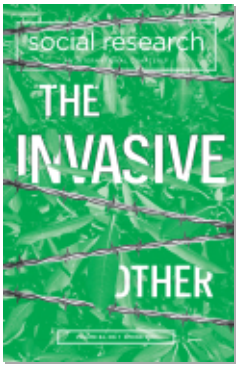
Who's Invading Whom?: Zika and Intergenerational Public Health



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THE END OF WAR (METAPHORS)!

Metaphor, properly deployed, often accomplishes what facts alone cannot. Daniel Federman, long the dean for medical education at Harvard Medical School and an eminent clinician and scholar, famously greeted each incoming medical school class with a lecture on, of all things, the analogies between medicine and music. To be more precise, it was a talk about the *forms* of medical interaction and their parallels among the varieties of musical performance: the duet between patient and doctor; the trio when a child entered the pediatrician's office with a parent; and so on, up to and including the entire orchestra that symbolized the full symphony of activity that comprises the modern academic medical center. Analogies like these can go far in making medicine more transparent to the layperson and practitioner alike—for medicine is a field that deals with the manifestation in the flesh of that which is in fact invisible to the unaided eye (think viruses, bacteria, immune cells, amyloid plaques, etc.), compounded by the unseen nature of most private medical encounters. By reaching outside medical facts, Federman elegantly provided newly enrolled students with a heuristic that would help bind their diverse experiences over the coming years of training into a comprehensible map of the ecosystem of medical practice.

Left out of Federman's talk, however, was the "other" (nonclinical) side of medicine that is typically lumped under the heading of "public health." As illustrated by the seemingly unending onslaught of zombie apocalypse shows on television these days, modern society ceases to function effectively when the basic but often unseen pillars of public health fall apart. Safe air and water, sanitation, access to power for refrigeration and cooking, information infrastructures to apprise populations of health threats—these are the products of generations of investment in public health science and practice, providing the backdrop against which access to medical care is almost the icing on the cake. Threats to this basic regime can come from within (for example, the gutting of environmental regulations that ensure clean air and water, for the benefit of corporate interests) or from without. Those "withouts" have included the pantheon of outbreaks that altered, in large or small ways, the course of human history through their societally disruptive impacts, such as the medieval Black Death; the smallpox, cholera, and yellow fever outbreaks that shaped the Enlightenment and Early Modern periods; the 1918–19 H1N1 influenza pandemic at the dawn of the modern age; and in the current era, the intersecting epidemics of human immunodeficiency virus (HIV), tuberculosis, and malaria.

For most of its history, medicine was content with an uneasy but obliging coexistence with pestilence and disease, largely because of its impotence in the face of what we now know to be an expanding set of deviously brilliant pathogens that evolved to exploit the pathophysiological systems that keep us alive (the modern understanding of the subcellular process by which cholera can kill a person in hours by hijacking their gastrointestinal ion channels is perhaps the crowning testament to this claim). Then, with the advent of arsenical antibacterials and the subsequent discovery of natural antibiotic agents (ie, penicillin), things got personal. What had been seen as a complex ("miasmatic") interplay between individual and environment became a dyadic war between patient and pathogen. The recognition that certain diseases such as malaria were carried by mosquitoes and other

animals simply served to "shift the target" from the pathogen to the vector (Figure 1). Campaigns against pestilence adopted increasingly militaristic jargon during and after the Second World War as public health became synonymous with fortitude in the face of strategic threats, both military and political. To this day, major journals and international health bodies speak of a "war on disease," marshaling statistics such as decreasing global age-adjusted mortality to prove our strategic advantage over the pathogens. And yet this need to prove victory with numbers rings somewhat hollow if we recall the manufactured sunny statistics of Secretary of Defense Robert McNamara and company before the bottom fell out of the Vietnam War effort in the 1970s.

Figure 1.

Then, contemporaneously with the fall of the Soviet Union, something interesting happened in epidemiology: a new paradigm emerged to radically alter this conceptual framework underlying public health practice. In place of the dyad of patient and pathogen (that occasionally extended to the triad of patient, pathogen, and environment, akin to the French notion of "*terrain*"), public health researchers rapidly embraced notions of more complex and dynamic frameworks that determined the health of populations, both human and non. These new models—ranging from early population dynamical frameworks pioneered by Lisa Sattenspiel and others, to network models that permitted simulated diseases to "percolate" over interpersonal bonds, and now to large-scale agent-based simulations on a planet-wide scale—borrowed heavily from the nonmedical fields of physics and mathematics as well as anthropology and demography, largely because their original proponents came from those fields, with many subsequently going on to found influential training programs, such as the one at Imperial College London, that have bred a new generation of mathematical epidemiologists (Sattenspiel 1987; Meyers et al. 2006; Colizza et al. 2006).

The success of these approaches in illuminating both the manifestations of and potential control strategies for an increasingly catastrophic set of outbreaks—from HIV in the 1980s to Ebola in 2014—has lent them wide appreciation in both the public and private spheres. The United States federal government, for example, invested heavily in the field by creating the Modeling of Infectious Disease Agent Study (MIDAS) international multi-institutional collaborative in 2004. Dwarfing that investment, the reinsurance industry has plowed hundreds of millions of dollars over the last decade into financial "instruments" like catastrophe bonds that base their returns on mathematical models predicting outcomes, such as, for example, statistically excessive mortality from influenza pandemics.

Complexity, therefore, has been the new coin of the realm of epidemiological research, invoked over the last decade as an explanatory framework for everything from disease outbreaks to falls

in geriatric populations (Nowalk and Hubbard 2009). And yet, despite increasingly intricate models—typically requiring graduate-level training to read with any comprehension—the fundamental binary setup of host and pathogen, of us versus them, continues to form the bedrock of policy-level discussions. Scientists at the National Academy of Medicine recently published an article in the *New England Journal of Medicine* titled, "Beyond the Ebola Battle—Winning the War against Future Epidemics" (Dzau and Sands 2016).

It has been argued that this continuous recourse to martial metaphors, in use since the dawn of the antibiotic era and particularly directed at new and emerging pathogens, is thought to motivate both public health action and funding (Larson et al. 2005). An alternative offered in the medical anthropology and communications literature has been to abandon the stable of conflict-based metaphors and to embrace instead an "ecological" framework that emphasizes ecosystem connectivity and interdependence. In a sense, this represents a simple substitution: instead of *us/them*, this new formulation posits that the proper viewpoint is *us* + *them*. In the remainder of this paper, I argue that the South American Zika virus outbreak of 2015–16 poses a fundamental challenge to both conceptual approaches. Zika is the first global health emergency to punctuate a new metaphorical claim, that in fact *us* = *them*. What if the host-pathogen battle is no more than an epicycle off the main issue, namely that we are no longer in a war against a *them* but rather against *ourselves*? Fundamentally, the emergence of Zika forces us to ask whether we are entering a phase of anthropogenic impact on global ecosystems in which the complexity of human-environment-pathogen interactions makes any dyadic metaphor insufficient to capture the reality of the situation.

ANTHROPOCENIC RISK

Defining risk is messy, both theoretically and in practice. Despite this, mathematically concise definitions of risk are a bedrock of the modern state, since they permit the maintenance of solvent reinsurance markets, which in turn enable insurers to backstop the corpo-

rations that power the economies that keep states functioning. An overly simplistic quantitative definition might invoke two probabilities: that of an event happening, combined with the potential impact that such an occurrence would occasion. Stated in plain language (and widely though likely apocryphally attributed to one Cornelius Keating), this is like saying that risk is "the unwanted subset of a set of uncertain outcomes." An alternative but classic view, often misquoted and misapplied, is that risk is defined by the consequence of a threat exploiting a vulnerability (Cox 2008).

Typically, these risk formulations single out *one* threat or another, since there is a limit to how well we can interpret, model, and act on information about multiple concurrent intersecting threats. And yet, this is exactly the state of modern society at the dawn of what has been termed the Anthropocene, an age of global change instigated not by extraterrestrial rocks or subterranean convolutions but by the spread of humans and their pollution (Whitmee et al. 2015). The increasing concentration of carbon dioxide in the atmosphere, caused by the burning of fossil fuel, is known to be responsible for altering both ambient climate and the viability of the oceans, with implications both dramatic (superstorms, drought) and depressingly eye-catching (bleached coral, retreating glaciers). Carbon dioxide, the poster child of the new era, is only part of the story; steady population growth and industrialization are now entering a phase of interaction with climatological and oceanic change to reshape—in many cases literally—the face of the planet.

These changes take two basic forms: absence and presence. Deforestation is the classic example of the first form of change. While timber use for building and firewood has been a staple of human existence since the earliest settlements, the demand for vast amounts of virgin lumber since the nineteenth century and, more recently, the rush to clear jungles for industrial meat and crop production, have caused devastation of temperate and tropical ecosystems. Deforestation interacts with anthropogenic climate change in as yet poorly understood ways, reducing natural carbon capture just as multiple

mechanisms (eg, methane release through warming tundra) that may dramatically and nonlinearly alter the temperature of our planet for the foreseeable future are being unleashed. Already, the signs of this anthropocenic risk are clear: four of the hottest years ever recorded occurred in the last decade, and 2016 was named by many scientists as the warmest year on record.

Little more than a decade after satellite photos of denuded forests from Landsat's land-oriented cameras first shocked the world in 1972, scientists discovered that human civilization could give as well as it could take, at the planetary level (Landsat 1972). From 1985 to 1987, scientists first noticed what is now called the Pacific Trash Vortex or the Great Pacific Garbage Patch, a now-Texas-sized field of abandoned nonbiodegradable material made up mostly of plastic (Law et al. 2010). Of perhaps greater ecological concern, all corners of the world's oceans are now beset by "microplastic" particles and residues that, once consumed by aquatic animals, serve as vectors for a host of toxic petrochemicals (Liboiron 2016). The quantities are such that mathematical models predict that, absent improved controls on nonrecycled plastic pollution emanating mainly from Southeast Asia, by 2050 the oceans will contain more plastic by weight than they will fish (Eunomia 2016). Combined with increasing evidence that wild fish stocks have been declining globally since the mid-1990s, these facts paint a dire portrait of the ocean's sustainable health (Pauly and Zeller 2016). And since the sea has long been our dumping ground of last resort, this means that land-based petroleum-byproduct pollution is likely more dispersed but equally prevalent. Taken together, these long-term trends suggest that we are gifting to our children and our children's children a hotter, denuded planet that is increasingly covered in plastic. The mosquitoes that transmit Zika virus could not have asked for a more favorable habitat.

AEDES THE CONQUEROR

Like the other 66 flaviviridae in its family (Latin: "flavus" = yellow; this virus family is named for its most famous member, the Yellow

Fever virus), Zika is a simple organism that relies on a single strand of ribonucleic acid to transmit its genetic code through mammalian hosts and insect vectors. For the past century, this family has been on the move from tropical jungles to more temperate climes and urban regions. One of its members, West Nile Virus (WNV), became recognized as a serious threat to human health only after causing outbreaks in North Africa and Eastern Europe in the 1990s. It then leapt across the Atlantic, causing selective die-offs of crows and robins that were first noted by astute public health clinicians in New York City in 1999. The enabler of these deaths was the virus' vector, the *Culex* mosquito. This species must have felt right at home in the Big Apple, being both a famously picky eater—favoring only a handful of ornithological delectables, including those crow and robin species—and also a very messy dweller, favoring organically contaminated water for breeding. The result is that, a decade later, WNV is now well established in North America as a low-level endemic disease, with primary serious manifestations encompassing a variety of neurological and febrile syndromes, some of which are fatal.

Another cousin of Zika, the dengue fever virus, began its global peregrinations prior to World War II and then experienced an almost exponential increase in its attack rate in the postwar period, mainly in equatorial regions worldwide (Gubler 2011). Dengue, which in its severe form is called breakbone fever, is likely responsible for hundreds of millions of infections annually, with many tens of thousands dying of both the primary infection and its manifold complications (eg, kidney failure). Although malaria, tuberculosis, and HIV get the lion's share of attention by the global press, dengue remains a stubbornly large contributor to morbidity and mortality worldwide. In contrast to WNV and dengue, the Zika virus was thought to be the relatively tame member of the family, causing at worst a febrile illness characterized by a rash, joint pain, and conjunctivitis. For this reason, until this decade there was little concern about Zika from a public health perspective. Then in 2013, the virus popped up in French Polynesia, thousands of miles from its last known site of infec-

tion. And although it was not noted until a later retrospective analysis had been conducted in light of Zika's subsequent devastating landfall in South America, something very unusual happened during this outbreak that rapidly spread through these Pacific islands: a subtle but significant increase in cases of microcephaly in infants born to mothers who were infected with the virus during pregnancy.

What happened next shocked the global public health establishment, a group that has a very low tolerance for surprises (Ferguson et al. 2016). Continuing its eastward journey (likely carried by mosquitoes hitching a ride inside a container ship or stowed away on a cargo or commercial airplane), Zika arrived in South America in 2015 and soon caused an epidemic of these same fetal malformations, in addition to other neurological illnesses extending across all age categories. In February 2016, less than a year after the connection was first made to congenital injury in Brazil and after the virus's lightning-fast spread throughout the continent and into the Caribbean, Zika was declared a public health emergency of international concern by the World Health Organization, and the latest "war on disease" had begun.

Despite their very different clinical presentations and global impact, dengue and Zika have long shared the same vector, the *Aedes* genus of mosquito. In Greek, αηδης means "unpleasant," and this mosquito certainly lives up to the billing. Where *Culex* buzzes in your ear and bites sparingly at night, *Aedes* (of which *albopictus* and *aegypti* appear to be the main species transmitting Zika) are known to be silent, ravenous daytime feeders that have been described as resembling fleets of stealthy predator drones traveling ankle to ankle through whatever human population they come upon (Specter 2012). A better transmitter of blood-borne pathogens would be hard to find. Yet the most crucial difference between the *Aedes* and *Culex* genera is not feeding habits, but rather the ability of *Aedes* to live and breed in minute quantities of relatively sterile water. This distinction is critical, since it means that *Aedes* can flourish anywhere there is a concave piece of plastic exposed to rain, which as noted above is now basically everywhere on the planet.

The ability of *Aedes* to exploit our plasticized environment would be complete save for one constraint: temperature. Classically, *Aedes* species are thought to live between two lines drawn on either side of the equator called the "10 degree [centigrade] January/July isotherms." This region of the globe that basically never gets too cold is now spreading toward the poles at a slow but distressingly increasing rate (Rochlin et al. 2013). Central and most of South America lie squarely within this region, along with huge portions of Africa and Southeast Asia. Southern regions of Europe and North America that previously remained just outside this expanding isotherm have, within the last decade, slipped within it, and the most recent mathematical models predicting habitat favorable to *Aedes* have included wide swaths of both continents that are now at risk for sustained outbreaks of *Aedes*-transmitted diseases. In the continental United States, for example, these mosquitoes now have a potential distribution spanning the entire southern border of the country from California to New England. And as noted by Rochlin and colleagues, "By the end of the 21st century, the climatic conditions suitable for *Ae. albopictus* will exist to cover roughly one-half of the land area in the northeastern USA." *Aedes* is thus the "anti-polar bear," a clear victor emerging from the anthropogenic warming that is rapidly changing the natural world. The question, from a public health perspective, is: what, if anything, can be done about it?

STRATEGIZING WITH THE ENEMY

Faced with a rapidly evolving public-health emergency and lacking a "magic bullet" in the form of a vaccine against the virus, nations at the epicenter of the outbreak initiated a war on Zika by attacking its vectors. Brazil, for example, marshaled military troops for both mass spraying and door-to-door canvassing for any unused plastic vessels that could harbor mosquito larvae. In this manner, the initial response to Zika mirrored the typically dyadic approach to most mosquito-borne illness outbreaks: in an *us* vs. *them* battle, killing *them* will save *us*. In fact, as noted by P. J. Hotez, this strategy worked extremely well in the

mid-twentieth century, but for an extremely brief time, to rid South America of the very same mosquito species that is the prime vector of Zika (Hotez 2016). In 1947, the Pan American Health Organization (PAHO) deployed a multimodal attack that centered on regional and household-based fumigation strategies to eradicate the mosquitoes. Results were rapid and impressive, permitting 20 member countries to declare themselves *Aedes*-free 15 years later.

The problem with the strategy was not its lethality to *Aedes*, but rather the fact that South and Central American countries that employed it were connected by land and air to the United States, which decided that such intensive and invasive procedures were not warranted against what was seen then as a relatively minor public health threat. Whether the wide reestablishment of *Aedes* throughout the Western Hemisphere over the ensuing decades (which can be tracked by watching the ebb and then rapid rise of dengue cases from the 1960s to 1980s) would have occurred even if all PAHO member nations had signed on for this "total war" approach is unknown; it is likely that importation of the vector from other endemic regions of the globe would have led equally to the current state of affairs.

In addition to tactical concerns about the durability of any gains against *Aedes* from this approach, there have been persistent strategic concerns about knock-on effects from these wide-scale chemical assaults on other species and habitats. From Rachel Carson's *Silent Spring* to protests in 2015 by Brazilian public health officials, concern for both ecological and human health has spawned numerous efforts to reduce mosquito populations using nonlethal means (Augusto et al. 2016). To varying degrees, these newer strategies mark a conceptual shift from *us*/*them* toward a more integrated *us* + *them* approach, which has been enshrined in the aptly titled "One Health" framework encompassing both human and nonhuman animal welfare. This is not to say that advocates of these newer approaches universally countenance coexistence; in fact, interventions that have been promulgated under a broader, more eco-friendly heading promote what appear to be simply "smarter" methods that capitalize on mosquito biology

in the hopes of minimizing collateral damage to humans and other species. In this way the new approach is less like a public health campaign without enemies and more like one utilizing "smart bombs," which made their military debut in the first Gulf War in 1991 (Specter 2012).

Both of the strategies that have been gaining traction under this non-chemical regime involve varying degrees of manipulation of existing biology, specifically through alterations of selection pressure on future generations of mosquitoes. One, based on the globally omnipresent rickettsial parasite *Wolbachia*, seeks to confer a mating advantage on non-infected mosquitoes while at the same time promoting their natural defenses against the Zika virus (with a potential knock-on effect against dengue and yellow fever). Subspecies of the parasite that preferentially infect *Ae. aegypti* and *albopictus* have been identified, and field tests introducing these in selected South American countries are slated to begin in 2017. Unfortunately, messing with nature has its risks: studies suggest that while *Wolbachia* infection may reduce transmission of certain of the flaviviruses, it may also paradoxically increase mosquitoes' concentration of WNV, threatening to increase their transmission potential.

A more direct but also more complex approach, championed by researchers at Oxford University, relies on genetic modification of *Aedes* mosquitoes to render them unable to create progeny—a genetic male pill, so to speak. The political and ethical barriers to introducing genetically modified insects into the wild are high, as chronicled by Michael Specter in his 2012 *New Yorker* article, "The Mosquito Solution." He noted, in relation to dengue control efforts (since Zika did not even factor into the equation less than a decade ago), that resistance to the open release of genetically modified insects did not arise among the potential local beneficiaries of the scheme so much as from the scientists and advocates who urged caution in the face of the multiple unknowns about altering nature in such a fundamental and irreversible manner. If using mosquitoes to "kill" themselves without untoward side effects seems too good to be true, the argument goes,

then it probably is. Now that these releases have already occurred in ongoing field trials, it is only a matter of time before we find out which side is correct.

It is possible that these approaches will succeed in diminishing the threat to public health caused by the spread of *Aedes* species, either by shrinking their habitats, reducing their fitness as a flavivirus vector, or both. But even if locally successful by these or other mechanisms, two further problems then arise: first, as with the midcentury PAHO campaign, one may question the durability of any crimping of *Aedes*' capability to transmit these pathogens in the targeted areas; and second, if Zika's geographic invasiveness is only symptomatic of the unaddressed intertwined global problems of warming in a plastic-filled environment, how long will it be before another vector better suited to these conditions takes *Aedes*' place?

This has all the makings of a classic public health dilemma: how much time, money, and effort should be spent locally to counter processes that have global structural roots but manifest in poor local health outcomes? Addressing the problem in this manner lets us see *Aedes*' rise and the Zika epidemic as symptoms of the larger problem, not simply as the problem itself. Who, then, is the enemy to occupy the role of *them* in our various constructs of public health action? If not the mosquito, perhaps the enemy is the Zika virus itself? This seems contrived because of what we know about vector-borne diseases: they are scourges, to be sure, but they are also somewhat passive actors in the complex interplay between vector and host giving rise to disease. Without the fleas transmitting *Yersinia pestis* from rats to humans in the fourteenth century, there would have been no Black Death, even in the presence of plentiful *Yersinia*.

Having cast doubt on the utility of the standard dialectic (*us*/*them*) and the newer unified model of outbreak control (*us* + *them*, which could be termed the "one-ecosystem" approach), we are left asking a fundamental question: can we conceptualize a public health campaign without enemies? Is there really no *them*? Unfortunately, such a move is both too facile and also too benign; not only does it

obscure what to do about Zika and future vector-borne diseases that may come in its footsteps, but it also ignores the elephant in the room: human alteration of the planet in ways that contribute *incontrovertibly* to human harm (World Economic Forum 2016). The conceptual framework that does the best both to explicate where we are in relation to diseases like Zika and to guide immediate and future action to minimize their adverse health impacts is to recognize that the *them* in these models is actually *us*. There are both weak and strong claims that arise from this new conceptual orientation.

The weak claim is that we should not engage in direct action against emergent pathogens (e.g., chemical spraying against mosquitoes) without *also* paying attention to the underlying structural/ecological problems that led us to this state of affairs (e.g., vector habitat "creep" due to changing climate and plastification of the planet). The strong claim is that we should not engage in vector control or other tactics to safeguard human health from emergent diseases like Zika *at all* in the near term *unless and until* we address those structural factors that are leading us down the path of ecological imbalances that provoke the emergence of new invasive pathogens (e.g., putting a halt to the production of petroleum-based plastic manufacturing) (Liboiron 2016). This strong claim, which may seem punitive and callous in the near term for failing to adequately protect those people who are currently living, is an attempt to reconcile standard public health practice with the well-described failure of modern society to deal justly with the manifold problems of recognizing and acting on intergenerational harms (Gardiner 2006). The following sections flesh out the implications of these claims, reflecting along the way on the meaning of invasiveness from the perspective of intergenerational ethics.

INVADING OUR (THEIR) FUTURE

What does it mean to say that, in confronting the Zika epidemic, the enemy is *us*, and *not* the Zika flavivirus itself or the *Aedes* mosquito that transmits it? This claim is sensible only if we expand our view

of disease causation to extend beyond the sick individual sitting in the doctor's office (for whom saying that the petrochemical industry caused their Zika infection is a stretch, and unhelpful from a therapeutic perspective to boot). But this is and always has been one of the main points of distinction between medicine and public health: the ability to take a wider view of disease causation in order to craft interventions that preserve the health of both current and future generations. The bulk of the public health response to Zika has been motivated principally by a sincere desire to protect the immediate future generation of exposed humans (namely the gestating and the newborn) from serious neurological injury and lifelong debility. Since protection of these individuals must be mediated by interventions that minimize Zika's risk to women and men of childbearing age, and since it is difficult (absent a targeted vaccination campaign) to single out only these demographic groups from the general population (ie, you *could* spray a village but skip all the grandparents' homes, but in fact this is not done) this motivation appears to license an approach that maximally safeguards currently living individuals from the risk of contracting this particular disease.

Thus although the global reaction to the Zika outbreak is commonly termed a public health response, in its focus on those immediately impacted by the disease it reflects more of a medical rather than public health flavor. To use a simplistic analogy, it would be the equivalent of calling an effort to find and destroy all cigarettes sold in retail shops as a "public health strategy against smoking." In fact, successful antismoking public health interventions target both antecedent (cigarette production and marketing) and downstream effects (behavioral and pharmacological aids for cessation), typically keeping their hands off cigarettes that have already made it into circulation. This reflects more than just a respect for the free market: in a resource-constrained environment, if the goal is to maximally and durably curtail tobacco use, it makes sense to focus more on reducing the financial benefits of cigarette production and drivers of demand than to simply attempt to manipulate access.

In this light, attacking mosquitoes while ignoring the "apocalyptic twins" of global climate change and plastification is the arboviral equivalent of firebombing the corner cigarette store while leaving the tobacco factory untouched (Winn 2016). It may help moderate the immediate injury of infection in the near term, but it will certainly leave the trajectory of future harms intact (and may cause collateral damage to boot within the "blast"/vector control radius). As noted by Gardiner, these future harms are notoriously difficult to internalize and operationalize, regardless of how likely or severe they may be (Gardiner 2006). Humans, it seems, have an extremely poor capacity to adjudicate short versus long-term risks, consistently prioritizing those that are sitting in front of our noses. In this manner, we act more like doctors trying to maximize the health of our next patient—sometimes in unthinking ways and at the expense of future patients—rather than as practitioners of public health who are supposed to consciously and conscientiously apportion limited resources in order to attain improvements in overall population health, even if this may not maximize the health of every individual member of that community (Julvez 2016). (Vaccines again provide a good example of this point: we as a society accept the fact that vaccinations may rarely cause grave harm in the service of a societal good, thus the existence of the National Vaccine Injury Compensation Program.)

Seeking to outrun the impact of vector-borne diseases in this manner recalls the timeworn engineering adage, "Local optimization leads to global disharmony." In the age of anthropocenic risks, however, this disharmony is of our own making and therefore presumably under our at least partial control (at least until the natural forces that we have unleashed become ungovernable), so perhaps the following ungainly modification of the adage is warranted: "Local health optimization lets us ignore the ongoing global disharmony that caused the problem requiring optimization in the first place." But even this inelegant extension obscures a crucial fact: the disharmony that we have created is not simply a *byproduct* of human activity. Rather, it is a *choice* (or more accurately, the result of an immense suite of choices)

that we as a society have made (mostly within the last century and a half) about everything from the necessity of disposable coffee cups to the probity of lopping off mountaintops for coal. Adjusting the adage to this fact yields "local health optimization without rectification of our own practices that spawned the problems requiring optimization leads to increasing global disharmony causing negative health consequences for future generations."

At this point, our self-identification as the enemy, as the *them* of the infection control dialectic, is most readily apparent. We as a global society (except, perhaps, the handful of indigenous groups that have never partaken of modern consumer culture) have not only *created* conditions ideal for enabling new and migrating diseases to threaten human health, but with each passing day, absent conscientious efforts to the contrary, we are *reinforcing and multiplying* those conditions. Vectors and pathogens like the *Aedes* mosquito and Zika virus are termed invasive because of their transgressivity: they don't stay where they used to and they don't do what they used to. From the moment we began to outstrip the natural world's ability to withstand our environmental depredations—that is, from the moment that the Anthropocene began—humans became transgressors as well, invading a future that, by our present actions, we believe is ours to befoul.

If this seems too extreme a statement, compare the lengths to which global public health authorities will go in the case of Zika to secure the health and welfare of two generations, with the inattention paid by those same authorities to the factors that permitted Zika to emerge as a global health threat in the first place. For example, despite the increasing weight of evidence that plastic pollution is a greater immediate threat to world health than climate change, the World Health Organization has not declared it to be a "public health threat of international concern." The situation is no better at the regional or national level: when Zika was first recognized as a major health threat in 2015, Brazilian troops were dispatched to find plastic refuse in urban areas, but not to shut down the factories that made the refuse in the first place. Zika proves that we cannot win this game

of catch up, but there are as yet no alternatives to effectively address, on a global scale, the root causes underlying the "vector creep" that will permit further Zika-like events to jeopardize the health of future generations.

INTERGENERATIONAL PUBLIC HEALTH: A RADICAL CALL TO ACTION

What do we owe our children that we do not owe our children's children? Devoting scarce public health resources to vector control—without concurrently engaging global governments and industry in addressing the well-documented anthropogenic factors forcing global habitat changes that will increase the likelihood of future arboviral outbreaks—would suggest that the answer, at least from the example of Zika, is: "a lot." What this means is that, by our actions throughout the multiyear global public health response to the Zika outbreak, we as a society have demonstrated a relative reluctance to look further into the future than the generation of human beings who are currently being born. From a commonsense perspective, this is understandable, since the efforts undertaken to date have goals that are plainly laudable—minimizing illness and infirmity, both currently and in the immediate future. But from a more strategic perspective, the absence of a longer-term agenda on the part of the public health establishment to address the fracturing and debasement of major ecosystems is also deeply out of touch with the reality of this anthropocenic age in which we are no longer able to rely on natural systems to maintain or restore ecological homeostasis. This notion of the self-correcting potential of living systems, first promulgated by French physiologist Claude Bernard in the nineteenth century and later adapted to the earth-encompassing Gaia Hypothesis, may no longer apply to a world increasingly choked with hydrocarbon detritus.

In clinical medicine, individuals who lose touch with reality are often labeled as psychotic; those experiencing true psychosis describe inhabiting in a world of their own making and may be quite resistant to the efforts of would-be interlocutors. An interesting clini-

cal trick when interviewing such a person is to physically move the doctor's chair over to the patient's side of the room, so that the two can sit side-by-side and, in a sense, "look out" onto the world with a shared vision. Breaking the traditional dialectical seating arrangement in this way is a small step, but it is sometimes enough to change the terms of engagement, permit conversation, and begin the process of healing. One question is whether a similarly radical step can be carried out within the current regime of global public health to catalyze action on fundamental drivers of future global health. Such a step would have to accomplish at least two things, one conceptual and the other operational. At the conceptual level, it would have to broach the fact that while current vector control actions described above to combat the immediate threats of Zika and other emerging diseases may be necessary from a medical perspective, they are insufficient to provide durable global public health security against invasive outbreaks in the long term and may in fact (by the diversion of scarce political and material resources at this critical anthropocenic juncture) decrease the likelihood of ever attaining that goal. This claim is likely to be greeted with reactions ranging from benign acknowledgement to outright resistance based on the counterargument that public health is powerless in the face of these larger forces of human activity (eg, the petrochemical industry). This is where the argument for intergenerational health equity—extending beyond the immediate next generation—may be deployed to great effect. If this effort can succeed in carving out the possibility that legitimate supervenient goals for global public health security extend well beyond immediate medical and (narrowly demarcated) public health vector-control interventions noted above, it would have achieved a modicum of success.

But to actually influence public health practice, any intervention would need to motivate change. This is where the strong claim noted in the third section of this paper may be used to advantage. If we abandon both the traditional infection-control dialectic and the unified One Health framework (abbreviated above as the *us*/*them* and the *us* + *them* approaches) on the grounds that neither sufficiently rep-

resents the anthropogenic factors permitting the increasing spread of invasive disease, we are left with the somewhat distressing notion that *us* = *them.* It follows logically from this proposition that any rational public health intervention to crimp the spread of these diseases would focus primarily on altering or eliminating those "upstream" forcing factors, with a secondary and (as I described above) more medical focus on intervening to preserve life and promote health, for example through "downstream" vector control. Since our experience of the current global public health regime has made it clear that it focuses almost exclusively on such distal interventions for outbreaks as Zika, it may be sufficiently disruptive to motivate action to state that intergenerational justice requires for the next outbreak, that vector control interventions temporally follow some sort of meaningful action on the underlying determinants of vector spread. Delaying the implementation of potentially lifesaving countermeasures is unlikely to happen in practice, but the seemingly counterintuitive claim that they *should* be delayed in favor of more far-reaching efforts to counter climate change and plastification, explicitly out of concern for the health of our children's children, may be sufficiently shocking to get those longer-term goals on the global public health agenda for the first time.

The dawning of the Anthropocene means that we humans are now the bull in the global ecological china shop; for outbreaks like Zika, which has been a catastrophe for many and a sentinel event for us all, public health's role has been to remain busy picking up the pieces while ignoring the fact that there is a large animal standing there. To corral the bull before it breaks everything, public health needs to change its tactics and, to finally beat the metaphor to death, swap its broom and pail for a rope that can help guide the animal to a safer environment. Public health has one of the greatest bully pulpits of any human undertaking, and it has yet to make its voice fully heard on the global stage regarding the extent to which our hydrocarbon powered and plastic-generating society has traveled down an environmentally unsustainable and medically unsafe road over the

last century (Liboiron 2016). As pointed out by the World Economic Forum in its 2016 report on "The New Plastics Economy," viable industrial alternatives to our current predicament are within reach (World Economic Forum 2016). Whether public health will help us get there will depend on how much ownership of the larger problem it believes it has.

In researching this paper, I was reminded of a line in one of my children's favorite movies, spoken by a mammoth: "Sid is not my kid. If I had a dog, and that dog had a kid, and that dog's kid had a pet, that would be Sid" (*Ice Age: The Meltdown* 2006). Despite his desire to distance himself, Manny, in his tortured way, acknowledges some bond of kinship with and responsibility for the lovable but hapless sloth. Our stakes are far higher, and we risk incurring serious sacrifices along the way that may impact current medical care, but we in public health may still hope to emulate this example by doing the ethically correct thing and claiming both responsibility for and a mandate for action on anthropogenic promoters of invasive disease.

NOTE

The findings and conclusions in this talk are those of the presenter alone and do not represent the official position of the U.S. Centers for Disease Control and Prevention (CDC) or Department of Health and Human Services (DHHS).

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