Battling a Common Enemy: Joining Forces in the Fight against Sewage Pollution

STEPHANIE L. WEAR

The health of both coral reefs and people are imperiled by a local threat that is widespread across the globe—sewage and the typical components it carries (e.g., nutrients, sediments, heavy metals, endocrine disruptors, pathogens, and pharmaceuticals). Despite this common threat, those concerned with human health and those concerned with coral reef health have rarely joined forces. To jump-start an alliance between coral conservation and human health sectors, this article documents the threats that humans and reefs face and identifies threat-abatement strategies that will benefit both people and reefs, highlighting the mitigation of water pollution as a prime example. By joining forces, marine conservationists and human health practitioners can increase the amount and efficiency of both intellectual and financial resources they bring to bear against sewage.

Keywords: coral reefs, human health, sewage pollution, sanitation, water quality

Historically, conservation and health sectors have rarely joined forces (Fleming et al. 2006). The irony of this is that in many cases these two sectors are fighting a common threat, for example, poor water quality. For near-shore coastal ecosystems, the disconnect between health and conservation efforts is especially apparent in coral reefs (Wear and Vega Thurber 2015). In this article, I argue for establishment of a cross-sector, collaborative approach, by highlighting that there are many links between coral health and human health.

To map the threat space for coral reefs and human health (figure 1), I surveyed the literature using a Web of Science search (see figure 1 caption for search details); Reefs at Risk Revisited (Burke et al. 2011), a comprehensive summary of threats facing coral reefs; and the Global Burden of Disease database (Institute of Health Metrics and Evaluation 2016). The results of this survey uncovered significant overlap among multiple threats that affect both humans and coral reefs, as well as distinct threats that are unique to either reefs or to humans (figure 1). For those threats held in common, six out of nine are related to water quality (e.g., lack of sanitation, agricultural pollution, runoff from coastal development), whereas the remaining three deal with overfishing and greenhouse gas emissions. In almost every case of threat overlap, conservation and human health sectors are already independently addressing these threats. This raises the possibility that by joining forces, positive outcomes could grow for both corals and people.

Dirty water sickens corals and people

Poor water quality is a prime example of a threat that both corals and humans face (Fewtrell and Bartram 2001, Vega Thurber et al. 2014), and poor water quality in tropical coastal regions is driven largely by sewage pollution (Fewtrell and Bartram 2001, Burke et al. 2011, Vega Thurber et al. 2014, Wear and Vega Thurber 2015). Historically, common attributes of poor water quality for coral conservation included high nutrient loads, high turbidity, and high sedimentation rates (Wear and Vega Thurber 2015). More recently, the list of components of poor water quality for corals has been expanded to include pathogens, endocrine disruptors, pharmaceuticals, and heavy metals (Wear and Vega Thurber 2015). Importantly, all of these components are commonly found in sewage outflows (Wear and Vega Thurber 2015). In comparison, common attributes of poor water quality for human health included high toxin and pathogen loads, both of which are characteristic of sewage (Sindermann 2005, Fleming et al. 2006). In both sectors, there has been considerable focus on defining thresholds for both poor and good water quality on the basis of research looking at relationships between water quality and coral or human health (Sindermann 2005, Fleming et al. 2006, Wear and Vega Thurber 2015).

doi:10.1093/biosci/biz025 Advance Access publication 22 April 2019

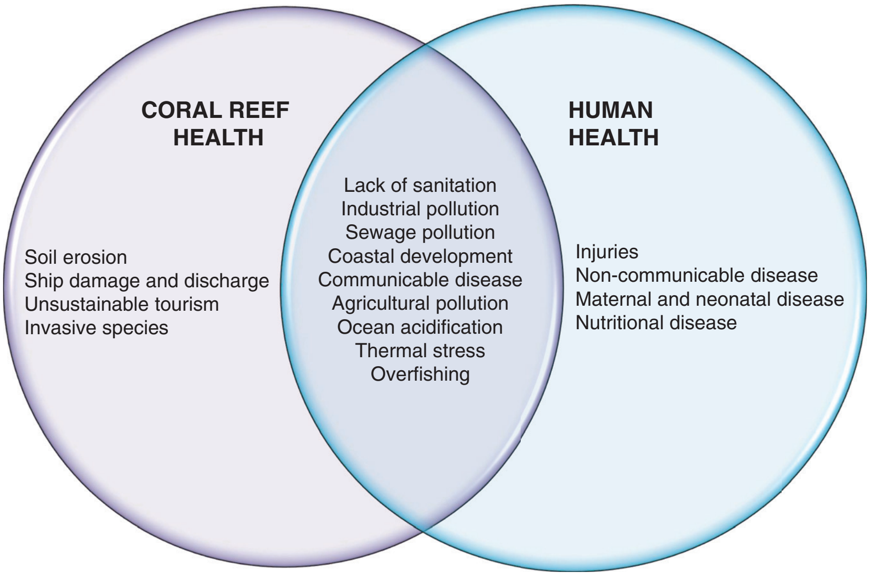

Figure 1. To assess the evidence of a common threat for coral reefs and human health, I surveyed the literature using a Web of Science search, with the following search terms: **TOPIC: "coral reef*" AND TOPIC: threat* OR stress* OR degrad* and TOPIC: "human health" OR "public health" OR "community health" AND TOPIC: threat* OR disease* OR ill* OR sick* OR mort* AND TOPIC: coast* OR tropic*.** ***To supplement this review, I used the GBD Compare Data Visualization tool from IHME (2016) to identify common threats to human health and Reefs at Risk Revisited (Burke et al. 2011) to identify common threats to coral reef health. This diagram illustrates the overlap between nine common and significant threats to both coral reefs and people.***

For coral reefs, numerous ecological studies have demonstrated a clear link between decreasing water quality and declining ecosystem health. Field researchers have observed that increased coral death occurs with high levels of sedimentation and turbidity following watershed development (Fabricius 2005). Experimental manipulations have also shown that fungal and bacterial disease in corals increase with increasing levels of nutrients in the water column (Bruno et al. 2003, Shaver et al. 2017). More recent studies have demonstrated that excess nutrients from land-derived pollution have negative impacts on reefs, causing increases in both disease and bleaching in Caribbean corals (Vega Thurber et al. 2014, Shaver et al. 2017).

The examples of how poor water quality driven by sewage pollution leads to decreased human health are diverse and widespread. Sewage contaminated water, for instance, can lead to increased incidence of diseases such as cholera and hepatitis A and E in human populations (World Health Organization 2001, Sindermann 2005, Fleming et al. 2006). Likewise, over 180 million cases of upper respiratory disease and gastroenteritis occur each year due to humans bathing in polluted ocean waters (Shuval 2003). Studies have shown that the incidence of these diseases among bathers increases with increasing levels of human sewage in coastal waters (Prüss 1998). Summed across the globe, pathogenic microorganisms from wastewater pollution into the sea cause an estimated $16.4 billion (in 2018 US dollars) in economic losses annually because of their direct impacts on humans alone (Shuval 2003).

Because freshwater flows near the coast and coastal waterways typically drain into the ocean, the same nutrients and pollutants causing problems in drinking water can cause problems for the ocean and coral reefs. Indeed, recent evidence has emerged showing increased overlap in the list of attributes that coral conservation and human health sectors use to define poor water quality. For instance, a direct link has been established between the human pathogen (*Serratia marcescens*) and white pox disease in Caribbean corals (Sutherland et al. 2011). This bacterium comes from sewage that is being directly discharged into the ocean, either intentionally, or because of faulty sewage management systems (Sutherland et al. 2011). Likewise, a recent literature review that was focused on coral reefs and sewage pollution revealed corals are not only susceptible to excess nutrients and pathogens in sewage, but also to the diverse cocktail of toxins it contains, including heavy metals, pharmaceuticals, and endocrine disruptors (Wear and Vega Thurber 2015).

In the human health sector, there has been increasing focus on how excess nutrients from untreated or poorly treated wastewater can lead to low water quality for humans. This is especially true for nitrates that find their way into drinking water, which can cause methemoglobinemia, an illness found especially in infants (Greer and Shannon 2005). Given that the health of humans and coral reefs is commonly threatened by the same components of poor water quality (pathogens, nutrients, endocrine disruptors, toxins) that are often found in untreated human waste across the globe (figure 2; Wear and Vega Thurber 2015), it is reasonable to believe that greatly enhancing treatment of sewage, before discharge into tropical coastal waterways, would positively affect both humans and coral reefs. Indeed, in a terrestrial analogue, public health and conservation organizations have come together in the Great Lakes region of the United States to address pesticide contamination of water sources that threaten both humans and aquatic insects. By working jointly to reduce pesticide runoff from agricultural systems, this cross-sector collaboration has been successful in decreasing the negative effects of pesticides on both people and nature (Kannan et al. 2006).

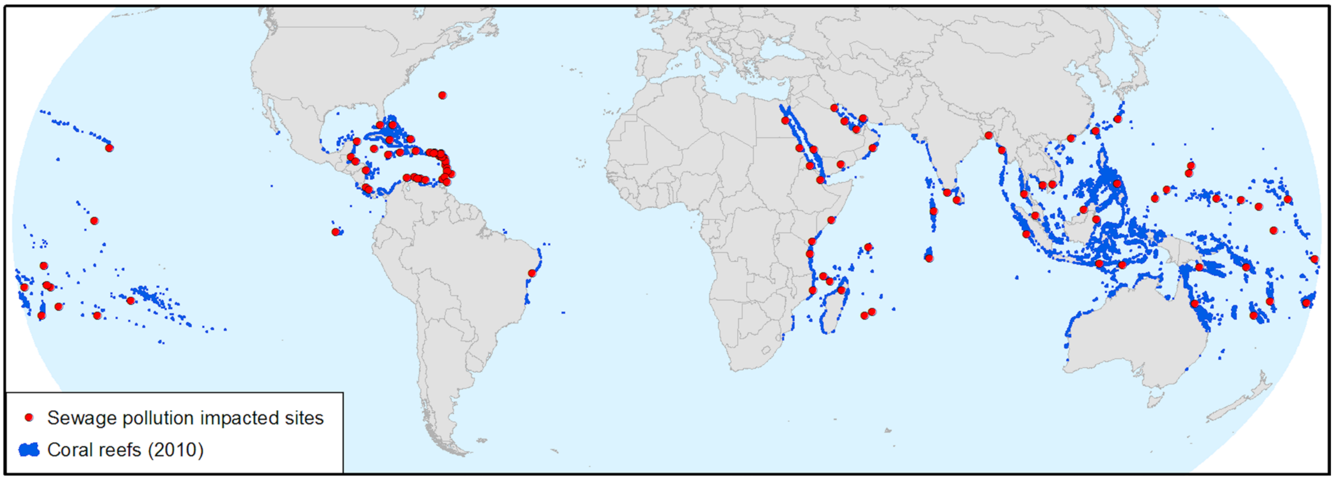

Figure 2. Global coral reef map showing 104 of 112 distinct coral reef geographies listed in the World Atlas of Coral Reefs (including 80 countries, 6 states, and 24 territories) with a documented coastal sewage pollution problem (Wear and Vega Thurber 2015).

Ready to walk the talk

The idea that collaborations among the human health and environmental organizations are critical to successful outcomes for both sectors is not new. Notably, in 2002, the World Health Organization and United Nations Environment Program launched the Health and Environment Links Initiative, which was joined a year later by the Health and Environment Alliance, an initiative of the European Public Health Alliance. In addition, the US Agency for International Development has been funding Population, Health, and Environment projects for a couple of decades, which are intended to integrate conservation and development goals. Although these examples represent far-reaching and substantial investment efforts in cross-sector collaborations, they are still the exception rather than the rule. Given the ever-growing levels of threat and increasing complexity of the problems facing the environment and human populations, it is time to build from these initial collaborative efforts and push forward toward more concrete collaborations and substantive results.

To provide a starting point for expansion of cross-sector collaboration, I examined whether any large organizations that work internationally already list improving both human and ocean or environmental health among their primary goals. To do this, I conducted a web search for large international human health organizations and ocean conservation organizations (including multilateral, government, academic, philanthropic, and nongovernment organizations). By examining more than 100 links, I compiled a list of 62 organizations that were well positioned to address one or both focal areas (table 1). This list is not wholly inclusive but rather meant to be representative of the potential for greater cross sector collaboration. I then went to each of these organizations websites and examined their mission, expertise, objectives, and current projects when available. I found that 32 of these organizations already list human and environmental health as shared goals of their organizations. This analysis reveals that some of the largest and most influential health and conservation organizations are well positioned to engage in cross-sector human–environmental work. We can look to these organizations as a starting point to broaden cross-sector collaboration between human and environmental health, but there are likely hundreds more that could join in a movement toward integration and foster even stronger alliances.

Global health and global conservation organizations could form a powerful alliance

If health and conservation organizations continue to work in our traditional silos, we can expect more of the same: incremental results, occasional successes, and temporary fixes that rarely get to the root of the problem. By working together, the conservation and human health sectors will be more likely to find lasting solutions that do not get undermined by external forces. For example, there is a recent history of well-meaning water charities working to improve access to safe drinking water by digging wells in communities. These wells often end up being only a temporary solution because either local communities fail to maintain them or groundwater levels fall because of depletion by agricultural demands. Indeed, a 2009 International Institute for Environment and Development briefing reported that up to $360 million has been wasted because of the inability to maintain drinking wells once they fall into disrepair, which often happens in just a few years (Skinner 2009).

In many cases, clean water is scarce because of poor environmental stewardship. Long-term solutions should include considerations of watershed protection to help ensure access to safe drinking water. An excellent example of how healthy

Table 1. List of 62 international human health and ocean conservations that are well positioned to address both human and environmental or ocean health.

Organization name	Environment	Health	Combo
5gyres			□
Conservational International			✓
Environmental Defense Fund			✓
Global Coral Reef Alliance			✓
Global Environment Facility			✓
Harvard School of Public Health			✓
Health and Environment Alliance			✓
Healthy Reefs for Healthy People			✓
International Federation Red Cross			✓
National Fish and Wildlife Foundation			✓
National Oceanographic and Atmospheric Administration			✓
One Health Initiative			✓
Oxfam			✓
Pacific Northwest Center for Human Health and Ocean Studies			✓
Paul G. Allen Philanthropies			✓
Rare			✓
Seacology			✓
Seaweb			✓
The Nature Conservancy			✓
The Pew Charitable Trusts			✓
The Water Institute (UNC School of Global Public Health)			✓
UN Refugee Agency			✓
UNICEF			✓
United Nations Environment Programme			✓
US Agency for International Development			✓
US Coral Reef Task Force			✓
US Environmental Protection Agency			✓
Wellcome Trust			✓
WHO Health and Environment Links Initiative			✓
Woods Hole Center for Oceans and Human Health			✓
World Bank			✓
World Resources Institute			✓
Coral Reef Alliance	✓		
Cousteau Society	✓		
Great Barrier Reef Marine Park Authority	✓		
Green Fins	✓		
International Union for Conservation of Nature	✓		
Oceana	✓		
Project AWARE	✓		
Reef Check	✓		
Reef Relief	✓		
SECORE	✓		
Surfrider Foundation	✓		
The Ocean Conservancy	✓		
The Ocean Foundation	✓		
Waitt Foundation	✓		
Wildlife Conservation Society	✓		
World Wildlife Fund	✓		

Table 1. List of 62 international human health and ocean conservations that are well positioned to address both human and environmental or ocean health.

Organization name	Environment	Health	Combo
Bill and Melinda Gates Foundation		✓	
Centers for Disease Control and Prevention		✓	
Global Health Council		✓	
IRC		✓	
PATH		✓	
Project Hope		✓	
Safe Water Network		✓	
Sanitation and Water for All		✓	
Sustainable Sanitation Alliance		✓	
Toilet Board Coalition		✓	
United Nations Habitat Programme		✓	
Water Aid		✓	
Water.org		✓	
World Water Council		✓	

watersheds can provide joint solutions was recently published and highlighted the role seagrasses play in removing bacterial pathogens that harm both humans and marine organisms (Lamb et al. 2017). Bringing together epidemiologists, engineers, economists, and ecologists is likely to result in better-informed—and, arguably, better-designed—solutions to problems facing both people and nature. By pooling resources as well as expertise, a more systematic and efficient approach based on technological or scientific breakthroughs generated from interdisciplinary collaboration could emerge for planning or threat reduction.

To begin to assess possibilities for cross-sector collaboration, I examined each shared threat identified in my literature survey (figure 1), and highlighted examples of commonly employed strategies for each threat that could be used to improve the conditions for both coral and human populations. For every shared threat that involves water pollution in figure 1, I have identified multiple threat-abatement strategies (table 2). Given the overlap in threats, and the possibility of shared strategies, it is evident much could be gained by focusing on interventions that benefit both human health and reef health.

An especially promising opportunity was initiated by the Bill and Melinda Gates Foundation. In 2011, The Bill and Melinda Gates Foundation announced a research and innovation challenge to invent the next generation toilet that does not pollute, removes germs from human waste, recovers valuable resources such as energy, clean water and nutrients, operates without electricity or sewer, and costs less than US$.05 cents per person per day. Once invented and deployed, the goal of this initiative is to increase water quality and reduce disease to those without adequate sanitation. This is no small endeavor—with approximately 2.4 billion people without access to adequate sanitation (World Health Organization 2013), ultimately leading to both socioeconomic and health problems for these populations. The new toilet design features, if achieved, would also have significant environmental benefits. In tropical coastal areas, widespread use of these toilets could dramatically improve water quality for coral reefs and other important ocean habitats, such as seagrasses and mangroves. Remarkably, there is no conservation group poised to use their community networks to assist in the implementation of "clean toilets," even though such a program could have immediate benefits to corals. Ecologists could help identify the best locations for the units to maximize water quality enhancement within a watershed context, and thus improve human health and well-being to a greater degree with the same investment of resources—a common goal that conservation and human health organizations should share.

Another example of synergy stems from the growing use of habitat restoration on coastal shorelines (e.g., forests, salt marshes, seagrasses, or oyster reefs) to increase the services natural communities provide humans, including mitigation of sewage pollution on shallow water ecosystems (e.g., coral reefs). The goals of these environmental projects are to decrease erosion, and increase fisheries production and shoreline protection, but also to enhance water quality via filtering out sewage pollution so that other more sensitive sea life may thrive. The objectives of these conservation projects, if achieved, would also likely decrease public health hazards as well because forests and wetlands filter toxins and pollutants (Myers 1997, Lamb et al. 2017). Conservation organizations possess the technical expertise to restore these ecosystems, and by joining forces and aligning with conservation, human health organizations can begin to tackle high priority human health issues from a more holistic perspective.

Maximizing return on investment

To generate successful collaborations between the conservation or human health sectors, the silos need to come down,

Table 2. Expected strategy outcomes.

Threat	Strategies	Coral Reefs	People
Lack of sanitation	Improve sewage treatment systems, install nonpolluting toilets, maintain septic systems	Decreased algal overgrowth, reduced disease occurrence, reduced coral bleaching	Reduced disease occurrence, positive social impacts (e.g., increased access to education, improved safety for women)
Industrial pollution	Industry regulations developed or enforced, corporate partnerships, technology innovations	Reduction in toxin-related stress to corals and reef associated organisms	Reduction in exposure-related illnesses, improved quality of life, improved socioeconomic status
Sewage pollution	Installation of modern sewage treatment facilities, tertiary treatment systems in place, staffing and maintenance standards implemented, improved onsite toilet systems	Decreased algal overgrowth, reduced disease occurrence, reduced coral bleaching	Reduced disease occurrence, positive impacts on tourism industry (reduced tourist illness, better tourist experience)
Coastal development	Increase coastal habitat buffers, implement best management practices for road building and land clearing, minimizing vegetation loss	Reduction in suffocation related stressors, decreased algal overgrowth, reduced disease occurrence, reduction in habitat loss	Reduction in exposure-related illnesses, stable income from reef related activities (e.g., fishing, tourism)
Communicable disease	Installation of modern sewage treatment systems, install nonpolluting toilets, maintain septic systems, restore coastal wetlands	Reduced disease occurrence, reduced coral bleaching, increase in coral dominance, decreased algal overgrowth	Reduced disease occurrence, positive social impacts (e.g., reduction is lost work, increase in school attendance)
Agricultural pollution	Increase riverine and watershed buffers, farm practices that reduce nutrient input including reductions in harmful fertilizers and pesticides	Decreased algal overgrowth, reduced disease occurrence, reduced coral bleaching, reduction in anoxia stress	Reduced disease occurrence (e.g., red tide related), improvement in fisheries or income

Note: Taken together, this list of strategies and outcomes is extensive but is not meant to be exhaustive. Rather, the list identifies many strategies that, when implemented, could benefit both people and reefs.

and organizations need to come together, in more concrete and expansive ways. What is required are more innovative approaches and disruptive ideas being put into practice, under progressive leadership in these agencies. For example, engaging in joint strategy development, fundraising efforts, and outreach campaigns would be a good start.

There is also the potential for substantial long-term savings by looking to root causes or taking a more holistic approach, which could be facilitated by the increased diversity of expertise and understanding that comes with a more united effort. For example, in 1997 it was estimated that it would take nearly $300 billion (in 1997 US dollars) to meet the entire developing world's needs for water and sanitation over a project period of 10 years (Myers 1997)—yet making a $3 billion investment (just 1% of the project cost) to protect watersheds would be as effective as the alternative option of installing water piping, stand taps, sewer systems, and other complementary infrastructure (Myers 1997). Not only would this be an incredible cost savings, but protecting those watersheds would also have a significant impact on protecting or improving coastal water quality by decreasing pollution and erosion.

The World Health Organization (WHO) states that eliminating environmental hazards to health can prevent up to a quarter of the global burden of disease (Prüss-Ustün et al. 2017). However, a win–win outcome is not easy and requires quantitative planning, modeling, and monitoring to maximize the potential for mutualistic outcomes between conservation and human health (Tallis et al. 2008). Without concerted efforts involving coplanning on the part of environmental and health organizations, opportunities for maximizing returns on investment will be left unfulfilled.

What are the costs of collaboration?

Given the potential additive and synergistic benefits that may result from collaborative efforts, one must question why examples are so rare. Management agencies spend a lot of time and energy developing their mandates and protocols. Without mandates to collaborate and solve problems across sectors, agencies stick to what they know. There is always the potential for unintended costs, and collaborations are complicated—demanding more staff and meeting time than would be the case if each organization were left to work on its own. There will be times when conserving nature has the potential to negatively affect human health (e.g., protecting wetlands that may serve as breeding grounds for mosquitos that spread human disease). In addition, some initial case studies of joint conservation and development projects have drawn pessimistic conclusions (Agrawal and Redford 2006).

However, more recent quantitative meta-analyses revealed that for World Bank projects, there was no cost to including conservation or biodiversity goals in development projects (Kareiva et al. 2008). That is, both conservation and development goals could be achieved with the same effort, without compromising the success of the project, or increasing the cost of the overall project. This would also support efforts toward the United Nations Sustainable Development Goals in which conservation goals are integrated into development planning and implementation. Although this analysis considered development broadly and not human health specifically, its results suggest that there may be ways of fruitfully combining health and conservation efforts without undue costs.

Human benefits beyond immediate health hazards?

In recent years, the case for conservation has evolved from one mostly focused on protecting nature for nature's sake to one that also highlights conserving nature because of the benefits it provides humans (Daily 1997, Kareiva and Marvier 2012). In the context of coral reefs, it is estimated that over half a billion people benefit from services provided by coral reefs: including food, jobs, and space to live (Burke et al. 2011). Besides these indirect links, coral reefs also provide clear, direct health benefits to people, through the myriad of medicines derived from coral reef animals. These include treatments for cancer, Alzheimer's, and HIV. Summed across all provisioned services, coral reefs have been estimated to provide $32.9 billion (in 2018 US dollars) annually in net benefits to people (Cesar et al. 2003).

It is time to act

Despite the magnitude and importance of reef-generated benefits, coral reefs continue to be degraded and disappear. Over the past 40 years, coral reef coverage has dropped steadily in the Caribbean and the Indo-Pacific (Bruno and Selig 2007). As the world population increases by at least 2 billion over the next 30 years, both the human health and nature conservation sectors will face greater and greater challenges achieving their goals. To reverse the decline, coral reef conservationists must devise new strategies to do more with less, and form new partnerships, such as with the human health sector, that increase resource availability and efficiency in generating desired outcomes. Recent research reveals these strategies must also be both local and global in nature. Climate change generates huge threats to coral reefs, and global action is needed to abate this threat, but experimental research has also shown that reducing local stresses (e.g., predation on corals, sewage pollution) through management actions significantly increases coral resistance to warming-induced bleaching (Shaver et al. 2018).

The argument that natural resource managers should combine forces with human health sector, however, does not stop with coral reefs. Diverse ecosystems in aquatic realms are negatively affected by sewage pollution (Mallin et al. 2005). For example, sewage discharge into rivers, streams, lakes, and estuarine waters lowers dissolved oxygen levels, increases sediment toxins, and elevates concentrations of toxic algae (Daniel et al. 2002, Mallin et al. 2005, Mallin et al. 2007). In turn, these stressors can lead to fish and shellfish kills that can endanger essential fisheries (Mallin et al. 2005, Mallin et al. 2007). Aquatic animals such as fish, mussels and insects also show elevated levels of endocrine disruptors when exposed to sewage (Petrovic et al. 2002, Goksøyr 2006). Natural resource, wildlife, and fisheries managers who seek to conserve these ecosystems and wildlife therefore face threats that overlap with the human health sector such as toxins and endocrine disruptors found in water contaminated by sewage. Combining forces with the human health sector should then be a priority.

It is clear that humans have intimate connections with nature: Healthy nature increases human well-being, and humans and nature have many threats in common. Recognizing these links and realizing how common they are is the first step in fostering cross-sector collaboration. If we can find ample evidence to motivate and inspire decision-makers worldwide to initiate alliances between nature conservation and human health organizations, both ecosystem and human health stand to achieve dramatic improvements.

Acknowledgments

This work was funded in full from The Nature Conservancy's NatureNet Science Fellowship to the author. Special thanks to Xavier Basurto, Peter Kareiva, Robert Lalasz, Michelle Marvier, Pete Peterson, Brian Silliman, and two anonymous reviewers for critical reviews and improving the manuscript and Sarah Sunu for assistance with organization reviews.

References cited

Agrawal A, Redford K. 2006. Poverty, Development, and Biodiversity Conservation: Shooting in the Dark? WCS working paper no. 26. Wildlife Conservation Society.

Bruno JF, Selig ER. 2007. Regional decline of coral cover in the Indo-Pacific: Timing, extent, and subregional comparisons. PLOS ONE 2 (art. e711).

Bruno J, Petes L, Harvell C, Hettinger A. 2003. Nutrient enrichment can increase the severity of coral diseases. Ecology Letters 6: 1056–1061.

Burke L, Reytar K, Spalding M, Perry A. 2011. Reefs at Risk Revisited. World Resources Institute.

Cesar H, Burke L, Pet-Soede L. 2003. The Economics of Worldwide Coral Reef Degradation. Cesar Environmental Economics Consulting.

Daily G, ed. 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press.

Daniel MH, Montebelo AA, Bernardes MC, Ometto JPHB, de Camargo PB, Krusche AV, Ballester MV, Victoria RL, Martinelli LA. 2002. Effects of urban sewage on dissolved oxygen, dissolved inorganic and organic carbon, and electrical conductivity of small streams along a gradient of urbanization in the Piracicaba river basin. Water Air and Soil Pollution 136: 189–206.

Fabricius KE. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. Marine Pollution Bulletin 50: 125–146.

Fewtrell L, Bartram J. 2001. Water Quality: Guidelines, Standards, and Health: Assessment of Risk and Risk Management for Water-Related Infectious Disease. IWA Publishing. www.who.int/water_sanitation_health/dwq/iwaforeword.pdf

Fleming LE, Broad K, Clement A, Dewailly E, Elmir S, Knap A, Pomponi SA, Smith S, Solo Gabriele H, Walsh P. 2006. Oceans and human health: Emerging public health risks in the marine environment. Marine Pollution Bulletin 53: 545–560.

Goksøyr A. 2006. Endocrine disruptors in the marine environment: Mechanisms of toxicity and their influence on reproductive processes in fish. Journal of Toxicology and Environmental Health 69: 175–184.

Greer FR, Shannon M. 2005. Infant methemoglobinemia: The role of dietary nitrate in food and water. Pediatrics 116: 784–786.

[IHME] Institute for Health Metrics and Evaluation. 2016. GBD Compare Data Visualization. IHME, University of Washington. http://vizhub.healthdata.org/gbd-compare

Kannan K, Ridal J, Struger J. 2006. Pesticides in the Great Lakes. Pages 151–199. in Hites RA, ed. Persistent Organic Pollutants in the Great Lakes. Springer.

Kareiva P, Marvier M. 2012. What is conservation science? BioScience 62: 962–969.

Kareiva P, Chang A, Marvier M. 2008. Development and conservation goals in World Bank projects. Science 321: 1638–1639.

Lamb JB, van de Water JAJM, Bourne DG, Altier C, Hein MY, Fiorenza EA, Abu N, Jompa J, Harvelle CD. 2017. Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science 355: 731–733.

Mallin MA, Cahoon LB, Toothman BR, Parsons DC, McIver MR, Ortwine ML, Harrington RN. 2007. Impacts of a raw sewage spill on water and sediment quality in an urbanized estuary. Marine Pollution Bulletin 54: 81–88.

Mallin MA, McIver MR, Wells HA, Parsons DC, Johnson VL. 2005. Reversal of eutrophication following sewage treatment upgrades in the New River Estuary, North Carolina. Estuaries and Coasts 28: 750–760.

Myers N. 1997. The world's forests and their ecosystem services. Pages 215–235 in Daily G, ed. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press.

Petrovic M, Solé M, López De Alda MJ, Barceló D. 2002. Endocrine disruptors in sewage treatment plants, receiving river waters, and sediments: Integration of chemical analysis and biological effects on feral carp. Environmental Toxicology and Chemistry 21: 2146–2156.

Prüss-Ustün A, Wolf J, Corvalán C, Neville T, Bos R, Neira M. 2017. Diseases due to unhealthy environments: An updated estimate of the global burden of disease attributable to environmental determinants of health. Journal of Public Health 39: 464–475.

Prüss A. 1998. Review of epidemiological studies on health effects from exposure to recreational waters. International Journal of Epidemiology 27: 1–9.

Shaver E, Burkepile D, Silliman B. 2018. Local management actions can increase coral resilience to thermally-induced bleaching. Nature Ecology and Evolution 2: 1075.

Shaver EC, Shantz AA, McMinds R, Burkepile DE, Vega Thurber RL, Silliman BR. 2017. Effects of predation and nutrient enrichment on the success and microbiome of a foundational coral. Ecology 98: 830–839.

Shuval H. 2003. Estimating the global burden of thalassogenic diseases: Human infectious diseases caused by wastewater pollution of the marine environment. Journal of Water and Health 1: 53–64.

Sindermann CJ. 2005. Coastal Pollution: Effects on Living Resources and Humans. CRC Press.

Skinner J. 2009. Where Every Drop Counts: Tackling Rural Africa's Water Crisis. International Institute for Environment and Development. http://pubs.iied.org/pdfs/17055IIED.pdf

Sutherland KP, Shaban S, Joyner JL, Porter JW, Lipp EK. 2011. Human pathogen shown to cause disease in the threatened eklhorn coral *Acropora palmata*. PLOS ONE 6 (art. e23468).

Tallis H, Kareiva P, Marvier M, Chang A. 2008. An ecosystem services framework to support both practical conservation and economic development. Proceedings of the National Academy of Sciences 105: 9457–9464.

Vega Thurber RL, Burkepile DE, Fuchs C, Shantz AA, McMinds R, Zaneveld JR. 2014. Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. Global Change Biology 20: 544–554.

Wear SL, Vega Thurber RL. 2015. Sewage pollution: Mitigation is key for coral reef stewardship. Annals of the New York Academy of Sciences 1355: 15–30.

World Health Organization. 2001. Water-related diseases. World Water Day 2001. World Health Organization. www.who.int/water_sanitation_health/diseases-risks/diseases/hepatitis/en

World Health Organization. 2013. Progress on sanitation and drinking-water: 2013 update. World Health Organization and UNICEF. WHO Press. www.who.int/mediacentre/news/notes/2013/sanitation_mdg_20130513/en

Stephanie Wear (swear@tnc.org) is a senior scientist at The Nature Conservancy, a visiting scientist at Duke University Marine Lab, and a visiting fellow at UCLA's Institute of the Environment and Sustainability.