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Invited ViewPoint

Opportunities for considering green infrastructure and ecosystems in the Sendai Framework Monitor☆

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ABSTRACT

Ecosystem-based disaster risk reduction has gained attention to complement or replace grey infrastructure. The paper explores ways in which ecosystems and green infrastructure (GI) are critical infrastructure in the context of disaster risk reduction to report respective losses in the Sendai Framework Monitor (SFM). We argue that reporting on GI under indicators D-4 and C-5 in the SFM represent an opportunity for tracking losses, yet do not provide direct information on progress made in reducing risk. Custom targets and indicators according to countries' needs within the SFM might be a more practical opportunity to report on both losses and progress.

Contents

1. The role of ecosystems and green infrastructure in the Sendai Framework

Disasters represent a major threat to sustainable development and will continue to do so in the future [1]. Thus, reducing disaster risk and the associated social, environmental, and economic impacts remains a global priority. The Sendai Framework for Disaster Risk Reduction (SFDRR) emphasizes the need to address underlying causes of disaster risk and to prevent the emergence of new risks, in addition to disaster preparedness. It is increasingly recognized that conventional engineered (or “grey”) infrastructure measures such as dykes, sea-walls, or groins, have shortcomings as they typically address protection needs without addressing the underlying drivers of risk (cf. [2,3]). Beyond their immediately designed purpose, grey infrastructures generally do not provide additional economic, environmental and social services. They also tend to be expensive and usually lack an ability to self-adjust to the consequences of changing conditions over time [4]. To account for these evolving perceptions and practices, a hydraulic engineer for instance is increasingly seeking collaboration with other disciplines, such as ecology, economy, social and administrative sciences for innovative and acceptable solutions. In other words design approaches are moving from a reactive one, minimizing and mitigating the impacts of a set design, to a pro-active one, optimizing on all functions and ecosystem services [4].

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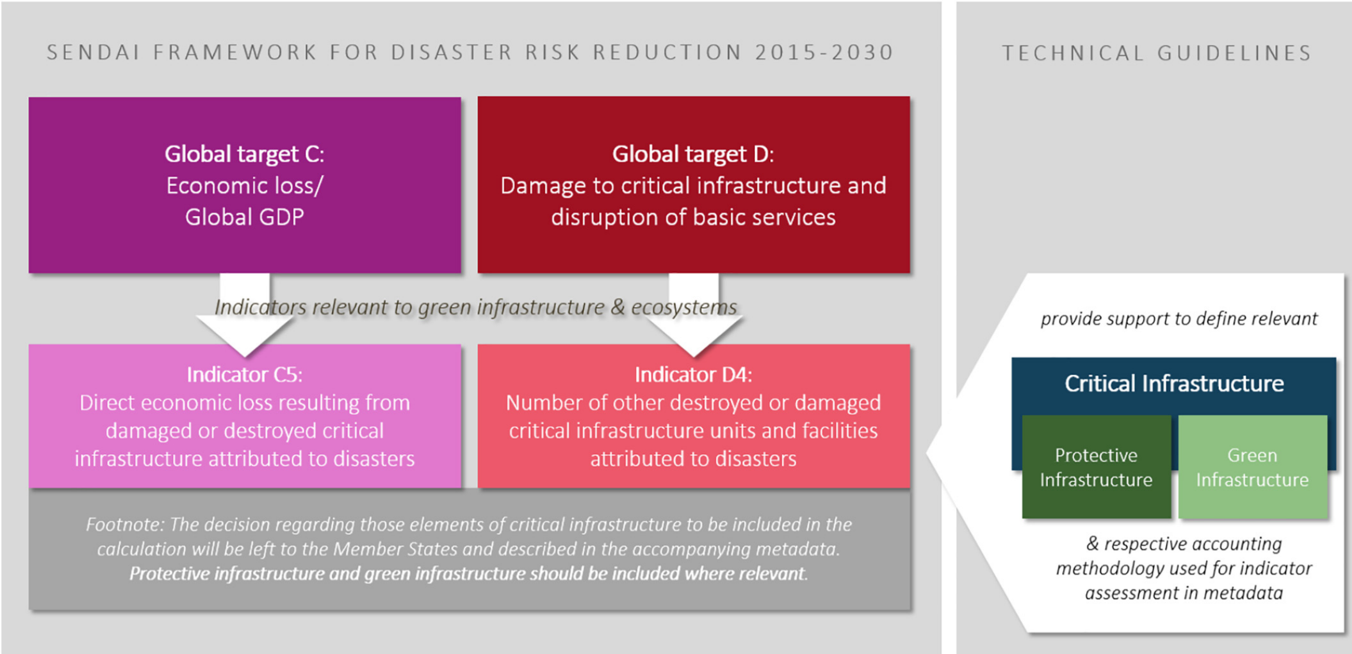

Fig. 1. Indicators on green infrastructure and ecosystems in the SFDRR (own figure).

A solution that is being increasingly encouraged by the global research and DRR communities is the investment in ecosystem-based approaches to disaster risk reduction (Eco-DRR). Ecosystem-based solutions are relevant to various dimensions of DRR: for example, they can help reduce social vulnerability due to their contribution to food and water supply [5]; as an important difference to grey infrastructure, green solutions may also attenuate the hazard itself. For example, restored and maintained wetlands, such as floodplains, marshes, peatlands and lakes help to increase rain infiltration and thus reduce peak river discharge [6] but also buffer low-flow situation and thus water scarcity [7,8]. Finally, when ecosystems are protected or restored along coastlines or riverbanks, they can act as a natural buffer to hazard events and as such possibly reduce exposure to hazards [9,10].

With a growing number of Eco-DRR implementations, there is increasing evidence for the effectiveness of these approaches for DRR. For example, coral [11,12], and oyster reefs [13], seagrasses [12,14], sand beaches, dunes, and barrier islands [15,16], mangroves [12,16,17], salt marshes [12,18,19], and other wetlands [20] have been shown to contribute to e.g. shoreline stabilization, erosion control or wave energy attenuation. Ecosystem-based solutions can also protect grey infrastructure [21], thus reducing maintenance costs and enhancing the sustainability of grey infrastructure.

As a result of their increasingly recognized relevance, ecosystems are considered in the SFDRR in multiple ways such as in the description of the Priorities for Action, in the Guiding Principles, Goals, and Expected Outcomes. The SFDRR is clear about the crucial role ecosystems play in the DRR context e.g. when the importance is stressed "[t]o encourage the use of and strengthening of baselines and periodically assess disaster risks, vulnerability, capacity, exposure, hazard characteristics and their possible sequential effects at the relevant social and spatial scale on ecosystems, in line with national circumstances" ([1], p. 14) as well as "[t]o strengthen the sustainable use and management of ecosystems and implement integrated environmental and natural resource management approaches that incorporate disaster risk reduction" ([1], p. 15). However, ecosystems have not been directly included in any of the Global Targets [1], making more difficult the monitoring of both ecosystem losses and damages and the progress in implementing ecosystem-based measures [22]. Nevertheless, countries, that wish to monitor ecosystem related losses and measures can still do so using green infrastructure (GI) solutions as entry points. The monitoring of losses related to GI is possible under indicator C-5 on direct economic loss resulting from damaged or destroyed critical infrastructure (CI) attributed to disasters and indicator D-4 on the number of other destroyed or damaged CI units and facilities attributed to disasters in the Sendai Framework Monitor (SFM). More specifically, indicators C-5 and D-4 are enriched with a footnote, which states that "protective and green infrastructure should be included where relevant" ([23], p. 39; Fig. 1).

While CI is defined as the "physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society" ([23], p. 96), GI[1] are "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation, climate mitigation and adaptation, and management of wet weather impacts that provides many community benefits" ([23], p. 96). The Technical Guidance for the monitoring of the SFDRR provides support for the definition and monitoring of CI including relevant protective and green infrastructure as well as the respective accounting methodology used for the indicator assessment [23].

In this context, GI is considered to be a sub-component of CI opening up the opportunity to report on critical green infrastructure (CGI) losses – and to broaden the classical understanding of CIs as "grey". While this is clearly an opportunity, the terminology and its use in the SFDRR's Technical Guideline is not straightforward. This is counterproductive to the promotion of GI in national policies and procedures, especially in adjusting public infrastructure procurement frameworks to favor GI. Further, while the monitoring of loss and damage caused by hazards is ensured by including GI in the targets C and D, this neither accounts for loss and damage caused by other anthropogenic activities, which harms the DRR function of GI nor for the progress made towards achieving the goals of the SFDRR by implementing ecosystem-based solutions.

In the following section, the example of wetlands is used to showcase the role and functionalities of GI in the context of the SFM. We also reflect on the shortcomings in terms of both monitoring losses and reporting on progress. Finally, we suggest a practical yet scientifically grounded way to deal with the terminological rifts for the sake of improved understanding and potential uptake.

[1] We restrict ourselves to the usage of the term green infrastructure (GI), which in our perception includes blue infrastructure. This is in line with da Silva and Wheeler [24], who proposed to use the term GI over 'natural', 'blue', or 'ecological' infrastructure, because it is the term most widely used and has been adopted in US and EU policies. In addition, it corresponds to the terminology used in the Technical Guidelines of the SFM.

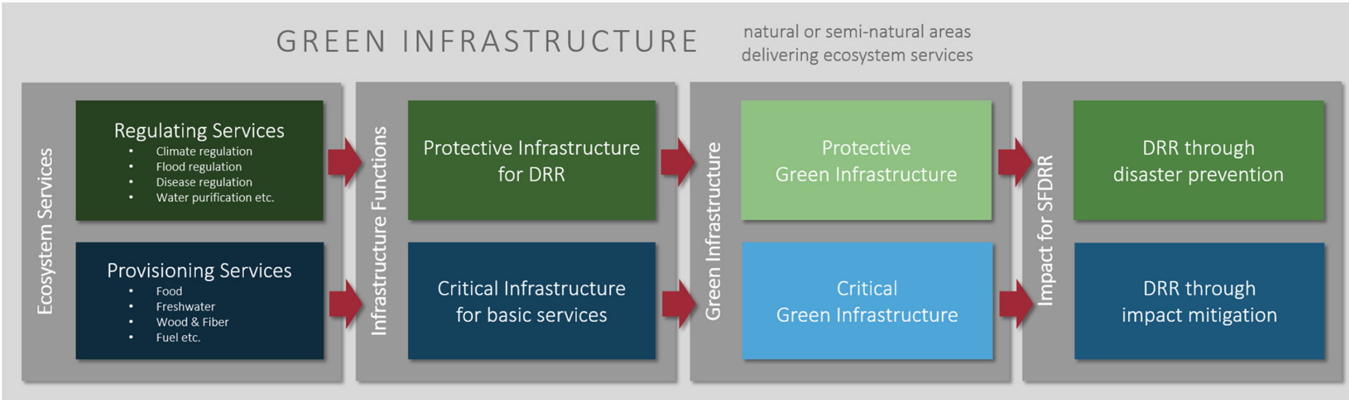

Fig. 2. Conceptualization of GI for the SFDRR. Own figure.

2. Wetlands as critical and protective green infrastructure

Wetlands, such as areas of marsh, fen, peatland or water [25] provide a great variety of ecosystem services [26,27]. For the purpose of the discussion we focus on the services *flood protection* and *water purification* as these represent two different, yet important services in the context of the SFM.

Firstly, a wetland's water retention and flow regulation capacity attenuates the flood magnitude which may result in reduced flood impacts [26,28–30]. Thereby, the regulating ecosystem service alleviates or even prevents the hazard itself. For example and speaking in general terms as many factors interact, mangroves can reduce coastal flood risk by reducing wind and swell waves; storm surge flood levels; the impacts of large waves and high wind speeds occurring during major storms (cyclones, typhoons or hurricanes); tsunami wave heights (depending on the magnitude of the event); limit coastal flooding from coastal erosion and counter sea-level rise by soil level increase (depending on sediment supply), thereby reducing loss of life and damage to property in areas behind mangroves [16]. Degradation of mangrove forests reduces the ecosystem services these ecosystems can provide, requiring the implementation of grey infrastructure such as sea walls to replace the lost DRR functions.

Secondly, wetlands provide water purification services whereby they take up nutrients and pollutants, and thus contribute to freshwater supply [26]. With this, the water purification service of the wetland fulfills similar functions, as grey infrastructure for water supply and sanitation. In the absence of a wetland, a water treatment plant would be needed. In this case, the wetland contributes to both hazard attenuation and the supply of freshwater (and with that so called societal basic services, as defined in the SFM), which helps to reduce vulnerability. In a more generalized way, when aligning the ecosystem services with infrastructure functions, two categories of GI emerge: i) *Protective* GI, which prevents or attenuates hazards or exposure to hazards and ii) *Critical* GI, which ensures the supply of basic services such as drinking water (Fig. 2).

The critical function of wetlands and more generally GI in the context of the SFM demonstrates the need for monitoring loss of and damage to GI caused by hazards, which directly speaks to indicators C-5 and D-4 of Global Targets C and D.

A disaster-related degradation of an ecosystem can be exemplified based on a case study in New Jersey. Ecosystem services provided by freshwater wetlands were valued in 2006 in the frame of a natural capital accounting in an area which was affected by Hurricane Sandy in 2012. This is one of the few cases worldwide where there is a good baseline study available, which was then complemented by a local study of ecosystem service losses in the aftermath of Sandy. In 2006 the ecosystem services provided by the freshwater wetland were valued as high as US$9.4 billion per year [28]. After the landfall of Hurricane Sandy in 2012, salt burning and marsh dieback caused by the storm surge led to the degradation of 34% of the wetlands [31]. This resulted in a 47% reduction of the ecosystem services value adding up to US$4.4 billion in loss (ibid). The loss and degradation of wetlands has direct implications for the progress towards achieving the SFDRR goals underlying the importance to monitor loss and damage of GI and more generally ecosystems [32,33]. Given that a baseline study was complemented with a study after Sandy, including economic valuations, this case demonstrates an opportunity to report wetland loss and damage under B-5 and C-4 of the SFM.

However, GI and ecosystems in general are often prone to loss and degradation driven by factors not related to hazards such as e.g. wetland loss by urban sprawl, habitat change as an effect of damming, river redirection or/and channelization, pollution, which either causes habitat loss or directly affect their ability to provide those critical services e.g. by loss of redundancy, functionality or biodiversity loss. This increases the vulnerability of these areas to hazards due to loss of the regulation capacity. These aspects are currently not covered in the SFM but highlight the importance of the need to monitor ecosystems in general and especially in the context of DRR.

3. Consequences for research and practice

The Technical Guidance for the monitoring of the SFDRR requires the reporting member states to define critical, protective and GI as well as the respective accounting methodology used for the indicator assessment in the metadata [23]. The categorization in protective GI and critical GI helps to showcase the relevance of ecosystems as exemplified in the case of wetlands. However, introducing new terminologies might lead to confusion and add complexity. A literature search in the *Scopus* database (December 2018) showed that the terms ‘protective green infrastructure’ and ‘critical green infrastructure’ have only been used sporadically. A web-based search of the two terms reveals similarly low number of results. For example, critical GI was mainly attributed to natural areas in urban environments and has been used in landscape planning contexts e.g. by the Greater London Authority,[2] in the context of the COST framework (European Cooperation in Science and Technology) [34], or by the Australian Institute of Landscape Architects. Furthermore, critical GI was related to forestry, e.g. by the National Association of State Foresters and the USDA Forest Service.[3] However, the use of the term CI in the context of GI is hardly related to the main use of the term in national security discourses [35,36]. Protective GI is mentioned in the framework of urban, regional, and coastal resilience strategies, e.g. in United Nations HABITAT III policy,[4] by The Rockefeller Foundation (100RC),[5] or the U.S. National Science and Technology Council [37]. In summary, although all these terms are used to some extent, overall, their use is sporadic and unsystematic.

[2] https://www.london.gov.uk/sites/default/files/green_infrastructure.pdf.

[3] http://www.stateforesters.org/sites/default/files/publication-documents/2016_State_and_Private_Forestry_Report.pdf.

[4] United Nations Conference on Housing and Sustainable Urban Development, Habitat III Policy Papers: Policy Paper 8 Urban Ecology and Resilience (New York: United Nations, 2017), www.habitat3.org.

[5] https://www.100resilientcities.org/prepared-future-greater-manchesters-journey-emergency-preparedness-resilience/.

Thus, suggesting the use of these terms would mean embarking on a terminology not widely used in related science and practice communities.

Independent of the terminology, to date no country has reported on the loss or damage of either ecosystems or GI in the SFM. We argue that indicators D-4 and C-5 in the SFM and specifically the footnote, which allows for the monitoring of GI, represent an opportunity but is not a very practical or straightforward solution. Additionally, reporting on GI under indicators D-4 and C-5 in the SFM mainly allows for tracking losses, yet do not provide direct information on progress made in reducing risk. Custom targets and indicators according to countries' needs within the SFM might be a more practical opportunity to report on both losses and progress. Custom targets and custom indicators according to countries' needs within the SFM might open up a more intuitive way to report on both, ecosystem losses and progress made on Eco-DRR solutions. In practical terms this could mean that wetland loss and damage could be directly reported formulating custom targets and defining respective custom indicators. This would also allow for using existing data from ecosystem service assessments, ecosystem valuation, or strategic environmental impact assessments as shown in case of the wetland example. A further coordination between entities collecting data in the scope of national and international frameworks would also allow one to reduce the monitoring load significantly. For example, indicator 6.6.1 of the SDG 6 tracks changes in extent of water-related ecosystems, Target 8 of the Ramsar Convention aims at complete national wetland inventories, and Aichi Target 5 of the Convention on Biological Diversity relies on data to monitor the reduction rate of loss of all natural habitats including wetlands. A country, which identifies wetlands as an important element of its DRR strategy could identify wetland restoration and protection as one of its custom targets, define respective custom indicators and align the monitoring process with the other mentioned global reporting processes or national goals and monitoring. This would constitute a more straightforward monitoring option than the more difficult to interpret D-4 and C-5 targets on critical infrastructure. However, setting additional, custom targets might add a burden to the monitoring efforts of countries and need to be decided on a case-by-case basis.

We conclude that ecosystems can be considered well in the SFM in its current configuration but more clarity in terminology and a clearer communication of these entry points would facilitate targeted monitoring action at the country level. As an immediate action, an enhanced integration of available data collected for international frameworks such as SDGs, Ramsar Convention, CBD's Aichi targets but also national forestry inventories, earth observation data, etc. could boost data availability for the SFM. This could be considered during the revision of the Technical Guidelines in 2019.

References and recommended reading[•,••]

[1] UNISDR. Sendai framework for disaster risk reduction 2015–2030. 3rd United Nations world conference on DRR. Sendai; 2015 Retrieved from https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.

[2] •Onuma A, Tsuge T. Comparing green infrastructure as ecosystem-based disaster risk reduction with gray infrastructure in terms of costs and benefits under uncertainty: a theoretical approach. Int J Disaster Risk Reduct 2018;32:22–8. https://doi.org/10.1016/J.IJDRR.2018.01.025. This paper uses a theoretical approach and a cost-benefit analysis to demonstrate at which set of conditions an optimal green infrastructure would be preferable as Eco-DRR measure compared to gray infrastructure expressed by parameters reflecting the probability of occurrence of hazard, probability of preventing exposure to the hazard, population size, and vulnerability to damage accruing from exposure, as well as costs and benefits of the two infrastructures.

[3] UNEP. Green infrastructure guide for water management: ecosystem-based management approaches for water-related infrastructure projects. Geneva. Retrieved from www.unepdhi.org/-/media/microsite_unepdhi/publications/documents/unep/web-unep-dhigroup-green-infrastructure-guide-en-20140814.pdf; 2014.

[4] de Vriend HJ, van Koningsveld M, Aarninkhof SGJ, de Vries MB, Baptist MJ. Sustainable hydraulic engineering through building with nature. J Hydro Environ Res 2015;9(2):159–71. https://doi.org/10.1016/j.jher.2014.06.004.

[5] Renaud FG, Sudmeier-Rieux K, Estrella M. The role of ecosystems in disaster risk reduction. The role of ecosystems in disaster risk reduction, 440; 2013. https://doi.org/10.1016/j.ijdrr.2015.08.001.

• Of special interest.
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[6] Javaheri A, Babbar-Sebens M. On comparison of peak flow reductions, flood inundation maps, and velocity maps in evaluating effects of restored wetlands on channel flooding. Ecol Eng 2014;73:132–45. https://doi.org/10.1016/j.ecoleng.2014.09.021.

[7] Acreman M, Holden J. How wetlands affect floods. Wetlands. Netherlands: Springer; 2013, October 17. https://doi.org/10.1007/s13157-013-0473-2.

[8] Qi J, Zhang Y, Zhang Y, Liu Y, Yang Q, Song L, et al. Water-holding capacity of an evergreen broadleaf forest in Ailao Mountain and its functions in mitigating the effects of Southwest China drought. Shengtai Xuebao/Acta Ecol Sin 2012;32(6):1692–702. https://doi.org/10.5846/stxb201103030259.

[9] Tanaka N. Effectiveness and limitations of coastal Forest in large tsunami: conditions of Japanese pine trees on coastal sand dunes in tsunami caused by Great East Japan earthquake. J Jpn Soc Civ Eng Ser B1 Hydraul Eng 2012;68(4):II_7–II_15. https://doi.org/10.2208/jscejhe.68.II_7.

[10] Tanaka N, Yagisawa J, Yasuda S. Breaking pattern and critical breaking condition of Japanese pine trees on coastal sand dunes in huge tsunami caused by Great East Japan earthquake. Nat Hazards 2013;65(1):423–42. https://doi.org/10.1007/s11069-012-0373-4.

[11] Ferrario F, Beck MW, Storlazzi CD, Micheli F, Shepard CC, Airoldi L. The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nat Commun 2014;5(1):3794. https://doi.org/10.1038/ncomms4794.

[12] •Narayan S, Beck MW, Reguero BG, Losada IJ, Van Wesenbeeck B, Pontee N, et al. The effectiveness, costs and coastal protection benefits of natural and nature-based defences. PLoS One 2016;11(5):1–17. https://doi.org/10.1371/journal.pone.0154735. This paper provides a synthetic information on the costs and benefits of projects designed for coastal protection and an analyses of the effectiveness of different coastal habitats such as mangroves, salt-marshes, coral reefs and seagrass/kelp beds for wave height reduction at the coast.

[13] Rodriguez AB, Fodrie FJ, Ridge JT, Lindquist NL, Theuerkauf EJ, Coleman SE, et al. Oyster reefs can outpace sea-level rise. Nat Clim Chang 2014;4(6):493–7. https://doi.org/10.1038/nclimate2216.

[14] Christianen MJA, van Belzen J, Herman PMJ, van Katwijk MM, Lamers LPM, van Leent PJM, et al. Low-canopy seagrass beds still provide important coastal protection services. PLoS One 2013;8(5):e62413. https://doi.org/10.1371/journal.pone.0062413.

[15] Hanley ME, Hoggart SPG, Simmonds DJ, Bichot A, Colangelo MA, Bozzeda F, et al. Shifting sands? Coastal protection by sand banks, beaches and dunes. Coast Eng 2014;87:136–46. https://doi.org/10.1016/J.COASTALENG.2013.10.020.

[16] Spalding MD, Ruffo S, Lacambra C, Meliane I, Hale LZ, Shepard CC, et al. The role of ecosystems in coastal protection: adapting to climate change and coastal hazards. Ocean Coast Manag 2014;90:50–7. https://doi.org/10.1016/j.ocecoaman.2013.09.007.

[17] Monty F, Murti R, Miththapala S, Buyck C, editors. Ecosystems protecting infrastructure and communities: lessons learned and guidelines for implementation; 2017. https://doi.org/10.2305/IUCN.CH..2017.14.en.

[18] Gittman RK, Popowich AM, Bruno JF, Peterson CH. Marshes with and without sills protect estuarine shorelines from erosion better than bulkheads during a category 1 hurricane. Ocean Coast Manag 2014;102:94–102. https://doi.org/10.1016/J.OCECOAMAN.2014.09.016.

[19] Möller I, Kudella M, Rupprecht F, Spencer T, Paul M, van Wesenbeeck BK, et al. Wave attenuation over coastal salt marshes under storm surge conditions. Nat Geosci 2014;7(10):727–31. https://doi.org/10.1038/ngeo2251.

[20] Barbier EB, Georgiou IY, Enchelmeyer B, Reed DJ. The value of wetlands in protecting Southeast Louisiana from hurricane storm surges. PLoS One 2013;8(3):e58715. https://doi.org/10.1371/journal.pone.0058715.

[21] Slobbe E, Vriend HJ, Aarninkhof S, Lulofs K, Vries M, Dircke P. Building with nature: in search of resilient storm surge protection strategies. Nat Hazards 2013;65(1):947–66. https://doi.org/10.1007/s11069-012-0342-y.

[22] PEDRR. Advancing implementation of the ecosystem solutions Sendai framework for disaster risk reduction (2015–2030) through. Retrieved from https://www.preventionweb.net/publications/view/49283; 2015.

[23] ••UNISDR. Technical guidance for monitoring and reporting on progress in achieving the global targets of the Sendai framework for disaster risk reduction. Retrieved from https://www.unisdr.org/files/54970_techguidancefdigitalhr.pdf; 2017. The purpose of this document is to support UN Member States in the operationalization of the global SFDRRindicators to measure progress towards the achievement of the global targets of the Sendai Framework and relevant targets of the Sustainable Development Goals.

[24] ••da Silva JMC, Wheeler E. Ecosystems as infrastructure. Perspect Ecol Conserv 2017;15(1):32–5. https://doi.org/10.1016/j.pecon.2016.11.005. This paper reviews the concepts of 'ecological', 'green', 'natural' and 'blue' infrastructures, shows that the term 'green infrastructure' became the dominant one since 2004 and concludes that this should be the term adopted to facilitate communication between scientists, conservationists and decision-makers.

[25] Ramsar Convention Secretariat. An introduction to the convention on wetlands. Gland, Switzerland: Ramsar Convention Secretariat; 2016.

[26] Russi D, ten Brink P, Farmer A, Badura T, Coates D, Förster J, et al. The economics of ecosystems and biodiversity for water and wetlands. Executive summary. Vasa 2013;84. https://doi.org/10.1007/s13398-014-0173-7.2.

[27] •Thorslund J, Jarsjo J, Jaramillo F, Jawitz JW, Manzoni S, Basu NB, et al. Wetlands as large-scale nature-based solutions: status and challenges for research, engineering and management. Ecol Eng 2017;108:489–97. https://doi.org/10.1016/j.ecoleng.2017.07.012. This paper systematically investigates large-scale dynamics of landscape systems with multiple wetlands, showing that the aggregated effects of multiple wetlands in the landscape modifies the provisioning of ecosystem services due to parallel and circular flow-paths, through which wetlands are interconnected in the landscape, compared to functions observed at individual wetland scale.

[28] Costanza R, Wilson MA, Troy A, Voinov A, Liu S, D'Agostino J. The value of New Jersey's ecosystem services and natural capital. …. Ecol Econ 2006(January):177. https://doi.org/10.1016/j.jfe.2011.02.007 ….

[29] Kumar R, Tol S, McInnes RJ, Everard M, Kulindwa AA. Wetlands for disaster risk reduction: effective choices for resilient communities. Ramsar policy brief. Retrieved from https://www.ramsar.org/sites/default/files/documents/library/rpb_wetlands_and_drr_e.pdf; 2017.
[30] Murti R, Buyck C, editors. Safe havens: protected areas for disaster risk reduction and climate change adaptation. Gland, Switzerland: IUCN; 2014.
[31] Hauser S, Meixler MS, Laba M. Quantification of impacts and ecosystem services loss in New Jersey coastal wetlands due to hurricane Sandy storm surge. Wetlands 2015;35(6): 1137–48. https://doi.org/10.1007/s13157-015-0701-z.
[32] Belle JA, Collins N, Jordaan A. Managing wetlands for disaster risk reduction: a case study of the eastern Free State, South Africa. Jàmbá 2018;10(1):1–10. https://doi.org/10.4102/jamba.v10i1.400.
[33] WMO. Integrated flood management tools series no.27 version 1.0. Geneva: World Meteorological Organization; 2017.
[34] Davies C, Andreucci MB, De Vreese R, Brussel VU. Guideline for urban forestry as critical green infrastructure in European urban areas, (January); 2017; 10–2. https://doi.org/10.13140/RG.2.2.35181.18405.
[35] Lauta KC. Regulating a moving nerve. Eur J Risk Regul 2015;6(2):176–84https://doi.org/10.1017/S1867299X00004475.
[36] Pescaroli G, Alexander D. Critical infrastructure, panarchies and the vulnerability paths of cascading disasters. Nat Hazards 2016;82(1):175–92. https://doi.org/10.1007/s11069-016-2186-3.
[37] Safford H, Wowk K. Ecosystem-service assessment: research needs for coastal green infrastructure; 2015. https://doi.org/10.13140/RG.2.1.4385.8009.