risk Reduction: Current Gaps and Future Directions

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Abstract: Climate change will increase the unpredictability, magnitude, and frequency of both slow and rapid onset disaster events. Although large-scale engineered interventions have been common for the purposes of risk reduction and adaptation in the past, emerging ecosystem-based approaches are gaining attention. In contrast to 'hard' infrastructure, ecosystem-based solutions that integrate risk management priorities with natural processes are touted as being more cost effective, socially equitable, and environmentally sustainable. Current developments in ecosystem-based approaches to climate adaptation (EbA) and ecosystem-based disaster risk reduction (Eco-DRR) tend to focus on scientific projections, engineering techniques, and their respective roles in shaping economic benefits. However, recent studies show that the effective implementation of such solutions is dependent on the governance practices and interactions between relevant actors, interests, and institutional structures. In response, this paper reviews the current status of governance studies in the context of EbA and Eco-DRR. The analysis is grounded in the interdisciplinary theories of governance, socio-ecological systems, infrastructure studies, and multilevel politics, with sources derived from scientific databases including Scopus and Science Direct advanced query. Based on the review, we evaluate existing governance theories, assessment methods, and implementation through illustrating emblematic examples from around the world. The paper concludes with a synthesis of governance gaps and opportunities, and notes that while emerging ecological engineering approaches provide distinct opportunities, there is a lack of comprehensive assessment beyond diagnosing potential financial, institutional, and political shortfalls. We therefore highlight the need for future research on socio-ecological, spatial/scalar, and political approaches to harnessing governance opportunities for EbA and Eco-DRR.

Keywords: disaster risk reduction, governance, ecosystem-based approaches, climate change adaptation, Eco-DRR, ecological engineering

1. Introduction

The Convention on Biological Diversity [1] and the Millennium Ecosystem Assessment [2] both highlight the emerging role of ecosystem-based approaches to tackling global environmental change. The application of ecosystem-based approaches was later introduced and referred to in the Hyogo Framework for Action 2005-2015[1] [3], Sendai Framework for Disaster Risk Reduction 2015-2025 [4], and the recent outcome of the Paris Agreement on Climate Change [5]. Recent research has shown that ecosystem-based strategies can either be an alternative to hard engineering structures – which can be non-flexible, spatially disruptive, and expensive – or be combined with hard engineering options to achieve effective disaster risk reduction and climate change adaptation [6,7]. The Convention of Biological Diversity defines ecosystem-based approaches as:

> ‘The integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. The application of the ecosystem approach will help to reach a balance of the three objectives, including conservation, sustainable use, and the fair and equitable sharing of the benefits arising out of the utilization of resources’ [1].

The concepts of ecosystem-based climate change adaptation (EbA) and ecosystem-based disaster risk reduction (Eco-DRR) were later introduced as an extension to the sustainable use of resources, and were presented as ‘win-win’ solutions [6].

Despite these global developments, a recent review by Huq et al. showed that mainstreaming ecosystem-based strategies into actual policies, strategies, and interventions is in fact a governance challenge [8]. Van den Hoek et al. similarly argued for the need to address social uncertainties through unpacking the governance implications of emerging Eco-DRR and ecological engineering efforts [9]. Others have further noted that such challenges are magnified when dealing with complex and uncertain governance arenas associated with multi-scalar environmental risks [6,10–13].

[1] The ecosystem perspective was mainly addressed under ‘Priority for Action 4’ of the Hyogo Framework for Action 2005-2015. It encouraged the sustainable use and management of ecosystems, including better land-use planning and development activities to reduce risk and vulnerabilities.

However, beyond the recognition that the governance of ecosystem-based approaches remains challenging, there has so far been no comprehensive analysis into which aspects of governance – i.e., whether the decision-making processes, resource networks, institutional arrangements, political powers and authority, or other determinants – shape the opportunities for and constraints to action in the context of Eco-DRR.

In response, this paper presents a comprehensive synthesis of the current literature to highlight the status of governance studies in the context of ecosystem-based disaster risk reduction (Eco-DRR). Research on ecosystem-based approaches is constantly evolving – with many evaluating it from global to local scales as well as from state-centric to decentralized and devolved actors and process – although there is an overwhelming focus on diagnosing governance constraints (i.e., in terms of finance, political jurisdiction, bureaucratic capacity, etc.) and not on governance opportunities. As a result, in addition to reviewing the literature, this paper explores the various governance opportunities that could enable future research and practice.

This paper is divided into seven sections. Section 1 introduces Eco-DRR as a governance challenge. Section 2 elaborates on the methods used in the literature survey. Section 3 reviews the theories of Eco-DRR and section 4 discusses the main methods of Eco-DRR. Section 5 explores a number of emblematic examples, illustrates how Eco-DRR is applied in disaster risk reduction and climate change adaptation, as well as charts emerging trends such as ecological engineering. Finally, section 6 elaborates on the gaps in the study of governing Eco-DRR and section 7 concludes by highlighting opportunities for future research.

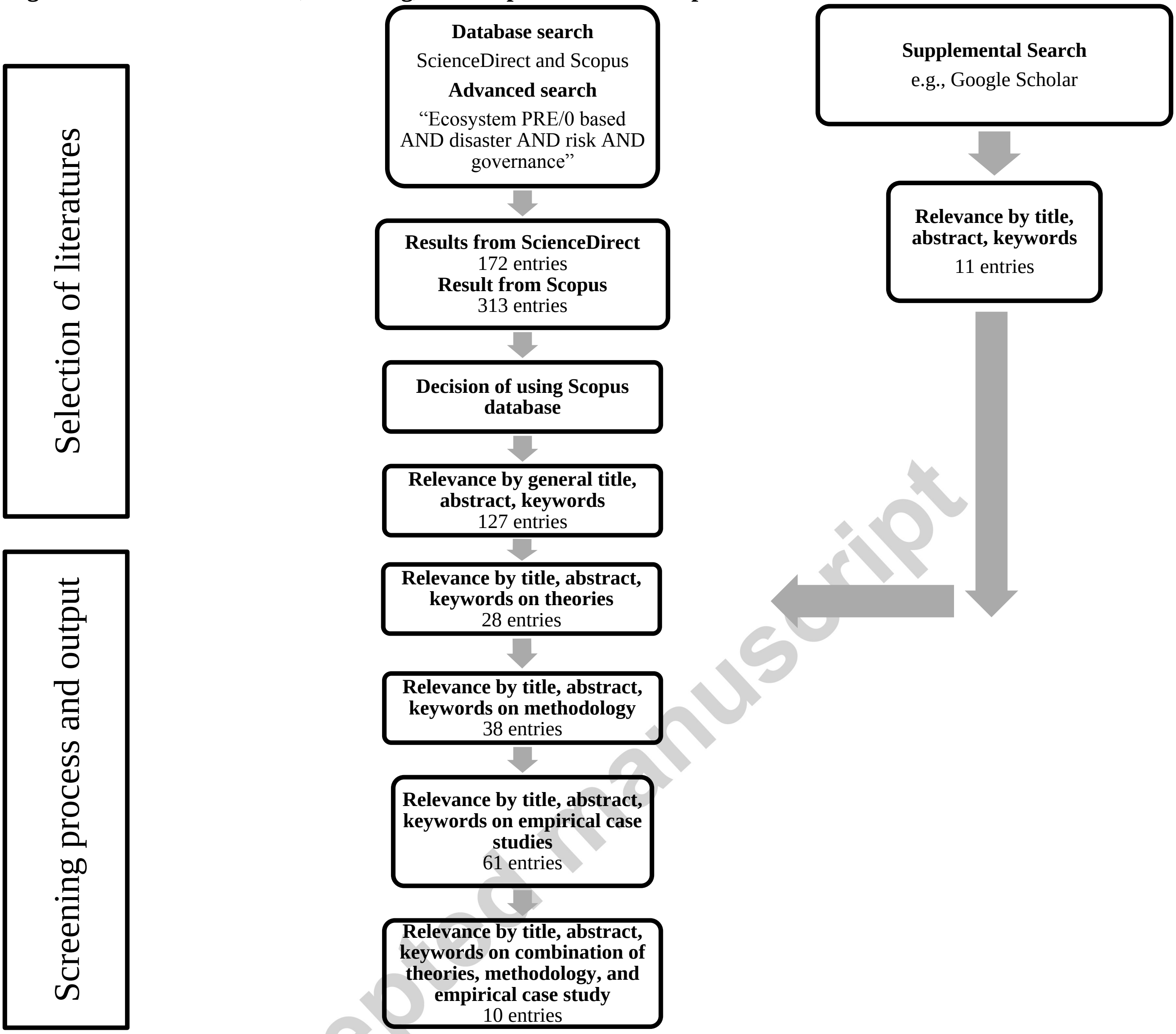
2. Survey Methodology

For the literature survey, we selected databases from Scopus and Science Direct since both provide advanced research query tools that help to focus and narrow down results based on searchable keywords. We employed a semi-structured method, which allowed us to add several prominent key literatures in addition to filtered literatures from structured queries extracted from the scientific databases. The keywords used in the search were ‘Ecosystem PRE/0 based AND disaster AND risk

AND governance' for both databases. This search method resulted in 172 entries from Science Direct and 313 entries from Scopus. For the purposes of achieving a wider scope, we selected Scopus as our main source to conduct the review. From it, 313 entries were screened and filtered into 149 articles that were most relevant to the topic of Eco-DRR and governance. Our criteria for relevancy were based on: (1) the inclusion of ecosystem-based approached to DRR and climate change and (2) the inclusion of discussions on management, governance, and politics.

After the application of these three criteria, we were left with 127 entries for in-depth analysis. Of these 127 entries, 20% (28 entries) were theoretical in nature; 28% (38 entries) were discussions of assessment methodologies; 45% (61 entries) were illustrations of particular case studies or examples; and finally, 7% (10 entries) were a combination of theory, methodology, and illustration. For the purposes of this review, we only selected the theory, methodology, and case study-based entries. Also, we added eight key publications that were not listed in our initial search results. Online public academic search engines such as Google Scholar were utilized for this purpose. In total, we surveyed 138 entries. Figure 1 provides a schematic of our methodological approach.

Figure 1. Document sources, screening, and output of the review process



3. Governance Theories and Eco-DRR

As noted earlier, we identified a total of 23 entries that interrogate theories of governing Eco-DRR. By far the most common umbrella theory used is socio-ecological systems (SES), which takes into account coupled social and environmental challenges in an interconnected world [14]. SES is often applied to resilience to emphasize the complexity of socio-ecological dynamics. It highlights the ability of systems to absorb disturbances while maintaining their structures and functions [15]. The argument is that resilience thinking embraces the interaction between ecosystems and human well-being. Furthermore, it sets the goal of preparing the system to tolerate – or bounce back from – current and future environmental changes exacerbated by climate change. In Table 1, we list the prominent concepts and theories used as a basis for governing SES.

Table 1. Theoretical literatures

Theory	Sources
Governance of socio-ecological systems and resilience	[14,16–25]
Adaptive governance	[14,26–33]
Climate change and risk governance	[34–37]
Transformative governance	[38–40]
Ecological economics	[22,41]

Building on theories of SES and resilience, the concept of adaptive governance focuses on learning and knowledge co-production within governance systems and in their interventions to adapt to external shocks [27,32,33]. However, significant challenges for adaptive governance have been identified, including the presence of institutional and legal barriers in ecosystem-based adaptation [29]. Examples of such constraints range from the lack of institutions supporting ecosystem-based approaches, poor law enforcement, corruption, and the lack of political will [29].

Some theories apply adaptive governance to climate change [36] and risk [34]. Both approaches build upon previous work on SES and argues that in order to govern climate change and to cope with emerging risks, policy-makers must embrace the notion of participation among stakeholders [26]. Necessary elements for effective participatory governance include decentralization, accountability, responsiveness, participation, and inclusiveness [34]. Scholars of climate risks further propose that governance should denote both the institutional structures and the policy processes that guide and restrain collective actions to regulate, reduce, or control environmental problems [34].

Emerging theories on transformative governance further pinpoint the importance of change, innovation, and technology in governing complex systems [34]. Transformative governance is rooted in ecological theory, and highlights new capacities such as increased risk tolerance, significant systemic investment, and restructured economies [39]. Transformative governance often explores new ecosystem-based innovations for addressing both disaster risks and climate change. Chaffin et al. provide an example of transformative efforts associated with building green infrastructures in Cleveland, United States, which aimed to enhance resilience by transforming vacant lots, land, and industrial sites into habitat for biodiversity, urban agriculture, and green infrastructure [39]. In another example, Ziervogel and Ziniades [42] described the FLOW (Fostering Local Wellbeing) program in Bergrivier Municipality, South Africa, which embraced the concept of 'transformative capacity'. By involving youth in civil society, business, and government agencies, the program boosts innovation to tackle climate change, resource depletion, and inequality [42]. One key activity is asset mapping, including mapping the municipal water and sewage systems promoting bioswales and recycling programs, as well as building capacity of civil society through movie-making and story-telling.

Finally, some theories pursue an ecological economics perspective, which argues that in order to cope with risks and extreme changes, sustainable development should be the priority rather than capital-led economic growth [41]. In particular, this notion is clearly articulated through efforts to balance ecological sustainability with economic co-benefits to achieve sustainable livelihoods [22]. However, in order to convince policy-makers to make investments in ecosystem-based approaches, evidence creation tools such as valuation of ecosystem are believed to be the most appropriate [22]. As a policy justification, it provides tangible and evidence-based data on the benefits of preserving ecosystems for the providers, suppliers, and beneficiaries of ecosystem services.

4. Methods for Governing Eco-DRR

Our review shows that there are different methodologies associated with documented Eco-DRR interventions, with a variety of governance assumption embedded within each. In this section, we elaborate on the six broad methodologies for governing Eco-DRR, which include decision-support tools, integrated management and network analyses, economic assessments, spatial knowledge generation tools, mainstreaming approaches, and transdisciplinary approaches. Table 2 summarizes these results.

Table 2. Methodological literatures

Methods	Examples	Sources
Decision support tools	• DPSIR (Drivers-Pressure-State(change)-Impact-Response) • Transformative Adaptation Research Alliance (TARA) approaches • Fit for Purpose Governance • Balanced Scorecard (BSC) • Source-Pathway-Receptor-Consequence model • Multiple actor analysis • Bayesian Belief Network (BBN)	[12,43–52]
Integrated management and network analysis	• Marine Integrated Decision Analysis System (MIDAS) • Integrated Flood Management • Integrated island management (IIM) • Collaborative disaster management • Bayesian networks	[53–59, 79]
Economic assessment	• Valuation of ecosystem services and ecological economics approach	[60–64]
Spatial tools and Knowledge generation tools	• GIS, spatial planning • PRISMA for Information need in coastal ecosystem-based adaptation	[65–70]
Mainstreaming approach	• Spatial ecosystem-based adaptation priorities at the sub-national level and local planning	[71,72]
Transdisciplinary approach	• Participatory approach to understanding change in coastal social-ecological systems • Ecology approach to science–policy integration in adaptive management of social-ecological systems • Private mainstreaming	[23,50,73–77]

4.1 Decision-Support Tools

As a type of decision support tool, The Driver-Pressure-State(change)-Impact-Response (DPSIR)[2] methods can help identify the current conditions of a particular socio-ecological system. This method uses a semi-quantitative method to structure complex environmental problem and aims to bridge the gaps between science, policy, and management [45,49–51]. This method was initially implemented in the form of Pressures-States-Response (PSR) by the Organisation for Economic and

[2] There are different terminologies used for this method. For example, the European Environment Agency (EEA) uses “driving-forces” instead of driver.

Cooperation Development (OECD), and is now commonly used across coastal areas to help stakeholders formulate coastal management practices [49]. The European Environment Agency (EEA) has since added two components – namely "Driving Forces" and "Impact" – to identify and assess progress toward sustainable development [49]. Furthermore, this method is often also combined with other assessments such as Bayesian Belief Networks, which help stakeholders understand the cumulative impacts of different policy decisions and interventions [45,50,51]. Despite its comprehensiveness, some have critiqued DPSIR for being a simplistic approach that fails to account for the complexity of multi-scalar and systemic environmental risks [49].

Another decision-support method that is relevant to Eco-DRR is the Transformative Adaptation Research Alliance (TARA) approach, which employs an ecosystem perspective to climate change adaptation [52]. Rooted in theories of transformative governance [39], TARA presents three types of transformations, namely transformation of ecosystems, transformation of decision context, and transformation as developing the capacity for adaptive governance. The first – transformation of ecosystem – is defined by a permanent shift to an alternative stable state, as in resilience thinking [52]. It considers the changes in how the ecosystem is perceived, especially how one ecosystem relates to others; the use of ecosystem services for societal benefit; and the options to manage the ecosystem in appropriate manner. Second, the transformation of decision contexts involves recognizing the need to evolve governance arrangements due to dynamic and changing ecosystems [56]. The third type is governance change to support transformation in the context of adaptation, which refers to developing adaptive and transformative governance capacities to accommodate uncertainties and changes in the system.

To operationalize the three types of transformations mentioned above, the TARA approach incorporates three conceptual elements that help stakeholders in decision-making and formulating transformative ecosystem-based adaptation actions. These include, first, the 'values-rules-knowledge' perspective for identifying decision-making contexts that enable or constrain adaptation [39]. The second is 'adaptation pathways', which evaluates implementation through ecosystem services assessments and the values-rules-knowledge perspective in order to explore possible actions based on available options and alternatives in the uncertain environment to avoid maladaptation [52]. The third is ‘adaptation services’, which is a subset of ecosystem services that provides benefits for people to adapt. The identification of the three elements mentioned above reflects the need to understand changes in adaptation services provided by ecosystems, incorporate values-rules-knowledge on how to use adaptation services, as well as understand the changing aspects of decision making to guide adaptation pathways. In general, the TARA approach emphasizes the critical elements of governance – i.e., the explicit process of transforming decision contexts and societal values as part of implementation – compared to EbA and Eco-DRR [52]. It also suggests the need for implementing adaptation through the redistributing power and agency for social change [52]. This can be achieved through a more bottom-up approach, such as by involving stakeholders in the co-learning, co-development, and co-construction of future scenarios.

4.2 Integrated Management

Several tools for operationalizing integrated management are listed in Table 2. These tools have generally been used in the context of flood and sea level rise [58], water resources management [70], as well as coastal zone management [44, 55]. However, for the purposes of this survey, we looked specifically into Integrated Island Management (IIM) and Marine Integrated Decision Analysis System (MIDAS) as notable examples. Both cases reflect the principles of integrated coastal zone management, which deals with coastal systems as a whole, spanning accross boundaries and involving different actors, resources, and sectors to achieve certain goals [79]. In the case of IIM, integrated management is defined as:

> “Sustainable and adaptive management of natural resources through coordinated networks of institutions and communities that bridge habitats and stakeholders at the scale of socioecological processes… with the common goals of maintaining ecosystem services and securing human health and well-being” [56].

IIM is currently applied through a coordinated network across the Pacific Ocean [56], where it is promoting ecosystem-based efforts to simultaneously address climate change, disaster risk reduction, and ecosystem conservation [78]. The MIDAS approach, on the other hand, offers an interface to model potential scenarios in dealing with certain threats, such as the analysis of oil spills on coastlines and the spatial risks caused by mangrove degradation in Belize's Marine Management Area (MMA) [57]. These scenarios are designed based on an interactive platform that simulates problems perceived by the users and managers of the Belize's MMA, including fishers, tourism operators, state environmental agencies, and the general public [57].

4.3 Economic Assessment

Economic assessments are important tools for understanding the economic value of ecological buffers, food/genetic resources, and recreational opportunities [60]. Previous studies have shown that economic assessments are not explicitly referred to in many ecosystem management policies [67] and have not been well documented in current research [61]. For Eco-DRR, economic valuation of ecosystems provides insights into the co-benefits of ecosystems besides its regulating function to reduce disaster risks and climate change impacts [61,63]. It also offers useful economic perspectives on the scope within which adaptation can be a co-benefit [61]. However, one limitation of economic assessments is the need to incorporate human behavior and uncertainty into their calculation [62]. An example of the successful application of economic assessments was found in Durban, South Africa, where ecosystem-based measures had a moderate benefit-cost ratio whereas infrastructure-based measures had a lower benefit-cost ratio [63]. Economic assessments are particularly useful for informing processes of designing market-based approaches – such as through certain incentives – for ecosystem conservation [60] (see section 5.1).

4.4 Knowledge Generation and Spatial Tools

The literature on ecosystem management focuses mainly on the planning and implementation of strategic processes and goals such as conservation or disaster management. In the context of Eco-DRR, however, the study of ecosystem services and its co-benefits have been a major focus for reducing socio-economic vulnerability to disaster impacts. Sierra-Correa and Cantera Kintz, for example, evaluated the method of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [68]. This method generates a systematic review based on clearly defined questions, which helps to narrow down the specific combination of knowledge for analysis. Other important tools such as GIS can help analyze the spatial distribution of potential ecosystem services, and therefore is often used as a basis for planning and management. In the context of Eco-DRR, multi-criteria analyses such as ecological resilience modelling against sea level rise [69] and green infrastructure spatial modelling – which integrates storm water management, social vulnerability, green space, air quality, urban heat island, and landscape connectivity [70] – have helped support decision-making and management by providing guidelines for future green infrastructure.

4.5 Mainstreaming Approach

A recent study by Wamsler et al. reviewed how EbA can be coherently implemented in local planning in Sweden [80]. The study revealed that although EbA has been integrated into national strategic adaptation planning, at the district and local municipality levels, ecosystem-based measures are limited and continue to focus on biodiversity conservation rather than on reducing climate and disaster risk or providing developmental co-benefits. Wamsler et al. subsequently identify the benefits of ecological structures and why they are needed for increasing the capacity of local authorities to reduce climate risks. For example, through using spatial tools, an inter-scale governance analysis can be conducted to identify the opportunities for adopting ecological engineering structures to improve storm water management [80]. Another example can be seen in South Africa, where officials from Namakwa District Municipality and Alfred Nzo District Municipality, in partnership with the private sector, used biome maps to define primary areas for EbA [71].

4.6 Transdisciplinary Approach

A transdisciplinary approach allows for the bridging between scientists, policymakers, practitioners, and stakeholders across different sectors and institutions. However, there are often barriers and gaps among these actors, including poor coordination and a lack of integrated knowledge [50,73,74,76]. Several approaches attempt to close these gaps, for example by including the private sector and businesses in adaptation strategies [75] or through ‘private mainstreaming’ approaches [81]. This latter approach introduces wider inter-organizational capacity, which builds linkages among heterogeneous institutions and agencies in climate adaptation [81]. For example, a recent study of the Great Barrier Reef in Australia showed that participatory techniques can be incorporated to develop transdisciplinary projects among scientists and to promote the results for better policy-making [76]. However, as the authors continue, to influence policy, the research should be appropriately supported by effective communication and science-policy integration. In light of this, the concept of information ecology is proposed as an effective approach for integrating science and policy cultures [73]. This approach helps to combine information technology with the ecological contexts in which it is embedded.

5. Case Studies of Governing Eco-DRR

Our results show that mitigating the risks of coastal disasters such as tsunami, flood, storm surge, and coastal inundation are the primary functions of Eco-DRR [82–84]. In terms of the regional distribution, nine emblematic case studies are found in Asia, whereas case studies in Africa and Small Islands Developing States (SIDS) are most limited, with three case studies for each region. Furthermore, seven case studies in the Americas and six case studies from Europe are identified. In this section, we describe these examples based on different governance strategies for implementing Eco-DRR, which are further summarized in Table 3.

Table 3. Case studies and empirical literatures

Case study	Country/Region	Source
Ecosystem-based hazard mitigation and general livelihood improvements	UK; Iceland; USA; Indonesia; Germany	[82–89]
Valuation of ecosystem	Caribbean Region; Tropical Pacific,	[90–94, 134, 135]

services	Southern Oceans, and UK coastal seas; Philippines; Indonesia; Gulf of Mexico	
Knowledge co-production	South Africa; Caribbean; Southeast Asia; SIDS	[95–98]
Community-based, inclusive, and participatory approaches	Thailand; Ethiopia; South Africa; Trinidad and Tobago; Pacific; Bangladesh; Ecuador; India; South Africa; Colombia; Belize; USA; Fiji; Brazil	[78,99–111]
Politics discourse	Nicaragua; Mali	[112,113]
Science-policy interface	Germany; Gulf of Mexico	[22,102,114]
Policy and governance design	Austria; Gulf of Mexico; Myanmar; India	[115–119]
Mainstreaming EbA into the multi-level governance for CCA and DRR	South Africa; Germany; Sweden; Australia; India; Seychelles; UK; Samoa, Cambodia; Pacific Islands; Antarctica	[10,11,29,120–132]
Innovative green infrastructure for ecosystem-based DRR and CCA	The Netherlands; Australia	[9,21,101,133]

5.1 Valuation of Ecosystem Services

A recent study shows that the number of EbA actions are limited compared to the potential of existing ecosystem resources [83]. In 2006, for example, the valuation of the UK's marine biodiversity supported the development of marine legislation and led to the National Ecosystem Assessment, which subsequently also provided input to the UK's Post-2010 Biodiversity Framework. However, the challenge lies in the lack of EbA in formal regulation, which could have negative impacts on ensuring the collection of new data – especially the non-use values of multiple ecosystem services that are currently deficient – to further support EbA policy-making in the UK [93]. In the Caribbean, recent research highlighted a gap in understanding factors that could potentially determine the value of ecosystem services for protecting shorelines from coastal storms. To address this problem, Rao et al. identified size, level of development, GDP, type of ecosystem, wind speed, storm frequency, and EbA implementation model as baseline variables for calculating the value of ecosystem services [92].

Better valuation of ecosystem services can support market-based incentives to promote biodiversity conservation, such as through Payments for Ecosystem Services (PES) [134]. PES is defined as ‘a voluntary, conditional agreement between at least one “seller” and one “buyer” over a well-defined environmental service – or a land use presumed to produce that service’ [135]. It tackles the trade-offs between land owner’s interest and external actors, particularly to promote biodiversity conservation [135]. However, the complexity of valuation methods often constrains PES uptake. Ruckelshaus et al. noticed that other external barriers such as property rights, governance (e.g., local to international jurisdiction), and the alignment of providers and beneficiaries can also impact the effective use of PES [91].

5.2 Knowledge Co-Production Approaches

For EbA and Eco-DRR, knowledge co-production is valuable because it identifies the current status of knowledge and provides directions for future research and decision-making [97]. For example, a recent review of food security in small island developing states (SIDS) analyzed the use of local knowledge within the context of community-based disaster risk reduction [95]. The study shows that gaps include the lack of coherence in approaching food security in line with the ecosystem-food-climate nexus; the lack of a regional framework despite similarities among SIDS; and the lack of knowledge integration [95]. The study proposes deepening the relationship between ecosystems, food security, and climate change through empowering local knowledge of EbA and Eco-DRR. In addition, it proposes the need to ensure that information developed and shared at regional and national levels is made understandable for local needs.

Another study conducted in Indonesia and the Philippines on coastal disaster risk reduction also mentioned the need for utilizing local knowledge for research and policy-making [96]. The study concluded that in order to facilitate better adaptation measures, the identification of local knowledge based on different types and uses – such as folklore, rituals, ceremony, and customary law – are needed. However, a recent study of disaster management in South Africa by Sitas et al. illustrated that some of the active barriers undermining the objective of knowledge co-production can include preconceived assumptions, entrenched disciplinary thinking, and confusing terminology [98]. To tackle these problems, all knowledge stakeholders should be involved in ecosystem-based management, and in the case where it cannot be afforded, the use of knowledge brokers can help [98].

5.3 Community-Based and Participatory Approaches

In the United States, ecosystem-based planning is being adopted by different state governments. For example, in the case of the Everglades in Florida, participatory ecosystem-based approaches have been taken into account by Florida's Department of Environmental Protection to facilitate local spatial planning and law enforcement [99]. In this case, the local community is consulted during the preparation of a comprehensive plan, which is legally binding and should be consistent with existing state laws on ecosystem management.

Research has also shown that sustainable EbA can simultaneously increase community resilience [56,101]. In the case of Durban, South Africa, biodiversity has been framed as a bio-infrastructure that increases the supply of ecosystem services and provides multiple long-term benefits for local communities, particularly through access to natural resources and livelihood opportunities [101]. However, challenges to this approach lie in the capacity of local actors, which is also a problem noted by a recent case study of community-based EbA in coastal Bangladesh [102]. This study illustrated the challenges faced by a community-based coastal afforestation project, where low capacity of the local government hampered its implementation. Conversely, a study of local action in Monkey River Village, Belize, showed that by affiliating with bridging institutions – such as journalists, researchers, and local NGOs – communities can mobilize and facilitate policy change [103]. Such forms of activism are successfully supporting local claims to political legitimacy, while also helping to raise the community's awareness of increased soil erosion rates.

5.4 Politics Discourse

Several case studies highlight the role of power relations in governing ecosystem-based approaches. In northern Mali, for example, a political campaign to return Lake Faguibine to a Prosopis forest ecosystem has triggered conflict among local groups [112]. In the long term, the Prosopis forest will reduce the community's vulnerability to drought since it is an excellent source of fodder during drought periods. However, local communities tend to only look at the short-term implications of the loss of agricultural land in place of maintaining the Prosopis forest. During the course of the conflict, issues of power and marginalization are clearly shown between regional politicians and local communities, as well as between men and women in extending their voices and interests [112]. Different political interests became a significant barrier to achieving sustainable use of ecosystem services. The study recommended the need for multilevel, participatory, integrative, and a gender-sensitive approach to managing conflicts in newly decentralized political arenas that are pursuing ecosystem based-adaptation [112].

Another study by Benessaiah and Sengupta in Estero Real, Nicaragua, elaborates on the significance of power relations in influencing governance outcomes of EbA. In this case, shrimp aquaculture was introduced as a new concept for privatizing coastal ecosystem resources, which made small-scale shrimp farmers lose their ponds [113]. However, the existence of strong social ties among small-scale fish farmers helped mitigate the negative impacts of privatization. They negotiated their position to communally manage the lagoons with additional consideration for reducing the impacts of environmental degradation [113]. The study promotes a co-management approach with clear guidelines for addressing power relations between a resource-dependent people and industries and government.

5.5 Science-Policy Interface

The collection of data on ecosystem valuation and socio-ecological conditions requires effective collaboration between politicians, communities, private actors, and researchers [102,114]. The involvement of researchers is important for monitoring, assessing, and forecasting scenarios [114]. One example is the coastal afforestation project in Bangladesh's National Adaptation

Programme of Action. A study by Ahammad et al. showed how the Ministry of Environment and Forest in Bangladesh managed to facilitate science-policy integration through knowledge co-production [102]. Scientific assessments were conducted to explore the sensitivity of coastal ecosystems, which in turn affected local vulnerability. The evaluation of ecosystem benefits attributed to mangroves has been formulated into a policy to reduce land degradation in the coastal areas of Bangladesh. In this case, the main success factors mentioned are strong institutional leadership from government authorities and the collaborative approach to ecosystem management [102].

5.6 Policy and Governance Design

A study by Jordan and Benson of the Gulf Coast of the United States shows that decision-making among stakeholders have the potential for being complementary, conflicting, or overlapping in nature [116]. Jordan and Benson conclude that certain modes of governance can produce different levels of effectiveness in the sustainability of a certain coastal ecosystem. In their study of three sites along the Gulf of Mexico, a networked, participatory, and consensus-based regime showed to be effective in facilitating a more sustainable coastal system, especially at the local level. For example, in Tampa Bay, Florida, the objective was to preserve the existing mangrove functions and water quality, which was supported by a strong regional platform, namely the Tampa Bay Regional Planning Council [116]. On the Louisiana coast, where disaster and climate change impacts are the main problems, the authors found that reactive policies and hierarchical governance hinder efforts toward finding a sustainable solution [116]. Beyond the Gulf of Mexico, research by Hernández-González et al. on Austria’s flood risk management plans (FRMPs) showed that in order to prevent conflict, improved coordination among different regions through a comprehensive land-use planning approach is necessary [119]. In this vein, the authors suggest including the planning and development of green infrastructure as an arena for consensus-based decision-making.

5.7 Mainstreaming EbA and the Multi-Level Governance of CCA and DRR

Although EbA is beginning to receive global policy attention [121,122], efforts to mainstream EbA and Eco-DRR approaches from national to local levels have not been critically evaluated. This is a challenge particularly for island nations in the Pacific Ocean that are experiencing severe climate change impacts and disaster risks. For many of them, there is yet to be integrated climate adaptation and disaster risk reduction policies within sectoral plans [10].

Factors that could potentially improve the effectiveness of mainstreaming EbA can been found in the Seychelles. These include leadership, institutional mechanisms, science–policy nexus, decision-making structures, stakeholder involvement, and technological innovation [126,127]. In the case of EbA implementation in the UK, a study by Burch et al. evaluated different barriers to mainstreaming approaches, which include uncertainty of funding and climate change as a policy priority; organizational silos leading to insufficient communication; and a legacy of policies that deliver sub-optimal outcomes in the event of a changing climate [124]. Furthermore, in Samoa and Cambodia, the barriers to mainstreaming EbA primarily lie in the institutional and legal constraints at the national level [29]. For example, in Samoa, the lack of institutional capacity, resources, and adequate laws made the management of natural resources fully dependent on customary law. In Cambodia, the lack of agency amongst resource-dependent communities is exacerbating poverty, illegal resource extraction, poor law enforcement, and corruption [29].

Finally, although adaptation measures are often implemented locally, local governance is often constrained due to limited capacity [29,123]. Pasquini et al. conducted a study on the barriers to mainstreaming climate adaptation around the world [123]. The study concluded that party politics at the local level reduces the effective performance and operation of local governments. In addition, there is a danger of public officials abusing their power for political gain instead of for the public good. To tackle this problem, the authors suggest that national governments provide stricter controls in appointing senior municipal officials [123].

5.8 Innovation in Green Infrastructure for Ecosystem-Based Approach to DRR and CCA

Since 2012, the literature has shown that ecological engineering – also referred to as bio-infrastructure, soft engineering, or green infrastructure – can be an innovative solution to current contradictions between unsustainable infrastructural development and ecological preservation [9,21,70,101,133]. Unlike traditional engineering approaches, which focus on solving problems with technological designs [136], ecological engineering provides protection against disaster and climate change impacts by combining infrastructural approaches with ecosystem services, which further promotes sustainable, adaptable, multifunctional, and economically feasible strategies. The so-called 'soft' engineering approach can also minimize the impacts of large-scale engineering projects that tend to neglect biodiversity and prohibit communities to gain access or benefit from livelihood improvements [21].

Ecological engineering was first piloted in The Netherlands, particularly in the context of coastal protection against land subsidence, sea-level rise, storm surges, and flooding through the Building with Nature Project (BwN) [133]. However, a study on the application of the "Sand Engine" technology implemented in the Netherlands by van den Hoek et al. showed that the social implications of the project were more consequential than the natural system itself [9]. Environmental uncertainties of the project – including climate impacts, water quantity and quality, and technological innovation pathways – were proven to not be a problem. On the contrary, social uncertainty – in the form of economic, cultural, legal, political, administrative, and organizational challenges – are far more constraining. One example mentioned by van Slobbe et al. is the existence of the Anti-Sand Engine Action Committee, who argued that recreational safety and drinking water quality can be affected by the Sand Engine project [133]. The movement was successful in negatively influencing the public's perception. Furthermore, to be able to manage social uncertainties, the research pinpointed the need to cope with diverse knowledge frames and interests through participation, cooperation, and dialogue among stakeholders.

Another challenge of ecological engineering is the lack of empirical baseline data to initiate the combined approach. Perkins et al. shows that current data on biodiversity and existing ecosystem services is lacking, which prohibits the evaluation of ecological impacts in the case of coastal structure and its effectiveness [21]. Given these recent lessons, emerging theories and strategies of ecological engineering require further institutional support. This support must facilitate participation, dialogue, and the co-production of knowledge, especially for uncovering the social impacts of either existing ‘hard’ engineering or pipeline ecological engineering structures.

6. Governance Opportunities and Challenges

From our literature survey, we find several governance opportunities and challenges that are reflected in the theories, methods, and case studies of governing EbA and Eco-DRR. In general, existing governance theories – including socio-ecological systems and resilience, adaptive governance, climate risk governance, transformative governance, and ecological economics – have provided strong foundations upon which to further assess emerging EbA and Eco-DRR interventions. In terms of existing methods and case studies, we noted several important dimensions, which include economics, institutions, and spatial planning and implementation at the national, sub-national, and local levels. Furthermore, emerging innovation and technology – such as ecological engineering – serve as opportunities for the future implementation of EbA and Eco-DRR.

Theories of ecological governance and ecological economics are clearly reflected through diverse methodologies and case studies. The *economic* aspects of ecosystem services – such as ecosystem valuation – are increasingly used to better inform decision-making and to support market-based mechanisms such as payments for ecosystem services. A challenge is the lack of data on the non-use values of ecosystems (i.e., recreational satisfaction or indirect use of ecosystem in the food chain) as well as multi-related ecosystems economic valuation (i.e., multiple ecosystem services among different land uses) [137].

Institutional aspects are addressed mainly through the identification of actors and stakeholders; their capacity and interaction among different actors; ways to develop resources and capacities; as well as the assessment of compatible governance modes for the implementation of EbA and Eco-DRR. This has been specifically targeted in decision support tools such as the example of TARA and different integrated management, mainstreaming, and transdisciplinary approaches. It has also been reflected in the case studies, especially in the context of science-policy interface and the processes for mainstreaming EbA into climate adaptation and disaster risk reducation across different governance scales.

The opportunities presented by *spatial planning and implementation* for mainstreaming EbA and Eco-DRR across national, sub-national, and local levels are also strongly reflected in our review. In terms of methodologies, many authors have suggested using collaboration platforms that facilitate discussion and consensus among policy-makers, government authorities, NGOs, local communities, private sectors, and researchers (e.g. as highlighted in the TARA approach, integrated management, and different transdisciplinary arrangements). Different community-based, knowledge co-production, and networked approaches, as well as integrated spatial management and science-policy interfaces have come through very strongly. Although fewer in number, the cases of *emerging innovation and technology* of combined ecological and 'hard' engineering have been ground breaking. The hybrid approach – also known as ecological engineering – has the potential to mitigate the ecological impacts from traditional engineering approaches.

Besides the opportunities mentioned above, we noticed several challenges in terms of *socio-political dynamics*. Very few assessment methods and case studies critically evaluated the *politics* of EbA and Eco-DRR in the form of different power relations, negotiated spaces, equity and justice, and the role of community mobilizations. Instead, many of the cases focused on idealised elaborations of accountability, legitimacy, and adaptability [34]. For example, there have been no discussions of how governance actors are interacting with each other as well as how political behaviors, authorities, and powers can influence the governance outcomes of EbA and Eco-DRR. Other prominent issues such as equity, inclusiveness, and justice are still largely absent, as are nuanced analyses of the diversity, complexity, and competing socio-political scales. A structured methodology for diagnosing the opportunities and constraints of socio-political dynamics across different contexts is therefore required.

7. Synthesis: Towards a Critical Governance Approach to Eco-DRR and Ecological Engineering

Althought the literature on the governance processes, interactions, and outcomes of EbA, Eco-DRR, and ecological engineering is only recently emerging, many authors highlight how governance is increasingly the main challenge facing disaster risk reduction and climate change adaptation. Future research should therefore consider the existing literature and enrichment of case studies with clear operationalization steps to catalyze policy changes. Our inventory of the different principles of governance – as well as how it is applied in different contexts – can be useful for adaptive learning. In particular, our review highlighted several notable gaps.

First is the lack of diverse disciplinary representation. Currently there are few social and political scientists involved in EbA and Eco-DRR research, which has contributed to an overall lack of critical, reflective evaluations of governance. Although most authors either explicitly or implicitly refer to theories of socio-ecological systems and resilience, the topic of Eco-DRR is still very much dominated by the natural sciences. Our survey uncovered many methodological and empirical examples that use ecological and economic assessments (such as ecosystem valuation and cost-benefit analyses); however, there have been no corresponding methodologies for assessing the political, social, and institutional dimensions of Eco-DRR or ecological engineering. Furthermore, there are only two case studies on political discourses in the context of EbA and Eco-DRR.

Second, there are no methodologies that promote integrated assessments to analyze the diverse and complex socio-political dynamics associated with implementing EbA and Eco-DRR. This may be addressed by first developing a database of regional and local case studies, with the objective of assessing lessons, developing evaluative criteria, unpacking the politics behind different projects, and highlighting potential implementation approaches across different contexts. This is particularly needed in the context of governing new innovations such as ecological engineering. Furthermore, we find inconsistencies in terminology across the board, where similar projects can be referred to as ecosystem-based adaptation, ecosystem-based disaster risk reduction, or Eco-DRR. Developing robust assessment criteria will help with reducing this confusion.

However, the several gaps mentioned above can also be seen as potential opportunities. There are rich theoretical traditions that help to frame current ecosystem-based practices. These can be further complemented by the study of the institutional and political dimensions of governance, with particular focus on the 'lived experiences' of local politicians, implementation agents, and community beneficiaries. Similarly, with the methodology, there are opportunities for expanding into different regional contexts. Future research must interrogate the implications for 'alternative' governance models – i.e., ones that are not state-centric – such as self-governance, polycentric governance, and other more inclusive or participatory approaches. The theory of transformative governance and the TARA approach, for example, could be opportunities to provide guidelines for incorporating the institutional and political dimensions of governance. Finally, recent studies also shed light on the need to analyze resource/capacity inputs, institutional processes, and governance outcomes in the case of emerging ecological engineering and green infrastructure approaches [9,21,138].

In sum, future studies must focus on building comprehensive operationalization strategies based on existing governance theories and methodologies, while also lending additional focus on appropriate integrated assessments that evaluate important socio-political, institutional, and power dynamics found across different spaces, scales, communities, and political arenas. The criteria for the integrated assessment should be sourced from the ground up, but should also be available for translation across different contexts. This would ensure robust science-based – but also contextually appropriate – policy outcomes that are consistent with future EbA and Eco-DRR aspirations. These results will be important for further interrogating issues of governing emerging trends and innovations in EbA and Eco-DRR, including in the case of ecological engineering or green infrastructure.

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