




# Conservation of Wetlands and Other Coastal Ecosystems: a Commentary on their Value to Protect Biodiversity, Reduce Disaster Impacts, and Promote Human Health and Well-Being

Ariana E. Sutton-Grier<sup>1,2</sup>  · Paul A. Sandifer<sup>3</sup>

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## Abstract

There is substantial, growing literature that details positive human health effects, psychological and physiological, of exposure to “nature,” including “green” and “blue space,” with evidence suggesting that diversity of species or environments may have specific positive human health benefits. These health benefits are important ecosystem services provided by healthy ecosystems. In this paper, we discuss several critical ecosystem services provided by wetlands including disaster risk reduction, with an emphasis on benefits to human health and well-being. Impacts to human health via damage to ecosystem services from disasters have rarely been considered in disaster planning or mitigation, nor have the health benefits been part of the framework for planning urban greenspaces and land-use. Coastal wetlands can be part of “natural and nature-based” solutions, minimizing the impacts of disasters by buffering coastal communities from storms and erosion and absorbing flood waters. In addition, mental and physical health benefits of experiencing healthy wetlands could offset some stress and disease encounters related to disasters. Thus, coastal wetlands should be part of a strategy for reducing the risk posed by disasters and facilitating recovery. We conclude with recommendations for research priorities and specific inclusion of wetlands in coastal community planning for disaster response and recovery.

**Keywords** Green & blue space · Natural and nature-based infrastructure · Disaster planning, response and recovery · Urban planning and land-use · Human health

## Introduction

It is now well established that exposure to “green” spaces of many kinds (e.g., parks and protected areas that are more natural and biodiverse) and that include water or coasts (“blue”) provides a broad suite of mental, physical, and social

health benefits to people of all ages, gender, ethnicities, and socio-economic status (e.g., see Jiang et al. 2014; Sandifer et al. 2015; Jiang et al. 2016; White et al. 2016; Cox et al. 2017; Frumkin et al. 2017; Van den Berg 2017; White et al. 2017). There are several theories about how nature experiences produce health benefits, such as encouraging physical activity (Bauman et al. 1999; Depledge and Bird 2009; Barton and Pretty 2010), promoting attention restoration (Kaplan 1995) and reducing stress and anxiety (Ulrich et al. 1991). However, much work remains to be done to identify and understand mechanisms of action, causality, dose-response characteristics, and other factors (Sandifer et al. 2015; Frumkin et al. 2017). Nonetheless, available information is sufficiently robust that a growing number of medical practitioners is already prescribing nature exposure (green space, parks, coasts) for certain patients (Poulsen et al. 2015; Wessel 2017; Zarr et al. 2017), although this trend is still in relative infancy (Haubenhofer et al. 2010; Van den Berg 2017).

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✉ Ariana E. Sutton-Grier  
ariana.suttongrier@gmail.com

<sup>1</sup> The MD/DC Chapter of The Nature Conservancy, 425 Barlow Rd, Bethesda, MD 20814, USA

<sup>2</sup> Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA

<sup>3</sup> College of Charleston, Center for Coastal Environmental and Human Health, Hollings Marine Laboratory, 331 Fort Johnson Road, Charleston, SC 29412, USA

## Linking Nature Exposure, Ecosystem Services, Biodiversity, and Human Health

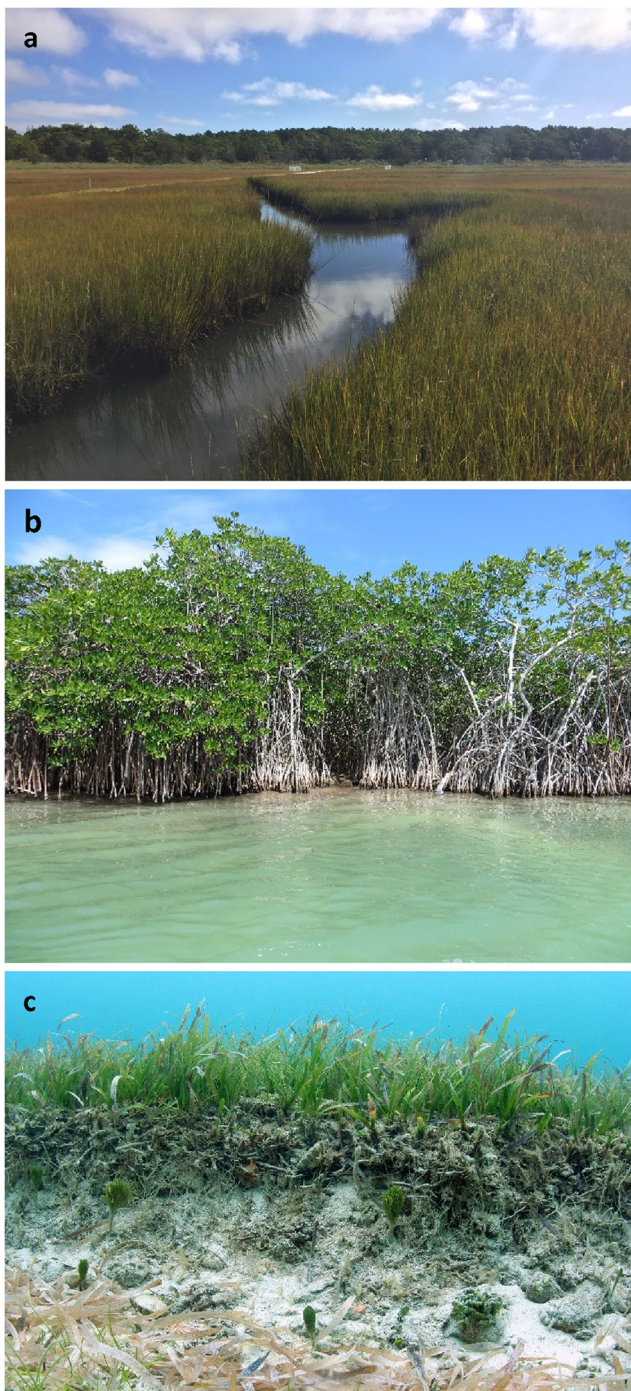
Because most, if not all, ecosystem services are important to human health and well-being (MEA 2005), Sandifer and Sutton-Grier (2014) characterized human health as the “cumulative or ultimate” ecosystem service (see also Frumkin et al. 2017). Healthy ecosystems provide high quality ecosystem services while stressed ecosystems produce degraded services that may cause negative psychological and physical health effects (Sandifer and Sutton-Grier 2014; Sandifer et al. 2015). With the exception of hydraulic head, mechanical filtration, and a few others, most ecosystem services are, to one degree or another, supported by biodiversity (Palumbi et al. 2009). Biodiversity-supported ecosystem services that support human well-being can be lumped into a variety of categories for ease of consideration, such as improved psychological health; enhanced physiological condition; decreases in some inflammatory-based illnesses and other non-infectious diseases; decreased transmission of certain infectious diseases; aesthetic, cultural, recreational, socioeconomic and spiritual benefits; and tangible materials such as food, fiber, and medicines (Sandifer et al. 2015). In addition, exposure to rich microbial biodiversity in managed ecosystems, such as traditional farms and in more rural areas, also has been found to support human immune functioning with several examples of children growing up on farms having lower incidences of conditions such as asthma (Debarry et al. 2007; Ege et al. 2011; Ruokolainen et al. 2017c). From this and other evidence we infer that exposure to biodiversity in both more natural as well as some managed ecosystems, such as traditional farms, can support human immune function and a reduction in disease burden.

## Wetland Ecosystem Services and Biodiversity Are Important for Human Health

The biodiversity in coastal and marine ecosystems, including marshes, mangrove forests, and seagrass meadows (Fig. 1), is important for providing ecosystem services humans desire from coastal ecosystems such as fish nursery habitat, water purification, flood risk reduction, climate modulation, nutrient cycling and others (MEA 2005; Mitsch et al. 2015). In addition to these better-known services, coastal wetlands also produce a broad range of cultural ecosystem services which are often ignored or poorly accounted for in ecological analyses. Rodrigues et al. (2017) summarized available literature and recorded the following cultural ecosystem services from salt marshes, mangroves and seagrass meadows: recreation and leisure; aesthetic; spiritual; cultural heritage and identity; educational; inspirational; sense of place; social; scientific; and existence.

According to the Valencia Declaration (Delegates of The World Conference on Marine Biodiversity 2008), “Marine biodiversity underpins the functioning of marine ecosystems and their provision of services - without biodiversity there would be no ecosystem services.” Wetlands, especially tidal marshes and mangroves, are widely considered to be the most, or at least among the most, valuable of our ecosystems in terms of contributions of ecosystem services (Costanza et al. 2014; Mitsch et al. 2015), and their biodiversity provides an essential foundation for the sustained production and delivery of ecosystem services. However, the loss of native biodiversity along our coasts already has resulted in both diminished ecosystem capacity to provide ecosystem services and increased health threats to humans from harmful microbes, extreme weather, chemical contaminants, etc. (Worm et al. 2006). Although our knowledge of how marine biodiversity and ecosystem services are causally linked remains poorly developed (Ricketts et al. 2016), we know that functional diversity is especially important (Diaz et al. 2006) and we have sufficient understanding to support the conservation of biodiversity as an essential element in sustaining critical ecosystem services (Palumbi et al. 2009).

Biodiversity also may play complex roles in the occurrence and transmission of disease. Based on an extensive review of the literature, Sandifer et al. (2015) posited that global biodiversity losses may be contributing to increasing prevalence of a variety of inflammatory-based diseases, such as allergies, asthma, some cardiovascular disease, irritable bowel disease, type 2 diabetes, some obesity, and others. They presented findings from a number of studies that linked development of healthy human gut and skin microbiota to exposure, especially during childhood, to environments with diverse microbiota, and in turn linked healthy human microbiota to better immune function and less inflammatory disease (Lynch et al. 2014; Ruokolainen et al. 2015). More recent studies, such as those by Ruokolainen et al. (2017a, b) provide added support for what has been termed the “biodiversity” or “hygiene” hypothesis. As Ruokolainen et al. (2017b) stated, “Contact with beneficial bacteria, particularly early in life, seems to be instrumental to the normal development of immune response.” In Australia, Liddicoat et al. (2018) found that good respiratory health correlated with landscape biodiversity and suggested possible beneficial immunomodulatory effects from environmental microbiota in diverse areas as a potential mechanism. Wetlands and coasts were included in areas of high biodiversity they recommended should be investigated further. Lasher et al. (2009) studied the bacterial communities in anaerobic marsh soils of Sapelo Island, GA, and found that overall bacterial diversity was similar to that of terrestrial soils but with a unique composition. Interestingly, the marsh bacterial community contained representatives of Firmicutes and Bacteroidetes, two of the bacterial groups to which exposure was negatively associated with allergic reactions in young



**Fig. 1** Coastal wetland ecosystems that provide many important ecosystem services include: (a) Coastal salt marshes, such as this one in Waquoit Bay National Estuarine Research Reserve, Massachusetts, USA; (b) mangroves, such as these in from Sian Ka'an Biological Preserve in Mexico; and (c) seagrass meadows. Photos: (a & b) A. Sutton-Grier and (c) Commission for Environmental Cooperation (CEC)

children (Lynch et al. 2014). Thus, while evidence is yet fragmentary, there is ample reason to develop and test hypotheses that wetland biodiversity, and more specifically wetland microbial biodiversity, may provide health protective benefits for humans, both from infectious and inflammatory-based diseases.

A variety of studies have examined the role of local biodiversity on transmission of infectious diseases that affect humans, generally through effects of species and habitat diversity on the abundance, behavior, or condition of hosts, vectors, or parasites. Some studies have shown a positive effect of biodiversity in reducing disease transmission (e.g., see Young et al. 2014), but overall the evidence is equivocal and may depend on the disease and also the scale at which the relationship is examined. Because there was no clear, generally applicable answer as to whether biodiversity may positively or negatively affect human risk of acquiring infectious disease, Sandifer et al. (2015) suggested that diseases and circumstances should be considered on a more or less case by case basis but recommended continued application of a precautionary approach and strengthening of biodiversity conservation for human well-being benefits. More recently, Ostfeld and Keesing (2017) found strong evidence for an infectious disease protection function of high biodiversity. Potential roles of coastal wetlands and wetland biodiversity in reducing human disease burdens of both infectious and non-infectious etiology deserve additional study.

For wetlands specifically, there is limited but growing evidence that they do help prevent disease transmission, although this function has not been linked specifically to biodiversity but more to wetland presence and area. For example, De Jesus Crespo et al. (2018) (in this issue) found a relationship between the occurrence of dengue and the presence of wetlands in neighborhoods in San Juan Bay Estuary (SJBE), Puerto Rico. Dengue occurrence was lower in neighborhoods with higher wetland cover even after controlling for population density and other socio-economic aspects. Similarly, Skaff and Cheruvilil (2016) reported that incidence of West Nile Virus in humans was lower in US counties with higher average wetland size compared to those with lower wetland size, but apparent wetland effects were also related to the dominant species of mosquito vector and drought status. Lamb et al. (2017) determined that when seagrasses were present there was a 50% reduction in bacterial pathogens capable of causing disease in humans and marine organisms. Corals adjacent to seagrasses showed two-fold reductions in disease levels compared to corals at sites without adjacent seagrasses. The researchers designed this study following field work in coral reefs in Indonesia after which everyone who went in the water got amoebic dysentery (Bittel 2017). This led the researchers to return to the site to take water samples where they determined that levels of *Enterrococcus*, a bacteria that can cause vomiting, nausea, and diarrhea, in some areas were much higher than recommended levels but were far lower in the seagrass meadows (Bittel 2017). There may be many more direct, positive health benefits of exposure to coastal wetlands that have not yet been discovered. This is a field of research with a great deal of potential.

There is also new evidence that suggests that exposure to coastal, river, lake and other freshwater ecosystems (termed



“blue” space) as well as greenspace, has important mental and physical health and well-being benefits for humans (Nichols 2014). This research into the health benefits of water exposure has several descriptors including “BlueHealth” (Grellier et al. 2017), the “Blue Gym” (Depledge and Bird 2009; White et al. 2010, 2016), and simply “blue space”. Water features typically attract a lot of people and promote physical activity such as running or walking along the shore of a lake or along a beach (Volker et al. 2016). In addition, water is an important part of restorative experiences and helps people feel a stronger connection with a place (Volker et al. 2016), ocean views provide people with greater peace of mind (Peng et al. 2016), and those who live nearer the coast tend to be healthier (Wheeler et al. 2012), all of which suggest that there are many health benefits of coastal environments, including benefits for psychological well-being. However, more research on the mechanisms by which water exposure has these beneficial health outcomes is greatly needed, as well as more consistent ways to measure the long-term health benefits of “blue” contacts (Gascon et al. 2015). Despite the limitations in data, however, several studies provide evidence for measurable health benefits, particularly for mental health, of water exposure including coastal environments.

### Potential to Leverage Health Benefits of Wetlands in Disaster Planning, Response, and Recovery

Disasters affecting coastal areas typically include major storms, such as hurricanes, extreme precipitation events that result in wide-spread flooding, droughts, post-earthquake tsunamis, as well as man-made or exacerbated technological and natural disasters such as the 2010 Deepwater Horizon oil spill in the Gulf of Mexico and recent wildfires in California. These events are very damaging to coastal communities and can have long-term impacts on communities, economies and human health and well-being, including mental and physical health and stress levels (IOM (Institute of Medicine) 2007; Palinkas 2012; Leaning and Guha-Sapir 2013; Adkins 2015; Shultz et al. 2015; Laffon et al. 2016; Sandifer et al. 2017). During 2017 alone, the US experienced 16 separate weather and climate-associated disasters, including hurricanes, severe storms, a freeze, drought, and wildfires, each of which caused damages in excess of \$1 billion with a total cost of over \$300B, the highest annual total on record (NOAA 2017). Better means of preparing for, coping with, and recovering from such traumatic but all too frequently occurring “extreme events” is a significant need here and elsewhere around the world.

One approach to improve the protection and resiliency of coastal communities is use of natural or “green” infrastructure or combinations of natural and built (“green” + “gray”) infrastructure (Sutton-Grier et al. 2015, 2018). In this regard, there

is growing scientific evidence that wetlands and other coastal ecosystems can play significant roles in storm, flood and erosion risk reduction for coastal communities (Tanaka et al. 2007; Gedan et al. 2011; Shepard et al. 2011; Arkema et al. 2013; Bouma et al. 2014; Ferrario et al. 2014; Möller et al. 2014; Narayan et al. 2016) and conservation of biodiversity (Scholte et al. 2016). Coastal ecosystems, particularly mangroves, salt marsh and coral reefs, help reduce wave heights, capture water and sediment, and assist in shoreline stabilization, reducing the level of flooding and damages, thereby delivering important protection for vulnerable coastal communities (Sutton-Grier et al. 2015 and references therein). These risk reduction benefits have substantial economic value for coastal communities. For example, Narayan et al. (2017) determined that coastal wetlands avoided \$625 million in direct flood damages during Hurricane Sandy.

Perhaps of equal importance is a role that wetlands and other natural coastal ecosystems may play in providing direct mental and physical health benefits to those impacted by disasters. People are often stressed for weeks to months or longer post-disaster because their livelihoods have been upended and they are concerned about how disasters will impact their families, neighborhoods, incomes, and future economic prospects (e.g., see Sandifer et al. 2017 and references therein). Although, to our knowledge, there has been relatively little research into the potentially significant roles that green and blue space can play in disaster recovery, there is evidence to suggest that contact with nature might be an effective way to reduce health problems, including stress, post-disaster. For example, exposure to natural and biodiverse areas reduces both mental and physical stress symptoms, supports attention restoration, and improves cognition (Sandifer et al. 2015). Thus, it may be possible to help alleviate mental and physical stress after a disaster by providing opportunities for at-risk individuals to experience increased exposure to healthy natural and biodiverse environments, including saltmarshes and other wetlands (e.g., Poulsen et al. 2015; Wessel 2017; Zarr et al. 2017 and the National Park Service’s Park Rx program [[www.Parkrx.org](http://www.Parkrx.org)] about prescriptions for nature contact). Coastal and other environments that provide opportunities for wildlife viewing have been identified as having some health promoting effects (de Bell et al. 2017; White et al. 2017), especially where “charismatic” fauna such as birds, butterflies, and flowering plants (e.g., Fuller et al. 2007; McGinlay et al. 2017; White et al. 2017) can be viewed. Also, a variety of nature-assisted therapies have been and are being tried to treat post-traumatic stress disorders and other stress-related mental illness (e.g., Poulsen et al. 2015; Pálsdóttir et al. 2018). Salt marshes, mangroves, and freshwater wetlands can provide wonderful and peaceful opportunities for restoration and reflection and also regular opportunities for encounters with birds and other interesting wildlife.

To be clear, we are not suggesting that disaster managers, and in particular first responders, should change their focus from providing immediate help and care for people who are struggling to find safety, food, shelter, and medical care. But for longer-term recovery from major storms or oil spills, which often takes months to years, it could be useful for disaster response efforts to incorporate access to healthy coastal ecosystems to support mental restoration and reduce anxiety and stress among disaster victims. And in the pre-disaster planning phase, it would be useful to consider the roles that healthy coastal wetlands and other ecosystems play in promoting community resilience and human health. These benefits are often overlooked or given little attention in disaster planning and response. We hope that this Commentary will reach a broad audience, including experts in disaster response as well as scientists, so that more people will consider the multiple benefits coastal wetlands provide and routinely incorporate them in efforts to increase coastal community resilience.

One way that coastal communities might include wetlands and other coastal ecosystems in resilience and disaster planning activities could be via appending a “nature-based solutions” section to emergency preparedness plans. Such an addendum could encompass contributions coastal wetlands and their functions can make to disaster preparation, response, and recovery including but not limited to: (1) storm protection, wave attenuation, and sediment control; (2) trapping, filtration, and sequestration for carbon, nutrients, a variety of pollutants, and infectious disease-causing microorganisms); (3) water capture, management, supply, flow and flood control; and (4) trauma recovery and alleviation of stress and anxiety for people affected by a specific disaster. Incorporating coastal wetland functions broadly into coastal planning could occur at the national and state levels but might be most effective at county and municipal levels where both disaster impacts and response effects are greatest.

The roles of natural and restored wetlands in support of human health and well-being could also be incorporated into ongoing coastal resilience and restoration activities of the US Army Corps of Engineers (USACE). USACE does a substantial amount of wetland restoration work and is starting to include more natural and nature-based (NNBF) features in their coastal resilience projects (Bridges et al. 2015). In addition, USACE is leading an effort to develop additional guidance for when and how to use NNBF features; this guidance includes the ecosystem services provided by NNBF and we suggest it should include a discussion of health benefits as well.

Another important reason for highlighting the myriad roles of natural and restored coastal wetlands to protection of human life and property in emergency plans and by emergency management officials is that such inclusion

would likely increase the visibility of these wetland functions among the public, with consequent increases in public support for conservation and restoration of wetlands and their biodiversity. Raising awareness could lead to additional partners helping to fund and support coastal protection and restoration projects for coastal resilience.

## Conclusions

There is potential to improve the resilience of coastal communities to major disasters by incorporating into disaster planning and response efforts more natural landscapes and protecting, restoring, and creating green and blue spaces. It should go without saying that this investment in natural infrastructure should be in conjunction with building and maintaining other critical infrastructure such as roads and bridges. Since the funding for natural infrastructure projects such as wetland restoration often comes from different sources than the funding for other critical infrastructure, these do not have to be in competition but instead could work together to increase the resilience of coastal communities and ecosystems. Using this approach, coastal communities can both reduce the impacts of disasters and help people recover from the stress and some other health impacts associated with catastrophes.

It is also important to note that, despite a significant accumulation of evidence on disaster reduction and health benefits of green, blue and biodiverse spaces, there are still many more questions remaining for which we need additional research and evidence-based answers. This makes it challenging to help communities and cities incorporate more green and blue spaces into their design and growth because we do not know yet exactly which characteristics of green and blue spaces elicit human health benefits (Flies et al. 2017). Some of these research needs we have highlighted already (Sandifer et al. 2015), and there have also been other efforts to specify research priorities (Flies et al. 2017; Frumkin et al. 2017). Frumkin et al. (2017) laid out seven domains of nature-health research that need further attention, including better understanding of the psychological and physiological mechanisms by which nature improves human health, determining how best to measure “nature contact” and doses, identifying which elements of nature exposure matter, and incorporating roles of human diversity and equity issues with regard to access to nature. We agree with their recommendations and suggest that in addition, these research domains should be expanded to include blue spaces, particularly coastal environments and their wetlands. Further, publicizing their importance for human health promotion and disaster impact reduction could help generate strong, additional public support for biodiversity and wetland conservation and restoration activities. Based on observations here,

our previous research, and the comprehensive lists in Frumkin et al. (2017), some of the research questions or topics we think are most important to tackle include:

1. How do coastal wetlands and their biodiversity support ecosystem services that promote human health and well-being and what are the mechanisms by which this health enhancement occurs?
2. Do greenspace prescriptions provide quantifiable health benefits for people, especially children?
3. How does biodiversity produce psychological and physiological human health benefits? What physiological and psychological mechanisms are involved and how do they operate to produce positive health effects?
4. Is it feasible to use biodiversity metrics as proxies to identify and quantify certain health effects of nature exposure?
5. Can we measure the potential immunomodulatory effects of differing levels and kinds of environmental microbiota, in particular those associated with wetlands?
6. What characteristics of “blue spaces” (water) are associated with health benefits and how might these benefits occur? How may biodiversity of coastal and freshwater wetlands support the production and delivery of health benefits? What roles may charismatic and easily observable marine fauna such as marine mammals, sea turtles, sea birds, seals, sea lions, etc. play? Can underwater biodiversity that generally cannot be observed except in aquaria or clear tropical waters also have an effect?
7. Do salt marsh and mangrove forests provide similar levels of infectious disease risk reduction as those observed in seagrass? Does the effect hold for a range of infectious diseases or is it limited? Does it also hold for other diseases such as asthma, allergies, and other inflammatory-based disorders? Could we use wetland mesocosms to explore some of these questions?
8. Can we quantify disaster effects and costs averted by green and gray + green infrastructure, including how nature exposure can serve to alleviate negative health effects associated with stress?
9. Can we better test hypotheses that nature and biodiversity exposure, including contact with wetlands, can alleviate stress, reduce post-traumatic stress symptoms, increase physical activity, and otherwise improve health?
10. How can we integrate and quantify disaster reduction roles of natural coastal infrastructure in policy and emergency preparedness, response and recovery plans?

As our knowledge of the nature and human health relationship improves, there are numerous promising avenues for how this information can be used to improve ecosystem conservation *and* human health. Possibilities include: (1) how we can better design cities to ensure that people come into contact

with more natural areas daily; (2) how we can plan and reconfigure developed coastal areas to better capitalize on the natural storm impact reduction characteristics of coastal wetlands and other ecosystems while simultaneously leveraging those ecosystems to provide people with restorative experiences to help reduce anxiety, depression, and assist them in recovering from disasters more quickly; and (3) how we can design and conduct ecosystem restoration and protection projects in ways that best conserve biodiversity and provide a diversity of recreational nature exposure experiences for people. Focusing on research to answer some of the most pressing questions, such as those noted above, will equip scientists, urban planners, and policy makers with critical information to enable society to build more sustainable and resilient cities and communities and maintain and protect healthy ecosystems.

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## References

- Adkins, J. 2015. The Gulf coast economy: ten years after hurricanes Katrina and Rita., Digital Coast GeoZone: Tech Talk for the Digital Coast., NOAA, <https://geozoneblog.wordpress.com/2015/08/24/katrina-10yr-econ/>
- Arkema KK, Guannel G, Verutes G, Wood SA, Guerry A, Ruckelshaus M, Kareiva P, Lacayo M, Silver JM (2013) Coastal habitats shield people and property from sea-level rise and storms. *Nature Climate Change* 3:913–918
- Barton J, Pretty J (2010) What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environmental Science & Technology* 44:3947–3955
- Bauman A, Smith B, Stoker L, Bellew B, Booth M (1999) Geographical influences upon physical activity participation: evidence of a 'coastal effect'. *Australian and New Zealand Journal of Public Health* 23:322–324
- Bittel, J. 2017. Ocean meadows scrub seawater of harmful bacteria. *Nature News*. <http://www.nature.com/news/ocean-meadows-scrub-seawater-of-harmful-bacteria-1.21504>
- Bouma TJ, van Belzen J, Balke T, Zhu ZC, Airoidi L, Blight AJ, Davies AJ, Galvan C, Hawkins SJ, Hoggart SPG, Lara JL, Losada IJ, Maza M, Ondiviela B, Skov MW, Strain EM, Thompson RC, Yang SL, Zanuttigh B, Zhang LQ, Herman PMJ (2014) Identifying knowledge gaps hampering application of intertidal habitats in coastal protection: opportunities & steps to take. *Coastal Engineering* 87:147–157
- Bridges TS, Wagner PW, Burks-Copes KA, Bates ME, Collier ZA, Fischenich CJ, Gailani JZ, Leuck LD, Piercy CD, Rosati JD, Russo EJ, Shafer DJ, Suedel BC, Emily EA, Vuxton A, Wamsley

- TV (2015) Use of natural and nature-based features (NNBF) for coastal resilience. Engineer Research and Development Center. U.S. Army Engineer Research and Development Center, US Army Corps of Engineers, Washington, DC
- Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK (2014) Changes in the global value of ecosystem services. *Global Environmental Change-Human and Policy Dimensions* 26:152–158
- Cox DTC, Shanahan DF, Hudson HL, Plummer KE, Siriwardena GM, Fuller RA, Anderson K, Hancock S, Gaston KJ (2017) Doses of neighborhood nature: the benefits for mental health of living with nature. *Bioscience* 67:147–155
- de Bell S, Graham H, Jarvis S, White P (2017) The importance of nature in mediating social and psychological benefits associated with visits to freshwater blue space. *Landscape and Urban Planning* 167:118–127
- de Jesus Crespo, R., P. Mendez Lazaro and S. H. Yee. 2018. Linking wetland ecosystem services to vector-borne disease: dengue fever in the San Juan Bay estuary, Puerto Rico. *Wetlands*
- Debarry J, Gam H, Hanuszkiewicz A, Dickgreber N, Blumer N, von Mutius E, Bufe A, Gatermann S, Renz H, Holst O, Heine H (2007) *Acinetobacter lwoffii* and *Lactococcus lactis* strains isolated from farm cowsheds possess strong allergy-protective properties. *The Journal of Allergy and Clinical Immunology* 119:1514–1521
- Delegates of The World Conference on Marine Biodiversity. 2008. The Valencia declaration – a Plea for the protection of marine biodiversity. The world conference on marine biodiversity. Valencia, Spain
- Depledge MH, Bird WJ (2009) The blue gym: health and wellbeing from our coasts. *Marine Pollution Bulletin* 58:947–948
- Diaz S, Fargione J, Chapin FS III, Tilman D (2006) Biodiversity loss threatens human well-being. *Plos Biology* 4:1300–1305
- Ege MJ, Mayer M, Normand A-C, Genuneit J, Cookson WOCM, Braun-Fahrlander C, Heederik D, Piarroux R, von Mutius E, G. T. S. Grp (2011) Exposure to environmental microorganisms and childhood asthma. *New England Journal of Medicine* 364:701–709
- Ferrario, F., M. W. MBeck, C. D. Storlazzi, M. Fiorenza, C. C. Shepard and L. Airoidi. 2014. The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications*
- Flies EJ, Skelly C, Negi SS, Prabhakaran P, Liu QY, Liu KK, Goldizen FC, Lease C, Weinstein P (2017) Biodiverse green spaces: a prescription for global urban health. *Frontiers in Ecology and the Environment* 15:510–516
- Frumkin H, Bratman GN, Breslow SJ, Cochran B, Kahn PH, Lawler JJ, Levin PS, Tandon PS, Varanasi U, Wolf KL, Wood SA (2017) Nature contact and human health: a research agenda. *Environmental Health Perspectives* 125:075001
- Fuller RA, Irvine KN, Devine-Wright P, Warren PH, Gaston KJ (2007) Psychological benefits of greenspace increase with biodiversity. *Biology Letters* 3:390–394
- Gascon M, Triguero-Mas M, Martinez D, Dadvand P, Fornis J, Plasencia A, Nieuwenhuijsen MJ (2015) Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. *International Journal of Environmental Research and Public Health* 12:4354–4379
- Gedan KB, Kirwan ML, Wolanski E, Barbier EB, Silliman BR (2011) The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. *Climatic Change* 106:7–29
- Grellier J, White MP, Albin M, Bell S, Elliott LR, Gascon M, Gualdi S, Mancini L, Nieuwenhuijsen MJ, Sarigiannis DA, van den Bosch M, Wolf T, Wuijts S, Fleming LE (2017) BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces. *BMJ Open* 7:e016188
- Haubenhofers DK, Elings M, Hassink J, Hine RE (2010) The development of greencare in western European countries. *Explore* 6:106–111
- IOM (Institute of Medicine). 2007. Environmental public health effects of disasters: hurricane Katrina workshop summary. p. 101 p. In L. Goldman and C. Coussens (rappoteurs) (eds.), Institute of Medicine Roundtable on Environmental Health Sciences, Research, and Medicine. The National Academies Press, Washington, D.C.
- Jiang B, Chang CY, Sullivan WC (2014) A dose of nature: tree cover, stress reduction, and gender differences. *Landscape and Urban Planning* 132:26–36
- Jiang B, Li DY, Larsen L, Sullivan WC (2016) A dose-response curve describing the relationship between urban tree cover density and self-reported stress recovery. *Environment and Behavior* 48:607–629
- Kaplan S (1995) The restorative benefits of nature-toward an integrative framework. *Journal of Environmental Psychology* 15:169–182
- Laffon B, Pasaro E, Valdiglesias V (2016) Effects of exposure to oil spills on human health: updated review. *Journal of Toxicology and Environmental Health-Part B-Critical Reviews* 19:105–128
- Lamb JB, van de Water J, Bourne DG, Altier C, Hein MY, Fiorenza EA, Abu N, Jompa J, Harvell CD (2017) Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. *Science* 355:731–733
- Lasher C, Dyszynski G, Everett K, Edmonds J, Ye WY, Sheldon W, Wang SY, Joye SB, Moran MA, Whitman WB (2009) The diverse bacterial community in Intertidal, anaerobic sediments at Sapelo Island, Georgia. *Microbial Ecology* 58:244–261
- Leaning J, Guha-Sapir D (2013) Natural disasters, armed conflict, and public health. *New England Journal of Medicine* 369:1836–1842
- Liddicoat C, Bi P, Waycott M, Glover J, Lowe AJ, Weinstein P (2018) Landscape biodiversity correlates with respiratory health in Australia. *Journal of Environmental Management* 206:113–122
- Lynch SV, Wood RA, Boushey H, Bacharier LB, Bloomberg GR, Kattan M, O'Connor GT, Sandel MT, Calatroni A, Matsui E, Johnson CC, Lynn H, Visness CM, Jaffee KF, Gergen PJ, Gold DR, Wright RJ, Fujimura K, Rauch M, Busse WW, Gern JE (2014) Effects of early-life exposure to allergens and bacteria on recurrent wheeze and atopy in urban children. *Journal of Allergy and Clinical Immunology* 134:593–601.e12
- McGinlay J, Parsons DJ, Morris J, Hubatova M, Graves A, Bradbury RB, Bullock JM (2017) Do charismatic species groups generate more cultural ecosystem service benefits? *Ecosystem Services* 27:15–24
- MEA. 2005. Millennium ecosystem assessment. Synthesis report. Island Press [www.millenniumassessment.org](http://www.millenniumassessment.org), Washington, D.C.
- Mitsch WJ, Bernal B, Hernandez ME (2015) Ecosystem services of wetlands. *International Journal of Biodiversity Science, Ecosystem Services & Management* 11:1–4
- Möller I, Kudella M, Rupprecht F, Spencer T, Paul M, van Wesenbeeck B k, Wolters G, Jensen K, Bouma TJ, Miranda-Lange M, Schimmels S (2014) Wave attenuation over coastal salt marshes under storm surge conditions. *Nature Geoscience* 7:727–731
- Narayan S, Beck MW, Reguero BG, Losada IJ, van Wesenbeeck B, Pontee N, Sanchirico JN, Ingram JC, Lange GM, Burks-Copes KA (2016) The effectiveness, costs and coastal protection benefits of natural and nature-based Defences. *PLoS One* 11:e0154735
- Narayan S, Beck MW, Wilson P, Thomas CJ, Guerrero A, Shepard CC, Reguero BG, Franco G, Ingram JC, Trespalacios D (2017) The value of coastal wetlands for flood damage reduction in the north-eastern USA. *Scientific Reports* 7:9463
- Nichols, W. J. 2014. Blue mind: the surprising science that shows how being near, in, on, or under water can make you happier, healthier, more connected, and better at what you do. Little, Brown and Company New York
- NOAA. 2017. Billion dollar weather and climate disasters: an overview. NOAA. National Centers for Environmental Information
- Ostfeld RS, Keesing F (2017) Is biodiversity bad for your health? *Ecosphere* 8:e01676



- Palinkas LA (2012) A conceptual framework for understanding the mental health impacts of oil spills: lessons from the Exxon Valdez oil spill. *Psychiatry-Interpersonal and Biological Processes* 75:203–222
- Pálsdóttir AM, Stigsdóttir UK, Persson D, Thorpert P, Grahna P (2018) The qualities of natural environments that support the rehabilitation process of individuals with stress-related mental disorder in nature-based rehabilitation. *Urban Forestry & Urban Greening* 29:312–321
- Palumbi SR, Sandifer PA, Allan JD, Beck MW, Fautin DG, Fogarty MJ, Halpern BS, Incze LS, Leong JA, Norse E, Stachowicz JJ, Wall DH (2009) Managing for ocean biodiversity to sustain marine ecosystem services. *Frontiers in Ecology and the Environment* 7:204–211
- Peng C, Yamashita K, Kobayashi E (2016) Effects of the coastal environment on well-being. *Journal of Coastal Zone Management* 19:1000421
- Poulsen DV, Stigsdóttir UK, Refshage AD (2015) Whatever happened to the soldiers? Nature-assisted therapies for veterans diagnosed with post-traumatic stress disorder: a literature review. *Urban Forestry & Urban Greening* 14:438–445
- Ricketts TH, Watson KB, Koh I, Ellis AM, Nicholson CC, Posner S, Richardson LL, Sonter LJ (2016) Disaggregating the evidence linking biodiversity and ecosystem services. *Nature Communications* 7
- Rodrigues JC, Conides AJ, Rodriguez SR, Raicevich S, Pita P, Kleisner KM, Pita C, Lopes PFM, Roldan VA, Ramos SS, Klaoudatos D, Outeiro L, Armstrong C, Teneva L, Stefanski S, Bohnke-Henrichs A, Kruse M, Lillebo AL, Bennett EM, Belgrano A, Murillas A, Pinto IS, Burkhard S, Villasante S (2017) Marine and coastal cultural ecosystem services: knowledge gaps and research priorities. *One Ecosystem* 2:e12290
- Ruokolainen L, von Hertzen L, Fyhrquist N, Laatikainen T, Lehtomaki J, Auvinen P, Karvonen AM, Hyvarinen A, Tillmann V, Niemela O, Knip M, Haahtela T, Pekkanen J, Hanski I (2015) Green areas around homes reduce atopic sensitization in children. *Allergy* 70:195–202
- Ruokolainen L, Fyhrquist N, Haahtela T (2017a) The rich and the poor: environmental biodiversity protecting from allergy. *Current Opinion in Allergy and Clinical Immunology* 16:421–426
- Ruokolainen L, Lehtimaki J, Karkman A, Haahtela T, von Hertzen L, Fyhrquist N (2017b) Holistic view on health: two protective layers of biodiversity. *Annales Zoologici Fennici* 54:39–49
- Ruokolainen L, Paalanen L, Karkman A, Laatikainen T, von Hertzen L, Vlasoff T, Markelova O, Masyuk V, Auvinen P, Paulin L, Alenius H, Fyhrquist N, Hanski I, Makela MJ, Zilber E, Jousilahti P, Vartiainen E, Haahtela T (2017c) Significant disparities in allergy prevalence and microbiota between the young people in Finnish and Russian Karelia. *Clinical and Experimental Allergy* 47:665–674
- Sandifer PA, Sutton-Grier AE (2014) Connecting stressors, ocean ecosystem services, and human health. *Natural Resources Forum* 38:157–167
- Sandifer PA, Sutton-Grier AE, Ward BP (2015) Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: opportunities to enhance health and biodiversity conservation. *Ecosystem Services* 12:1–15
- Sandifer P, Knapp L, Collier T, Jones A, Juster R, Kelble C, Kwok R, Miglaresse J, Palinkas L, Porter D, Scott G, Smith L, Sullivan W, Sutton-Grier A (2017) A conceptual model to assess stress-associated health effects of multiple ecosystem services degraded by disaster events in the Gulf of Mexico and elsewhere. *GeoHealth* 1:1–20
- Scholte SSK, Todorova M, van Teeffelen AJA, Verburg PH (2016) Public support for wetland restoration: what is the link with ecosystem service values? *Wetlands* 36:467–481
- Shepard CC, Crain CM, Beck MW (2011) The protective role of coastal marshes: a systematic review and meta-analysis. *PLoS One* 6:e27374
- Shultz JM, Walsh L, Garfin DR, Wilson FE, Neria Y (2015) The 2010 Deepwater horizon oil spill: the trauma signature of an ecological disaster. *Journal of Behavioral Health Services & Research* 42:58–76
- Skaff NK, Cheruvilil KS (2016) Fine-scale wetland features mediate vector and climate-dependent macroscale patterns in human West Nile virus incidence. *Landscape Ecology* 31:1615–1628
- Sutton-Grier AE, Wowk K, Bamford H (2015) Future of our coasts: the potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environmental Science & Policy* 51:137–148
- Sutton-Grier AE, Gittman RK, Arkema KK, Bennett RO, Benoit J, Blich S, Burks-Copes KA, Colden A, Dausman A, DeAngelis BM, Hughes AR, Scyphers SB, Grabowski JH (2018) Investing in natural and nature-based infrastructure: building better along our coasts. *Sustainability* 10
- Tanaka N, Sasaki Y, Mowjood MIM, Jinadasa KBSN, Homchuen S (2007) Coastal vegetation structures and their functions in tsunami protection: experience of the recent Indian Ocean tsunami. *Landscape Ecological Engineering* 3:33–45
- Ulrich RS, Simons RF, Losito BD, Florito E, Miles MA, Zelson M (1991) Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology* 11:201–230
- Van den Berg AE (2017) From greenspace to green prescriptions: challenges and opportunities for research and practice. *Frontiers in Psychology* 8. <https://doi.org/10.3389/fpsyg.2017.00268>
- Volker S, Matros J, Classen T (2016) Determining urban open spaces for health-related appropriations: a qualitative analysis on the significance of blue space. *Environmental Earth Sciences* 75
- Wessel LA (2017) Shifting gears: engaging nurse practitioners in prescribing time outdoors. *Jnp-Journal for Nurse Practitioners* 13:89–96
- Wheeler BW, White M, Stahl-Timmins W, Depledge MH (2012) Does living by the coast improve health and wellbeing? *Health Place* 18:1198–1201
- White M, Smith A, Humphries K, Pahl S, Snelling D, Depledge M (2010) Blue space: the importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *Journal of Environmental Psychology* 30:482–493
- White MP, Pahl S, Wheeler BW, Fleming LEF, Depledge MH (2016) The 'Blue Gym': what can blue space do for you and what can you do for blue space? *Journal of the Marine Biological Association of the United Kingdom* 96:5–12
- White MP, Weeks A, Hooper T, Bleakley L, Cracknell D, Lovell R, Jefferson RL (2017) Marine wildlife as an important component of coastal visits: the role of perceived biodiversity and species behaviour. *Marine Policy* 78:80–89
- Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. *Science* 314:787–790
- Young HS, Dirzo R, Helgen KM, McCauley DJ, Billeter SA, Kosoy MY, Osikowicz LM, Salkeld DJ, Young TP, Dittmar K (2014) Declines in large wildlife increase landscape-level prevalence of rodent-borne disease in Africa. *Proceedings of the National Academy of Sciences of the United States of America* 111:7036–7041
- Zarr R, Cottrell L, Merrill C (2017) Park Prescription (DC Park Rx): A New Strategy to Combat Chronic Disease in Children. *Journal of Physical Activity & Health* 14:1–2