

## ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

Issue: *Annals Reports*

TECHNICAL REPORT

# The science behind One Health: at the interface of humans, animals, and the environment

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Humans face a grand quality-of-life challenge as growing demands for resources for an ever-expanding population threaten the existence of wildlife populations, degrade land, and pollute air and water. Public investment and policy decisions that will shape future interactions of humans, animals, and the environment need scientific input to help find common ground for durable and sustainable success. The Second International Conference on One Medicine One Science brought together a broad range of scientists, trainees, regulatory authorities, and health experts from 34 countries to inform and discuss the human impacts of air quality; the complexities of water quality, access, and conflicts; the opportunities and uncertainties in precision medicine; and the role of science communication in health policy formulation. Workshops focused on the roles and development of physician–scientists and multidisciplinary teams in complex problem solving, Big Data tools for analysis and visualization, international policy development processes, and health models that benefit animals and humans. Key realizations were that local and regional health challenges at the interface of humans, animals, and the environment are variations of the same overarching conflicts and that international gatherings provide new opportunities for investigation and policy development that are broadly applicable.

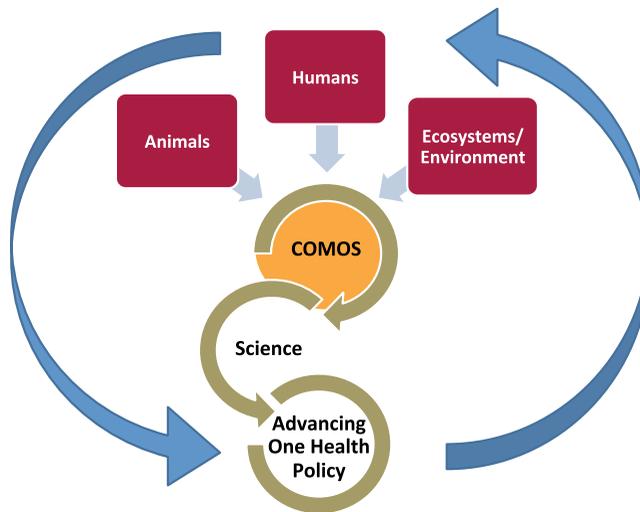
**Keywords:** iCOMOS; precision medicine; medical ethics; food security; health policy

## Introduction

One Medicine One Science emphasizes the scientific knowledge base that is common to all of human and animal medicine. It is the science behind One Health that enables efficiencies in research in individual species and provides benefits that are broadly applicable to humans and animals. It facilitates transdisciplinary teams whose consideration of biological, social, cultural, engineering, economic, and other factors is necessary for effective translation and implementation of health policies nationally and internationally. It is inextricably linked to environmental health, as animals and humans inhabit the same air space, access the same water sources, and require food derived from land and water (Fig. 1).

According to the One Health Commission, nearly 75% of emerging human infectious diseases in the past three decades originated in animals. Poor environmental health brought on by contamination, pollution, and degradation of air, water, and land creates disturbances that foment cross-species infectious disease transmission, as well as noninfectious disease spread across entire populations of humans and animals. Health professionals and their related institutions and disciplines must work collaboratively to develop solutions to One Health problems. Balancing competing demands for high-quality natural resources that foster human and animal health while not exhausting, polluting, or contaminating the environment is a growing challenge at

doi: 10.1111/nyas.13355



**Figure 1.** The concept of One Medicine One Science (COMOS) embraces common scientific approaches that unify health-related research at the intersection of humans, animals, and ecosystems. Environment plays an enormous role, hence the prominence of both air pollution and water access and quality in the conference and their impact on health. Understanding the science behind health and knowing how to communicate it effectively in influencing health-related policies was a third major theme, along with precision medicine and its inherent ethical policies. The circular arrows illustrate the ongoing process of science advancing policy to promote health, knowledge, and communication and its inclusion in policy development. COMOS stands at the health intersection, bridging science and communication across human medicine, animal medicine, and ecosystems/environment.

the local, regional, and global levels. The challenge of providing adequate health care, food, and water to a global population—which is expected to surge 28% to more than nine billion people by 2050—will only escalate the scale of threats and needs.

Complex interactions among human, animal, and environmental health underscore the importance of addressing health from a scientific foundation that considers all contributing factors. This level of interaction requires integration of health science disciplines that span the spectrum from personalized care to public health. For instance, the global water crisis is one of the biggest risks the world is facing, according to the World Economic Forum's Global Risks Report 2016. Worldwide, approximately 700 million people, or one out of 10 people, lack access to a safe water supply. Approximately 2.5 billion people (one in three) lack access to adequate sanitation—the world's primary means of reducing disease.

The problems of polluted air and water, access to water and sanitation, food security, and how to implement science, particularly precision and advanced medical approaches, are not only problems of science, but they are also political and economic problems. Major obstacles to informing policy with science include special interests, global

concerns that tend to get traction only when a local connection is made, and lack of integration and communication among experts from related health disciplines.

The International Conference on One Medicine One Science (iCOMOS) is a global forum to communicate the importance of science in solving pressing One Health issues; to facilitate interdisciplinary, international collaborations embracing health, science, and economics; and to inform public policy development necessary for preserving human, animal, and ecosystem health. The inaugural iCOMOS, held at the University of Minnesota on April 27–30, 2014, attracted more than 300 participants from across the United States and 13 other countries.<sup>1–3</sup> The second iCOMOS, iCOMOS 2016, was held on the University of Minnesota Twin Cities campus April 24–27, 2016, with 350 participants representing 34 countries and six continents. Expertise spanned the fields of human and animal health care, economics, computer science, engineering, environmental sciences, ethics, public health, chronic disease, agriculture, food, and environmental affairs.

A major goal of iCOMOS 2016 was to bring together diverse international partners from nonprofits, government, academia, and private

industry to explore the role of science in setting public policy. Michael Osterholm, regents' professor at the University of Minnesota and coauthor of *Living Terrors: What America Needs to Know to Survive the Coming Bioterrorist Catastrophe*, was the keynote speaker. Osterholm told participants that it is not a question of whether a lone terrorist or terrorist group will use infectious disease agents to kill unsuspecting citizens, it is a question of when and where. At the other end of the spectrum, clean water, a resource often taken for granted, limits many communities, as described by guest speaker and arctic explorer, Ann Bancroft, in her initiative to educate and reshape how people and communities relate to water. These presentations highlighted the inescapable need to embrace a holistic approach to health security such that when one suffers, all suffer.

The conference was organized into plenary, panel, and workshop sessions. Plenary sessions emphasized the role of science in policy debate and development at local, regional, and global levels. Specific themes addressed the science of air and water pollution threats to animal and human health, the emergence of personalized medicine afforded by enormous scientific advances in understanding individual variations in health outcomes, and the challenge of effectively communicating science. Panels emphasized the role of science in the pursuit of policies that safeguard and enhance One Health. Concluding workshops served as case-based studies of the connection between science, public policy, and private-sector implementation of real-world solutions needed to address important challenges in health. Workshop topics included team science and the central role of physician–scientists in One Health implementation; the risks and benefits involved in developing global standards for food security in a diverse world; the use of Big Data in advancing personalized medicine and One Health; and epilepsy as a model illustrating the bidirectional benefits of biomedical research advancing both animal and human health.

### Conference themes

The first major theme focused on balancing precision medicine and public health in a changing environment. The biological revolution linking genotypic variation to health and disease has created vast potential for tending to the health of indi-

viduals based on individual health risks, drug sensitivities, nutritional needs, and yet-to-be-discovered variables. However, precision medicine requires large investments and commitments of resources to address individual needs, while public health, based on scientific knowledge of generalized health risks and rewards, requires investments and commitments to population and health impacts in local and global environments. Given a fixed set of resources, maximizing the potential of both is challenging at best. Conference presenters highlighted some of the scientific complexities of individual and population health relevant to humans and animals.

The second major theme targeted health problems attributable to air pollution. Because the health of all living creatures that breathe air is inextricably linked to air quality and composition, it is essential to the health of humans, animals, and plants that air quality be managed effectively. To understand exactly what this means, it is essential to unravel the impact of human activities, animal metabolism, and plant biology on air quality, as well as the detrimental impact of specific air constituents on health. Conference presenters examined the air in today's world, the science behind major air-related diseases and overall health, and the human and economic costs resulting from these diseases.

The third major theme concentrated on the fundamental need for water, specifically the quality and quantity required to sustain health, a goal that becomes increasingly difficult to attain as populations grow, human land use expands, and water patterns shift owing to climate change. The problem that policymakers are facing is compounded by the fact that human, animal, and environmental health must be considered when making water policy, but each is measured by different standards. Economic and social values vary across the globe and tend to compound, rather than simplify, issues from the local to the global level.

Conference presenters highlighted the fact that data to adequately inform policy in the areas of water quality and quantity are often difficult to acquire, and putting one use of water above and out of balance with all its other uses has already led to unintended and undesirable consequences. In addition, the nature of water resources often leads to international conflicts over quality, use, and access. iCOMOS can serve as a neutral meeting ground for the presentation and debate of science.

The fourth major theme was food security. By 2050, the global population is estimated to exceed nine billion people, with most growth occurring in areas with limited food supplies. Currently, an estimated 30% of food is wasted, with some estimates as high as 50%. Eliminating food loss and waste could feed an estimated 870 million undernourished people worldwide without an increase in production.

In 2010, 600 million people were stricken by foodborne disease and 420,000 died, with the heaviest disease burden occurring in the developing world, according to the World Health Organization (WHO). Global regulations to reduce the monetary costs and health consequences of foodborne disease could also protect countries from unfair trade practices that are often based on politics, and not on science. Conference presenters detailed how, in some parts of the world, animal welfare has been elevated to the level of human welfare, illustrating that science alone cannot dictate policy and that a One Health approach is needed to reduce food waste and foodborne disease and to keep food moving freely so that it can reach to those who need it.

## Presentations

### *Ethical and legal challenges of translating genomic research into public health benefit*

Susan M. Wolf, McKnight Presidential Professor of Law, Medicine & Public Policy at the University of Minnesota, laid out the ethical and legal challenges of translating genomic research into public health benefit. As more research studies incorporate whole-genome sequencing, using next-generation sequencing tests—a cornerstone of the U.S. federal Precision Medicine Initiative (PMI)—investigators and institutional review boards are facing the ethical and legal challenges of determining how to handle “return of results,” including individual research results and incidental findings. This issue has generated tremendous controversy and is considered “one of the thorniest current challenges in clinical research,” according to National Institutes of Health Director Francis Collins.<sup>4</sup>

What is the obligation of researchers to inform study participants about incidental findings with potentially negative health or reproductive implications that are not related to the study objectives? What are the obligations of researchers to disclose clinically and/or personally significant individual research results? What criteria define returnable

incidental findings or individual research results? What protocol should be followed to report the findings? Do researchers have a duty to hunt in their data? What is the role and responsibility of biobanks that archive data? Do patients have an opportunity to opt out of receiving these findings if they choose?

Wolf and colleagues showed that the problem of incidental findings is intrinsic to research and is a fundamental problem of translational science crossing two domains—research findings and clinical care.<sup>5</sup> According to the World Medical Association Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Subjects, it is generally agreed that the results of research should be made available to participants, but, historically, sharing has been restricted to aggregate results.<sup>6</sup> Aggregate research results are generally published findings about the research population that are discovered during the course of research on the focal variables under the study’s aims.

Now, a growing consensus supports analysis of an individual participant’s primary findings, as well as incidental or secondary findings, offering at least a subset of these findings back to the participant.<sup>7,8</sup> Researchers have a duty to manage incidental findings and individual research results, and they should address these duties in advance by creating a protocol and consent process to address these issues and obtaining institutional review board approval. Researchers should return the results that are analytically valid and in compliance with legal requirements, reveal established and substantial risk of a serious health condition, and are medically actionable.<sup>7</sup> The complex problem of return of results requires a framework that spans the translational spectrum from research to clinical care to public health.<sup>9,10</sup>

### *Ethics of personalized medicine versus public health*

Arthur Caplan, professor of bioethics at New York University, explored the ethical challenges in genetic testing for neurological conditions. Genetic markers for hereditary diseases, such as Down syndrome, muscular dystrophy, Huntington’s disease, and certain types of cancer, can be identified in fetuses, newborns, and children. This is an emerging area of enormous ethical concern. The physical risks associated with the tests are very small, but other risks to consider are the emotional, social, and financial

consequences of the test results, including unnecessary treatment or surgery and a potentially false sense of security about risks when given a negative result.

Predictive genetic testing for adult-onset conditions that may manifest decades in the future is strongly discouraged until children are old enough to make decisions for themselves, but ultimately parents are still the decision makers for their children. Positive benefits of genetic testing include allowing individuals and families to take preventive measures against disease and improving response to treatment through more targeted therapies, such as those designed for BRCA<sup>+</sup> women with breast cancer. Guidelines provided by the American College of Medical Genetics and Genomics are not meant to be binding but to serve as recommendations for how physicians should ideally proceed. This guidance is especially important to help physicians navigate the increasing complexity of genetic testing. Owing to concern for the rights of persons with disabilities, for instance, a few U.S. states have already banned the abortion of fetuses diagnosed with Down syndrome.

### *Vaccines—opportunities and challenges in meeting global expectations*

Many challenges exist for vaccine innovation, but how scientists develop vaccines for emerging infectious diseases is one of the most critical. Scientists today need to deal with emerging diseases more quickly than ever before, and translating scientific progress into public health advancements depends on alignment and integration of private and public-sector stakeholders who are willing to share risks and fill gaps in preparing and responding to emerging public health threats. It is imperative that scientists proactively develop mutual understanding across disciplines to find new ways of approaching vaccine development.

Mark Feinberg, president of the International AIDS Vaccine Initiative, noted that successful vaccine development depends on a highly iterative, integrated system predicated on a bidirectional flow of information. Historically, developing a new vaccine has taken 15–20 years, and successful product development and implementation are difficult enough when pursued within a single company. Society's collective success will depend on the extent to which effective new partnership models and networks can be developed to address the challenges

of vaccine development for emerging diseases, Feinberg said.

There is still no vaccine for HIV/AIDS, a devastating disease. More than two million infections occur each year, half of all people living with HIV do not know they have it, more than 40 million people worldwide have died of AIDS, and more than 37 million are living with the HIV virus. Without a vaccine, AIDS will continue to kill. Significant scientific challenges to development of an HIV vaccine remain, and owing to limited public and private-sector collaboration, the mechanisms and models for the most effective strategies have yet to be developed.

Vaccine development in response to Africa's recent Ebola outbreak, however, provides a framework for vaccine development for emerging diseases. Ebola is a zoonotic virus, and bats are the most likely reservoir, although the species of bat is unknown. Infected wild animals, fruit bats, monkeys, and duikers spread the virus to humans, which is then followed by human–human transmission. The 2014–2016 Ebola outbreak, which began in Guinea, was caused by *Zaire ebolavirus* and killed more than 11,000 people. While the outbreak was declared over on January 17, 2016, new cases were detected in Guinea that very day.

During the outbreak, it became apparent that vaccine development was clearly needed. To pool expertise, share costs and risk, and manage uncertainties, vaccine development occurred in collaboration with public-sector partners. Merck's resulting rVSV-ZEBOV-GP (V920) vaccine is a replication-competent, monovalent, single-dose vaccine. Three large-scale accelerated phase II and III trials for the rVSV-ZEBOV-GP (V920) vaccine were implemented in Liberia, Guinea, and Sierra Leone. In January 2015, dose selection was made for the three efficacy trials. In July 2015, the phase III ring vaccination trial interim analysis results demonstrated vaccine efficacy, and, on August 17, 2015, the Merck Phase III Safety and Lot Consistency Study was initiated in the United States, Canada, and the European Union. According to the July 31, 2015, *Lancet* publication of the interim analysis of the Guinea study, people were 100% protected against the disease within 6 days of vaccination. However, trial implementation in affected countries has proved challenging.<sup>11</sup>

The lesson learned from the response to this outbreak is that private-sector partners need to work

together to share risks and responsibilities. Manufacturers need public-sector partners willing to be transparent about projected demand and willing to share the risks of accelerated production of doses that could go unused. The global health community needs to stay committed to developing Ebola vaccine candidates, or it will be more difficult to mobilize collective efforts to address future emerging infectious disease threats.

***The Precision Medicine Initiative—U.S. Department of Health and Human Services overview***

Precision medicine is a novel approach to disease treatment and prevention that accounts for individual genetic variability, environmental factors, and lifestyle. This emerging approach aims to gain better insights into the complex biological, environmental, and behavioral influences that constitute the development of disease. According to Adam Berger, senior fellow with the U.S. Department of Health and Human Services, the goal of the PMI is to utilize research and technology to empower patients, researchers, and providers to work together toward the development of individualized treatments.

One development of the PMI is the creation of a million-person voluntary national research cohort, which is a patient-powered research effort to leverage existing research and clinical networks. This longitudinal cohort will broadly reflect the diversity of America by including family members of all ages and health statuses and will have a strong focus on underrepresented groups. Participants, who are enrolled by directly volunteering or through a healthcare provider, will complete a baseline survey and examination and provide biospecimens. Data are expected to be collected from multiple sources, including electronic health records, participant-provided information, initial physical examinations, laboratory test results, and geographical location information.

***The science behind precision medicine: mapping complex traits and diseases***

Translational research applies findings from veterinary science to enhance human health. In translational research, dogs can serve as an important model for human disease. Using genomics to study canine diseases has many applications to veterinary and human medicine and can provide important insight into the etiology and pathology of

many diseases. Canine genetic research is a great example of the interplay between veterinary and human medicine and provides many examples of One Health in action.

Canines and humans share genetic and genomic advances. They also share medical concerns, with similarities in disease risk, presentation, pathology, and response to treatment, according to Elaine Ostrander, distinguished investigator with the National Institutes of Health. At the genetic level, humans and canines share similar chromosomal and gene organization, with similar sequences within many individual genes. More than 500 dogs of known health status have undergone whole-genome sequencing. Genome-wide association studies have been successful in finding disease genes and morphological traits, and results illuminate similar conditions in humans for cancers, autoimmune diseases, neurologic disorders, and many other conditions.

One example is the canine linkage study, which focused on canine hereditary multifocal renal cystadenocarcinoma and nodular dermatofibrosis in a closed breeding population of German shepherds. Closed breeding populations are helpful for canine geneticists and provide advantages over those enjoyed by human geneticists. Extensive pedigrees—which can easily be found in canine studies but are more difficult to find in human genetic studies, especially cancer studies—allowed identification of chromosome and gene locations. Mutations were found in a follicular gene that normally encodes a tumor suppressor. The locus was found first in canine studies, and human studies followed (Birt–Hogg–Dubé syndrome in humans).

Dogs are a particularly effective model for human transitional cell carcinoma (TCC) of the bladder. The cause of TCC is unknown in 50% of people with the disease. Frontline therapy is involved and expensive, and half of all patients undergoing treatment die from metastatic cancer. Scottish terriers, West Highland white terriers, and Shetland sheepdogs are affected by TCC. The tumor develops from transitional epithelial cells that line the bladder and then invades deeper layers of the bladder, including the muscle wall. Veterinarians have sequenced RNA from four tumors and two normal dogs to find genes that are expressed only in tumors or only in normal bladders. In 85% of the tumors in dogs, and none of the normal tissues, there was a point mutation

in the *BRAF* gene (*BRAF-V600E*). Point mutations make up 90% of all *BRAF* alterations identified in humans (melanoma, thyroid, and colorectal), and all are associated with poor outcomes. Preliminary studies using combination therapies in dogs show promise, reducing cell growth by 65–75% in cell lines with the *BRAF-V600E* mutation.

Squamous cell carcinoma of the digit (SCCD), a common nailbed cancer in dogs, is locally aggressive, highly breed-specific, and associated with black coat color in certain breeds, including standard poodles. Veterinary geneticists have identified the *KITLG* locus in the genome associated with SCCD in standard poodles. *KITLG* is associated with coat color and appears to play a role in cancer, especially skin cancers, such as melanomas. The number of copy variants upstream of *KITLG* regulates expression; the more *KITLG*, the blacker the coat color.

Canine transmissible venereal tumor (CTVT) is caused by a clonally transmissible parasite through sexual transfer of malignant cells. The tumor is caused by the world's oldest known continuously propagating somatic cell lineage, and all CTVT tumors have a shared origin, a strong genetic identity with one another that is markedly distinct from their transient host. Mutated genes disrupt all aspects of somatic cell participation and immunosurveillance. Somatic mutations may have contributed to genome instability. Genes known to be important in human cancers are also disrupted in CTVT, raising the question of whether humans will be next in acquiring some form of this disease. Similar cancers include a related facial tumor transmitted through biting and clawing in Tasmanian devils; a leukemia-type cancer in clams along the Atlantic coast; and experimentally transmitted CTVT in hamsters in laboratory settings.

### *The Minnesota effect and evidence-based policy in global health*

In the 1950s and 1960s, Seoul National University conducted a faculty exchange project with the University of Minnesota, and the University of Minnesota also provided aid for equipment. With support from the University of Minnesota, Seoul National University has extended the sharing model to help underserved populations around the globe *via* evidence-based medicine and evidence-based policy in global health.

Juhwan Oh, professor of International Health Policy and Management at the JW LEE Center for Global Medicine at Seoul National University College of Medicine, described a quantitative study conducted in eastern Ghana to explore barriers and enablers to enrollment in Ghana's National Health Insurance Scheme (NHIS) and to discover the interventions needed to support the attainment of universal population coverage. The study found that barriers to enrollment or renewal in the NHIS were due to design and implementation factors and that Ghana's health insurance could be improved using evidence-based practice. Most people in Ghana want to be enrolled in universal health care. More people who understood the scheme and/or the benefits package enrolled in the NHIS compared with those who did not. Richer people were willing to pay more for health care, but so were poorer people. Some people were initially registered, but failed to renew insurance because of barriers, such as distance to the registration office.

### *Air pollution, health, and policy*

C. Arden Pope III, the Mary Lou Fulton professor of economics at Brigham Young University, has extensively investigated the global health burden associated with inhaling contaminants. The number of deaths each year attributable to the inhalation of airborne contaminants exceeds 13 million. Tobacco smoking accounts for 5.7 million deaths; secondhand smoke for 600,000 deaths; household air pollution from solid fuels for 3.5 million deaths; ambient particulate matter (PM) for 3.2 million deaths; and ambient ozone for 200,000 deaths.

In his presentation, Pope looked at the links between air pollution, health, and policy. For instance, early "killer smog" episodes in developed countries resulted in many deaths. During a 1930 episode in the Meuse Valley of Belgium, 60 people died, which was 10 times the number expected. During a 1948 episode in Donora, Pennsylvania, half the town became sick and 20 people died. London's 1952 killer smog episode is considered to have caused thousands of deaths from respiratory and cardiac disease.

Pope and colleagues detailed a case-crossover study of acute coronary events (i.e., heart attacks and unstable angina) in 12,865 cardiac patients living on Utah's Wasatch Front who underwent coronary angiography related to short-term exposure to

fine particulate air pollution.<sup>12</sup> The study concluded that short-term particulate exposures contributed to acute coronary events, especially among patients with underlying coronary artery disease.

In general, short-term changes in air pollution exposure are associated with increased daily respiratory and cardiovascular death counts, hospitalizations, decreased lung function, symptoms of respiratory illness, school absences, and ischemic heart disease. His group's studies have looked at the long-term effects of air pollution and found a strong correlation between air pollution and disease, with age, sex, and race showing varying levels of association.<sup>13</sup> The Southern California Children's Health Study, for example, showed that children living in cities with greater air pollution and nearby major traffic sources had greater deficits in lung function.<sup>14</sup>

Additional research showed that, over the last several decades, the Clean Air Act has helped to decrease air pollution in cities like Los Angeles and to reduce bronchitis symptoms in children.<sup>15</sup> In 1998, for example, nearly eight out of 100 15-year-olds in Los Angeles had significant lung deficits, compared with only 3.5 in 2011. Pope noted that the improvement in air quality has increased average life expectancy by 7.3 months. With adverse health outcomes so clearly associated with PM inhalation, clean air should be considered an economic good. As with other economic goods, production of clean air contributes to economic prosperity, human well-being, and improved public health.

### *Air pollution and health: evidence and policy in 2016*

The scientific evidence linking air pollution and health is substantial and has motivated evidence-based, successful air-quality management, yet much of the world continues to experience unacceptable public health risks from air pollution. Jonathan Samet, distinguished professor and Flora L. Thornton chair in preventive medicine at the University of Southern California, provided a real-time air pollution tour of the globe, based on PM 2.5 levels (<http://aqicn.org/>). One week before the day of his presentation, Beijing registered 162, unhealthy; Jakarta registered 74, moderate; Hong Kong, 76, moderate; Taipei, 78, moderate; Delhi, 690, hazardous; New Delhi, 151, unhealthy; Mumbai, 87, moderate; Zurich, 13, good; Moscow, 50, good;

London, 60, moderate; Paris, 45, good; Madrid, 46, good; South Africa, 39, good; Buenos Aires, 53, moderate; Mexico City, 157, unhealthy; Montreal, 15, good; New York, 18, good; Los Angeles, 61, moderate; and Minneapolis, 25, good.

Today, air-quality management straddles two worlds, the high-polluted world and the low-polluted world. In the high-polluted world, large populations are at risk, and control of air quality is critical for public health and climate change. The link between air pollution and disease is conclusive; there is little need for additional research. Air quality in the high-polluted world needs to be monitored, and action needs to be taken, based on WHO guidelines.

In the low-polluted world, air quality has improved substantially in many high-income countries, yet epidemiological studies indicate that there is continued risk and associations with newly revealed health-related outcomes, such as aging of the human brain. Because of the Clean Air Act, air pollution in the United States has been declining. The percentage of the population with decreased lung function and the incidence of asthma and bronchitis symptoms have declined as well. The dilemma for the low-polluted world is that epidemiological studies show adverse effects at current exposure concentrations. Furthermore, some effects, such as lung cancer, occur seemingly without threshold. The message here is that constant vigilance and continuous efforts at improvement are required.

### *Household air pollution due to cooking practices*

Around the globe, 500 million households, or three billion people—nearly half of the world's population—rely on open fires or simple stoves that burn solid fuels, such as wood, animal dung, and coal, to prepare their food, and 4.3 million people each year die prematurely from illnesses attributed to household pollution arising from this practice. The use of solid fuel for cooking in the developing world creates \$123 billion in annual costs to health and local economies.

The Global Alliance for Clean Cookstoves is working to create a thriving market for clean cookstoves and fuels that will save lives, improve livelihoods, empower women, and protect the environment in the developing world. Sumi Mehta, senior director for research and evaluation at the

Global Alliance for Clean Cookstoves, which works with more than 1500 partners to promote clean cooking in more than 40 countries, stressed that clean cooking has been shown to improve human health while saving households time and money. Thus, clean cooking solutions address the most basic needs of the poor while delivering climate benefits. Up to 25% of black carbon emissions are the byproduct of burning solid fuels for household energy needs, and up to 34% of the wood fuel harvested is unsustainable because it contributes to forest degradation, deforestation, and climate change.

Household air pollution is caused by incomplete fuel combustion and results in a complex mix of health-damaging pollutants, including respirable particles, carbon monoxide, oxides of nitrogen and sulfur, benzene, formaldehyde, 1,3-butadiene, and polyaromatic compounds, such as benzo(a)pyrene. The problem is most acute in China and India, the world's most populous countries. In India, solid fuel emissions contribute 27% to outdoor air pollution, and in China the value is 15%. Household air pollution is one of the top global health risks, following high blood pressure, tobacco use, diets low in fruits, and alcohol use. Household emissions must be addressed, along with other sources, to meet ambient air quality standards and reduce global human health risk.

Reducing exposures to achieve health benefits is complex. Children's health has become the motivation behind reducing household exposure and emissions, but how clean is clean enough to make an impact on children's health and survival? Randomized controlled trials in Ghana, Nepal, and Nigeria found that women like using clean fuels and use them nearly exclusively when possible, creating a dramatic reduction in exposure to air pollution. Emerging evidence on the resulting health benefits is also trending in the right direction, with differences being seen in children's lung function at 1 month of age.

Ensuring public health benefits, however, will require increased efforts to supply the poor with safer cookstoves, innovation to ensure product performance and user acceptability, a diversity of products to meet different customer segments, and increased access and affordability. Compared with 10 years ago, more clean cooking methods are being distributed and promoted in countries in need, and clean cooking has been integrated into efforts to pre-

vent pneumonia. For instance, a clean-cookstoves initiative in support of women's empowerment, public health, reduction in air pollution, and climate mitigation is underway in India. Evidence on the contribution of household pollution to ambient air pollution is also spurring policy action: the Ministry of Health and Family Welfare in India, along with the Indian Council of Medical Research, is supporting research and exploring integration of clean cooking into India's pneumonia-prevention program.

### *Air pollution and environmental justice*

Not all people breathe the same air. In the United States, according to Julian Marshall, professor of civil and environmental engineering at the University of Washington, both race and household income are associated with exposure to air pollution, with race being a stronger predictor than income. Higher income and white households are less likely to be exposed to air pollution than lower income households and households of color in urban areas. The disparities are smaller in rural areas, compared with urban areas. Within a given urban area, some pollutants, such as ozone, are more common in suburban areas, whereas most pollutants, for example, diesel exhaust and benzene, are more common in downtown areas and near sources such as highways and industry.

Air is getting cleaner in the United States, and further improvements would lead to further improvements to human health. An important question for air quality management is which sources to control and by how much. Marshall gave examples to illustrate how emission reductions can take into account the dual goals of reducing total health risks and disparities in those risks. For example, for the case of PM from diesel engines in the Los Angeles area of California, he compared emissions from five sources. His research showed that ship emissions are a large source of exposures, yet a comparatively small contributor to exposure disparities, because ships affect people living by ports and by the coast—a group that includes nonwhites and whites and low-income and high-income populations. Trains have a large marginal impact on exposure disparities. Hence, reducing train emissions by a fixed amount—say, 1 ton per year—would yield a comparatively large reduction in exposure disparities. Nevertheless, the total impact to exposure

disparities is only modest because total train emissions are small. Beyond the specific findings for diesel emissions in Southern California, the example illustrated how targeting emission reductions may address total health impacts and environmental inequities based on income and race.

### *Air pollution and cancer risk*

Global estimates of lung cancer deaths due to exposure to air pollution show that residents of less developed countries suffer more disease and death owing to greater exposure to household pollutants and PM, according to Paolo Boffetta of the Icahn School of Medicine at Mount Sinai in New York. Strong evidence also exists that air pollutants cause lung cancer, though methodological challenges remain with respect to accurate assessment of risk.

Occupational and pollution studies have shown that many carcinogens are found in air pollution, including diesel engine exhaust, other mixtures of polycyclic aromatic hydrocarbons, volatile organic compounds, heavy metals, asbestos and other fibers, radon decay products, secondhand tobacco smoke, and coal combustion emissions. It follows that increased risk of air pollution is associated with increased risk of cancer. Studies of outdoor air pollution and cancer have shown that sulfur dioxide and mononitrogen oxides are not carcinogenic and have variable correlations with carcinogens, while exposure to PM 2.5 or larger particles increases cancer risk. Meta-analysis shows that there is a 9% increased risk with every 10-unit increase in exposure to pollution. In lung cancer, the effect of PM 2.5 exposure also seems to be stronger in men when relative risk is stratified by sex.

The bias of post hoc analyses stems from exposure misclassification. For example, ecological-level data used to assign exposure to individuals are imprecise. Misclassification occurs because individuals spend time in different locations, both indoors and out. If anything, exposure to carcinogens in air pollution is underestimated, while latency between exposure and lung cancer development may be a source of overestimation of risk. Residual confounding can also occur from tobacco smoking and occupational exposure to carcinogens.

### *Lack of access to water—the greatest threat to achieving global food and nutrition security*

A global water crisis is one of the three biggest risks the world is facing. The other two are invol-

untary large-scale migration and failure to adapt to and mitigate climate change, according to the Global Risks Report 2016 (World Economic Forum 2016).<sup>16</sup> Two-thirds of the world's population could face water stress by 2025, and, over the next 10 years, lack of access to water poses the biggest risk to society and the global economy. More than a third of the world's population has no access to modern sanitation. Some countries lose as much as 7% of gross domestic product owing to lack of adequate sanitation, and more than 80% of the world's wastewater is dumped into untreated water supplies. Climate change and urbanization will affect vital groundwater reserves, on which 50% of the world's population depends for drinking water. Agriculture is the world's largest consumer of water, accounting for 70% of total use, and rising energy production will increase water demand by 85% by 2035.

Ajay Markanday, director of the Food and Agriculture Organization (FAO) Liaison Office in North America, detailed world water issues based on the global outlook to 2050. Agriculture will remain the largest consumer of water, accounting for half of all water withdrawals from rivers, lakes, and aquifers. Groundwater withdrawals will exceed the rates of natural recharge in South Asia, Southeast Asia, the Near East, North Africa, North America, and Central America. Climate change will require investment in improved water management by agriculture. Many of the world's poor will remain food insecure owing to insufficient water resources to meet demands from agriculture. At the same time that rural water demands increase for food production, urban demands for water will soar owing to rapidly rising populations in cities in the developing world. Markanday concluded that our ability to meet future global water and food challenges will depend heavily on concerted water sector reforms, especially in irrigated agriculture, as well as incentives that encourage new water harvesting and water-saving technologies.

### *Pharmaceutical waste in water: reducing emissions from use and manufacturing*

Pharmaceutical residues in water are of great concern for several reasons: they are biologically active in living organisms, they are environmentally stable and not easily biodegradable, they are not often removed in wastewater plants, and they accumulate in waterways and groundwater supplies.

Marie-Louise Ovesjö, senior consultant with the Stockholm County Council, noted that, in 2010, the Swedish Environmental Protection Agency detected 26 pharmaceutical substances in Sweden's drinking water. Pharmaceutical residues originated from manufacturing, use, and disposal. Manufacturing of pharmaceuticals includes medicines used in hospitals, at home, and sold over the counter. Most of Sweden's pharmaceuticals are imported, so residues in water are not primarily the result of manufacturing. Pharmaceuticals excreted through urine end up in wastewater treatment plants, and household excretion accounts for 90% of the pharmaceutical residues in Sweden's waste water.

Since 2003, pharmaceutical substances in Sweden have been assessed regarding their environmental hazards with respect to persistence, bioaccumulation, and toxicity. Since 2005, pharmaceuticals have also been assessed for environmental risk or the risk that toxic concentrations will accumulate in Swedish water systems. To minimize cost to individuals and the environment, Stockholm created a Wise List to help prescribers choose the best medicines, which included environmental aspects and their assessment. More than 80% of prescribed medicines in the Stockholm healthcare region are on the city's Wise List.

The selection of medicines for the Wise List is based on medical effects and safety for a given indication. If several substances are deemed equal by these criteria, the medicine with the most favorable total cost and environmental classification is recommended. A substance with available environmental information should be recommended over substances lacking information, and, when possible, other environmental effects should be taken into account, such as the level to which the drug residue can be reduced in wastewater treatment plants.

Sweden has been measuring how wastewater treatment plants can reduce levels of various pharmaceuticals. For example, paracetamol/acetaminophen can be reduced by 90%, ibuprofen by 85%, naproxen by 69%, ketoprofen by 51%, and diclofenac by 11%. To raise awareness of the environmental impact of various medicines, Sweden is educating prescribers, looking at ways to improve wastewater treatment, and trying to minimize residues by teaching health-care personnel and the public how to dispose of pharmaceuticals correctly.

### *Science and water policy management*

Water and sanitation are inextricably linked. Every 15 s, a child dies from a water-related disease, and 98% of water-related deaths occur in the developing world. Safe water supplies are not accessible to approximately 700 million people, and about 2.5 billion people, or one out of three, lack access to adequate sanitation, the most critical factor in prevention of infection.

A Massachusetts Institute of Technology modeling study of water stress as a function of development and climate change found a high risk of severe water stress in China and India.<sup>17</sup> Deborah Swackhamer, director emeritus of the Water Resources Center at the University of Minnesota, noted that some headway has been made in providing access to safe drinking water, but less has been done to provide access to sanitation. The world does not have an international water policy. The closest thing to an international water policy is goal number six from the United Nations Environment Program's Sustainable Development Goals, which states that everyone should have access to water and sanitation by 2030.

The lack of water and sanitation is not a problem of science; it is a political and economic problem. For example, the United States has a long legacy of water protection and regulation. However, California, a state with competing water interests, struggled with a severe multiyear drought in 2016, but did not have policies to deal with drought. After the city of Flint, Michigan, changed its source of drinking water to the Flint River, dangerous levels of lead were detected in the water in 2015. In 2014, blue-green algae in Lake Erie shut down the water supply to the city of Toledo, Ohio, for an entire week with no warning.

Public outcry in the United States in the 1950s and 1960s led to the enactment of major legislation to protect water in the 1970s. On August 20, 1960, *Time* magazine declared Lake Erie "dead" from too much algae caused by high phosphorus levels that led to huge fish kills. In the 1950s, the Cuyahoga River in Ohio was set on fire multiple times. The 1974 Clean Water Act set two goals: the waters of the United States shall be swimmable and fishable and they shall have no unsafe pollution discharges. The act provided guidelines for policy that states were to implement. The 1974 Safe Drinking Water Act was the first federal law to mandate drinking

water standards for all public water systems. The act required the Environmental Protection Agency to set standards and provide financial assistance and enforcement to states, which implemented the act.

Even with enactment of public policies to protect water quality, there still are major gaps in U.S. water policy. There is no federal policy for access to water that is shared across state boundaries, since states are considered as trustees of U.S. waters within their own borders. There is no federal policy for groundwater rights or water quality; states may regulate groundwater, but only about half do so. There is no federal policy for the control and management of water quantity, neither surface nor groundwater, which is regulated by states even though water does not remain within state boundaries.

Social values play a huge role in water policy. If water is valued, it will be protected through policy. Other contributors to water policy development are scarcity of resources; local and national politics that have different but enormously important roles that can change with time; economics; science and information; and technology. Gaps in knowledge and uncertainty are weaknesses that do not allow science alone to inform policy. Policy is and should be dictated by more than science; however, good policy is impossible without good science. Science provides monitoring of data and identification of trends, it enables technological advancement, and it provides research data and interpretation. The role of science in informing policy is to link exposures to human and ecosystem health, identify gaps, and describe uncertainty.

There are three major obstacles to informing policy with science: special interests alter the conversation; concerns that are global may only get traction when a local connection is made; and the lack of knowledge integration when water policy data needs are interdisciplinary. Special interests and trade groups have been very successful in influencing water policy. For instance, the 2015 Clean Water Rule clarifies the definition of “waters of the United States,” reduces the case-by-case workload of the federal government, and sets a goal to protect waters downstream of streams and tributaries. It does not, however, change requirements for agriculture, interfere with private property rights, or change municipal storm water rules. There is now a court-ordered stay on the rule due to legal challenges.

An example of a local-versus-global issue is the hypoxic zone in the Gulf of Mexico. This dead zone is caused by nitrates entering the Mississippi River watershed and flowing into the Gulf of Mexico. Nitrates also contaminate well water. To date, 14 public water systems have had to buy reverse-osmosis systems to filter out nitrates, which raises local water bills by about \$200 per person per year. And sometimes what appears to be a state problem is more widespread. For instance, California’s unprecedented drought is not just a state problem. Half of the fruits and vegetables grown in the United States are grown in California, thus making a state drought a national food access issue.

Lack of thoughtful integration is also an issue in the development of coherent water policies. Desalination of ocean water is one approach to increasing available water supplies. Seventeen desalination plants are planned around the globe, with the biggest one in the United States just outside of the city of San Diego. Desalination is energy intensive. Removing salt from one million gallons of water requires 15,000 kW/h of electricity, making energy consumption half the cost of water, along with the unintended consequence of increased greenhouse gas emissions. There is also lack of integration in water policy for food production. The third most important part of a person’s water footprint is food consumption. According to the Water Footprint Network, for example, it takes 1056 gallons of water to produce a gallon of brewed coffee and nearly 300 gallons of water to produce a gallon of beer. More than 200 gallons of water are required to produce a pound of pasta. Meat production requires even more water: 518 gallons of water per pound of chicken and 1847 gallons per pound of beef.

The state of Minnesota provides a case study of sustainable water use. In 2009, Minnesota amended its constitution with the passage of the Clean Water, Land, and Legacy Amendment. It defined sustainable water use in law and designated a portion of state sales taxes, about \$120 million per year, to a clean water fund. The Minnesota Water Sustainability Framework is a 25-year plan to achieve water sustainability that is maintainable, comprehensive, and integrated. Effective water policy developed out of social values and a water ethic, political leadership, economic investment, science engagement, and integration and synthesis across silos. Continued support and development of the

policy may serve as a model for other regions of the world.

### *Environmental pollution impacts on fish and humans*

The Black Sea, one of the youngest seas in the world, faces several challenges. The water below about 150 m in depth is devoid of dissolved oxygen, making the Black Sea the largest anoxic body of water in the world. Such anoxic conditions, exacerbated by limited water exchange with the Mediterranean Sea, render the Black Sea extremely vulnerable to anthropogenic effects, according to Levent Bat, professor of fisheries in the Department of Hydrology at Sinop University in Turkey.

The Black Sea receives an estimated 42,600 tons, or 83% of its annual pollution load, from the rivers that flow into it. Another 8675 tons come from land-based sources. Contaminants include petroleum hydrocarbons, plastics, pesticides, heavy metals, sewage, radioactive waste, thermal effluents, detergents, chloroform, food-processing waste, lubricants, insecticides, and herbicides. Woe be to the fish and their prey.

There are 22 economically important species of fish in the Black Sea, and the most heavily fished area of sea is found along the Turkish border. Both bioaccumulation and biomagnification are issues, with heavy metals of particular importance to Turkish exporters, who use scientific data to demonstrate the quality of their product. Of the 92 naturally occurring elements, about 30 are potentially toxic to humans.

The FAO and the WHO have set tolerable weekly intakes of heavy metals for humans. On the basis of weekly intakes of fish in Turkey, none of the Black Sea fish studied so far have had chemical residue levels that pose a threat to human health. The livers of the fish species studied generally had the highest heavy metal content. Fish livers are not typically consumed, except that livers of small pelagic fish are difficult to remove, so are likely ingested. Unfortunately, small pelagic fishes, primarily European anchovy (*Engraulis encrasicolus*), have constantly represented more than half, and up to 75%, of total landings since 1970.<sup>18</sup>

A clear picture of heavy metal pollution in various regions of the Black Sea is difficult to obtain owing to a lack of comparable data from studies with similar methodologies. Nevertheless, indepen-

dent investigations and available data suggest that the water pollution situation is dire and that action is needed. Public and ecosystem health may be severely compromised, making it imperative that each country of the Black Sea adopts uniform rules and creates a uniform and coordinated environmental policy.

### *Influence of a natural water flow system in the epidemiology of anthrax at a human–wildlife–livestock interface: the case of Queen Elizabeth National Park*

Queen Elizabeth National Park is the second-largest national park in Uganda, Africa, in terms of protected area. Since the 1950s, the park has experienced numerous anthrax outbreaks. The anthrax bacterium is found in humans and other animals and can be fatal even when treated. Major anthrax outbreaks occurred in the park in 2004 and 2010, causing widespread death among wildlife.

Margaret Driciru, principal warden and wildlife veterinarian for the Uganda Wildlife Authority, noted that, for some unknown reason, the hippopotamus is very susceptible to anthrax, with water buffalo being a spillover and, perhaps, maintenance host. The park contains two major water bodies, Lake George and Lake Edward, which are connected by the Kazinga Channel. When hippos are in water, they school, piling one on top of another. Hippos are very aggressive animals that fight often and can travel long distances at night when they graze. Once a hippo dies, it sinks and stays submerged for about 16 h before the carcass floats to the surface and begins moving through the water, creating numerous spores and bacteria if infected with the anthrax bacillus.

When anthrax outbreaks occur in the hippo population, the carcasses need to be buried to control the outbreak. When not buried, they can float in the water for up to a year. During the 2004 anthrax outbreak, as many as 300 hippos could be seen floating in the water. This was so unsettling that the Uganda Wildlife Authority began burning and burying the dead animals.

With support from the U.S. Centers for Disease Control and Prevention, a surveillance program for anthrax in hippos was developed. To discover what is driving anthrax in the ecosystem and to understand the spatiotemporal patterns of the outbreaks, the mechanisms involved, and how the outbreaks

moved, wildlife ecologists looked at the locations where hippo carcasses were found as well as the epidemiologic behavior of the outbreak and the origin and behavior of the agent, using permutation with case-clustering and times-series models.

The epidemic curves show that outbreaks occurred in waves. There was a point-source propagated effect of anthrax in hippos in the park, which could be due to hippo social dynamics, and evidence that anthrax was spread between clusters. Because hippos are poached, anthrax in hippos is an important public health issue that could potentially spread to the Ugandan community and elsewhere.

### *Status and challenges of environment and health in China*

China, the world's most populous country, is undergoing rapid urbanization; the number of cities in China more than tripled between 1978 and 2015. This accelerated rate of urbanization has made it increasingly difficult to prevent environmental degradation, manage urban growth, and meet the demands of Chinese citizens for housing, food, energy, and transportation. The resulting pollution has led to numerous health problems related to air and water quality.

Jin Yinlong, professor with the National Institute for Environmental Health and Related Product Safety at the Chinese Center for Disease Control and Prevention, reported that rapid economic development in China has resulted in numerous environmental problems, such as serious air pollution, large amounts of wastewater discharge, and solid waste generation, all of which pose serious environmental health challenges. Total energy consumption in China increased 15-fold from 1970 to 2015. Coal accounts for about two-thirds of total energy consumption in China and will be the dominant energy source for the next several decades. The total number of civil and private automobiles increased 31- and 176-fold, respectively, between 1990 and 2015. China's traffic pollution is the most serious in the world, and the combination of pollution caused by coal burning and vehicle exhaust is now a severe problem.

Urban air pollution is a serious environmental concern in China. Among the 338 cities where the country's new environmental air-quality standards have been implemented, only 21.6% met

the new national standard for air quality. Malignant tumors, respiratory diseases, lung cancer, and chronic obstructive pulmonary disease have all been linked to air pollution in China. Air pollution is also a major cause of noncommunicable diseases and childhood pneumonia. Annually, an estimated 178,000 deaths, 350,000 outpatients treated with respiratory disease, and 6.9 million patients receiving emergency medical care are due to urban air pollution in China.

China's drinking water resources are also seriously polluted. Of 702 water-quality monitoring sections in the country's seven major river systems, only 71% are suitable for centralized drinking water resources. Of 62 state-controlled major lakes, only 61% meet the standard for centralized drinking water resources. Polluted drinking water in China has been linked to digestive tract cancers, endemic fluorosis, and chronic arsenic poisoning.

Body burdens from environmental pollutants have also been studied in China. Serum levels of seven polycyclic aromatic hydrocarbons were detected in 620 pairs of pregnant women and neonates in Taiyuan city by the Chinese Center for Disease Control and Prevention. Pesticides were also detected in serum samples of 247 pairs of pregnant women and neonates, indicating that organochlorine pesticides can transfer through the placenta. Heavy metals, arsenic, cadmium, and lead have also been found in maternal and cord serum.

Climate change is also causing health issues in China. According to the National Meteorological Bureau, the nationwide average air temperature is expected to increase 1.3–2.1 °C by 2020 and 2.3–3.3 °C by 2050 compared with average temperatures in 2000. Health impacts linked to climate change include heat-related sensitive diseases, including circulatory, endocrine, nutritional, metabolic, genitourinary, mental and behavioral, and respiratory. To provide health workers and community residents with information about health risks before a heat wave occurs, China has developed an early warning system for heat waves and health risks. It gives people valuable time to take appropriate action to prepare for and reduce potential health risks. While an abundant amount of research has been conducted on how pollution and climate change negatively affect health in China, limited research has been done on potential solutions to the problems.

### *The use of climate models in the prediction of vector-borne diseases*

Global climate change, one of the most critical environmental threats to human health, could result in changes in both the severity and distribution of vector-borne diseases. Infectious vector-borne diseases are transmitted by the bite of infected arthropod species, such as mosquitoes, ticks, triatomine bugs, sandflies, and blackflies. Because arthropod vectors are ectothermic, they are especially sensitive to climatic factors.

Vector-borne diseases, including malaria, occur at the point where pathogens, host, vector, and climate intersect. An estimated 584,000 deaths each year are caused by malaria, with 90% of these deaths occurring in Africa. Malaria's disease burden and transmission are sensitive to environmental conditions. As climate changes, so too could the distribution of malaria and other vector-borne diseases, according to Andy Morse, professor of climate impacts at the University of Liverpool, England. Climate models could prove especially useful tools to predict vector-borne diseases.

Models can show changes in the distribution patterns of malaria that result from climate change. Models that take into account the impact of temperature and climate on the transmission of malaria and other vector-borne diseases may be used with weather forecasts to determine the risk of disease transmission at different times of the year and at different geographic locations. Models that include changes in climate can also be used to develop information and early warning systems to minimize or prevent the spread of malaria and other vector-borne diseases. They can also be expanded to take into account additional variables, such as cost and other important economic considerations, when making policies.

### *Linking science and policy: the foodborne disease consideration*

Over the last decade, some countries have actually reduced the number of people killed in traffic accidents by 80% based on science. Why are countries not seeing similar decreases in the number of deaths caused by foodborne illnesses? Foodborne diseases are highly visible through outbreak events, but the true burden is invisible. Foodborne diseases cause considerable morbidity and mortality, the full extent of which has not been documented. Foodborne

diseases are complex and are caused by numerous hazards that result in various health outcomes and effects. Moreover, although food is only one of multiple transmission pathways of food-related hazards, quantitative and qualitative data are limited.

Jørgen Schlundt, Michael Fam Chair Professor of food science and technology at Nanyang Technological University in Singapore, reported that the global burden of foodborne disease can be measured in terms of illnesses, deaths, and disability-adjusted life years (DALYs), with one DALY equal to one healthy year of life lost. Total DALYs are calculated by adding years lived with disability and years of life lost. When measuring the global burden of foodborne diseases, scientists must look at the important foodborne hazards and estimate the total number of DALYs for each hazard, preferably also linking the hazards back to the food source.

The WHO has defined 14 geographical sub-regions based on child and adult mortality. The WHO's disease-burden investigations, finalized in December 2015, include estimates for only 31 foodborne hazards, including 11 microorganisms causing acute diarrheal diseases, seven microorganisms causing invasive infectious diseases, 10 helminth infections, and only three chemical hazards. Full systemic reviews have been conducted for all hazards, with imputation and expert knowledge used to fill data gaps. These methods are compliant with WHO methodology for assessment of the global burden of disease computed in other areas.

To attribute illness to a source, the proportion of the disease burden that is attributable to food is first determined for each hazard. Next, the reservoirs and/or food commodities leading to the illness are identified and, if possible, quantified. Expert elicitation is applied to all hazards that do not originate 100%, or nearly 100%, from a single food source or food reservoir. In 2010, 600 million illnesses, 420,000 deaths, and 33 million foodborne DALYs were attributed to the 31 hazards investigated, according to the WHO.

The disease burdens for many diseases or sources have been assessed. In each year, one in 10 people in the world is expected to suffer from foodborne disease, but the actual number may be higher. According to 2011 estimates, the most common causes of foodborne illnesses and death are diarrheal diseases caused by norovirus and by bacteria, especially *Salmonella*, *Clostridium perfringens*, and

*Campylobacter* ([www.cdc.gov/foodborneburden/index.html](http://www.cdc.gov/foodborneburden/index.html)). Diarrheal diseases cause more than half of global foodborne DALYs.

Differences in burden between regions—for example, low in North America and high in sub-Saharan Africa—suggest that foodborne diseases are preventable using currently available methods. Successful prevention, however, is linked to economic development and effective food-safety systems. Governments and societies need to move away from reactive, repressive systems to preventive measures. In food microbiology, the novel use of next-generation (DNA) sequencing seems to provide us with significant new potential. A global system of all microbial DNA sequences would enable two major lines of action: simple identification of all microorganisms and real-time global surveillance of microbial disease in humans and animals, as well as food contamination.

Using foodborne disease burden estimations is important to assess and prioritize food risks. Cross-sectoral data are needed, and a One Health approach is necessary to reduce the overall global burden of foodborne disease.

### *Animal welfare: a case study in translating science into policy*

In 1997, the European Union's Scientific Veterinary Committee reported that confined housing of swine in gestation crates, even in the best stall-housing systems, resulted in serious welfare problems.<sup>19</sup> By contrast, in 2001 in Australia, Barnett and colleagues determined that both individual and group housing systems could meet the welfare requirements of swine.<sup>20</sup> In response to these studies, the European Commission banned gestation crates, while Australia and many other countries took the position that both group housing and gestation stalls were satisfactory for pigs.

Credible scientists reviewed the same literature, conducted both studies, and yet came to very different conclusions. How did this occur? Each study approached the question using a different framework, according to David Fraser, professor of animal welfare at the University of British Columbia. The term “welfare” is an assessment, not a descriptive metric, like temperature or height, which can be measured. Instead, animal welfare is an evaluative concept, like food safety, mental health, and environmental sustainability.

Evaluative concepts are common in science, especially when science is used to guide practices, decisions, and policy. Evaluative concepts involve value-based beliefs about what is better or worse and organize factual information into a value-based framework. How these concepts are measured and interpreted is determined by a value-based system.<sup>21</sup>

Scientists develop terms to communicate ideas for things that can be measured. When scientific definitions of animal welfare were created, there were too many definitions and they veered significantly from everyday concepts held by the public. Animal welfare is not a scientific term; it is an everyday term as well as an evaluative concept. When an evaluative concept is also an everyday concept, scientists need to recognize the value frameworks that shape the everyday meaning and then provide the science that helps interpret and operationalize that meaning.

For example, defining “good bread” only in terms of its measured nutritional value can lead to the conclusion that moldy bread is as good as fresh bread. This is obviously not true, but the scientific definition of good bread in this example ignores the everyday concept that good bread should not be moldy. At the same time, welfare does not mean anything the public wants it to mean. For instance, a child might decide to provide welfare to a pet frog by giving it a warm, dry bed and peppermints to eat. In this case, the child misunderstands the empirical concept of welfare.

Animal welfare is an everyday concept that reflects people's concerns about how animals are being treated. It can be misleading when scientists try to change the concept into something that can be quantified independent of emotion. Why then do scientists approach animal welfare with such different frameworks? They approach human welfare in the same way. The debate about the nature of a good life for people is still unresolved, so it only makes sense that the same debate for animals is also unresolved. The same value frameworks that influence physicians and scientists in human medicine also influence veterinarians and animal scientists. Some study welfare by looking at disease prevalence, some look for states of pain and fear, and some look at how to accommodate natural behaviors within confinement systems. Thus, basic value frameworks underlie the science.<sup>22</sup>

But is science not supposed to be objective? There are two meanings of objectivity. Some

claim that scientists should use the same objective observations, so two different observers arrive independently at the same conclusion, but selecting objective measures is not the same as selecting measures objectively. Facts are either true or false, whereas values are right or wrong, and preference values are better or worse. Facts by themselves do not answer policy questions. For example, the Australian study was a fairly narrow evaluation of animal welfare that tended to dismiss public views and stated that public perception should not be confused with welfare. In setting science-based policies in these areas, political and value-based decisions about definitions and policy objectives are made, and then science is used to determine how the policy objectives can be achieved.

The European study looked at the affective suffering of swine based on natural behaviors. It recognized welfare as an everyday concept and accepted different views of welfare based on public values. It also prioritized the values of health, affective state, and natural living conditions ahead of the use of simple measures that could be assessed “objectively.” If the study had defined welfare as health alone, the result would not have been a ban on most uses of gestation stalls, but when welfare is defined more broadly, the resulting action is more likely to be a ban.

The lessons learned from this example are five-fold. First, evaluative concepts have both a factual and a value-based component. Second, everyday concepts and their meanings must be respected. Third, when an everyday concept is evaluative, the underlying value framework must be recognized. Fourth, measurement often needs to come after description and classification. And finally, choosing objective measures does not mean the measures are chosen in a value-free way.

### *Successes and challenges in bringing science to global food safety policy through the Codex Alimentarius Commission*

Food security is an ongoing challenge. By 2050, the global population is expected to exceed nine billion people, with most growth occurring in areas with limited food supply. Currently, about 30% and as high as 50% of food is wasted. It is estimated that eliminating food loss and waste could feed 870 million undernourished people worldwide.<sup>23</sup>

Food safety is the connection between health, agriculture, and trade agendas. Food is one of the most traded commodities, and enhancing food safety management is important for human and economic development. Food safety standards are preventive measures that create a “fair” food trade environment, yet most food waste is the result of food safety concerns. A robust food regulatory regime is meant to be used in conjunction with other measures, such as education and information dissemination, and should be evidence-based, feasible and achievable, enforceable, and evolutionary or part of a life-cycle approach. Divergent food safety measures can lead to important disruptions to trade due to discrepancies between standards and lack of trust in systems among countries. Differences occur when global standards are interpreted and implemented in different ways at a national, local, or industry level.

Samuel Godefroy, professor of food risk analysis and regulatory systems at the Université Laval in Québec, noted that, because foods are among the most traded products and important contributors to health, and information about risks and benefits associated with foods is provided by many sources, there is a need for a reference body to guide food standards development internationally. To fill this need, the Codex Alimentarius Commission was established in 1963 by the FAO and the WHO to protect consumer health, oversee fair practices in food trade, and serve as an international focal point for discussion on food safety.

The Codex Alimentarius Commission created a set of common values based on collaboration, inclusiveness, consensus building, and transparency. Food safety standards were built on three pillars of risk assessment, risk management, and risk communication. Risk assessment, in particular, is the foundation of food safety standard development, and it requires data. Ensuring the independence of scientific processes is crucial. One tends to think that science and policy are separate entities, but they intersect at the level of communication. Even in scientific assessments, policy considerations have to be made, especially during hazard characterization and conclusion of risk assessment.

Moving from science to policy creates challenges. Policymakers face challenges in translation, demonstrating that the steps to be taken use the right instruments of action, and setting objectives of consumer protection beyond health outcomes.

Science can define the space where the policy-maker evolves through a stronger rationale to define stronger measures or justifications of economic fallout or social impact. Translation of science considerations to policy is a major challenge. The major effort of the Codex is to formalize how risk assessment should be conducted. Formulation of standards requires more work (i.e., labeling provisions as part of food safety intervention). Despite these challenges, more than 90% of foods produced and traded are covered by Codex Alimentarius standards. The Codex has achieved major accomplishments in the areas of food chemical safety, food microbial safety, and labeling as a public health tool.

Once a Codex standard has been developed, the work is far from over. For a standard to be effective, it has to be adopted or adapted to domestic standards, which is not simple. Scientific evaluations and data that demonstrate how the standard will behave in various jurisdictions are needed. Additional requirements that need to be addressed are typically uncovered, as well as the need for more guidance on safe and effective use of veterinary substances in the context of food animal production.

Trends influencing food safety standards development include globalization of the food supply; the information age; increasingly complex supply chains; new contaminant pair, such as *Escherichia coli* and botulism; climate change; and a dynamic food regulatory environment. Food regulatory science is an area requiring investment. Competencies are needed in food chemical safety, food microbiology, food science and technology, mathematical sciences, social sciences, and economics. It is not possible with available resources to invest in this capacity building country by country. Hence, regional approaches are needed.

In conclusion, international food safety standards are a key preventive measure to support health and trade agendas. Strengthening the capacity of the Codex to develop science-driven food safety standards and investing in capacity development are needed to further improve food safety.

*Transforming agriculture and health: the Foundation for Food and Agriculture Research and the importance of public–private partnerships*

Agriculture is linked to health in many ways, including issues of antimicrobial resistance and infectious

disease transmission, two growing public health threats. The mission of the Foundation for Food and Agriculture Research (FFAR) is to build unique partnerships to support innovative science addressing challenges facing food and agriculture. Established by the 2014 U.S. Farm Bill, FFAR consists of a 20-member board charged with increasing food and agriculture research to complement and further the work of the U.S. Department of Agriculture.

Sally Rockey, executive director of FFAR, said that the foundation will fund cutting-edge research and development through grants and challenges, build unique public–private partnerships, convene stakeholders and thought leaders to foster collaboration, build human capacity to advance innovation, and utilize social, physical, and biological sciences to answer research questions. Public–private partnerships are a key part of FFAR's operating model, and all projects require matching funds from a nonfederal partner.

FFAR support of research is aimed at more productive, sustainable agriculture and better health through food. FFAR's first two projects, the New Innovator in Food and Agriculture Research Award and the Rapid Response Program, were announced in 2015. Future project areas could include a systems approach to cover crops and soil health, nutritional dietary reference intakes, pollinators, Big Data and water, breeding for nutritional quality, processing for nutritional attributes, raising the visibility of agriculture, foodborne illness and food component sourcing, phenotyping networks, and gene editing and public opinion.

FFAR is looking for partners with shared goals or values with the ability to secure matching funds and work in the precompetitive space, the area of research where outcomes offer no particular advantage relative to peers and all parties are potentially affected positively and equally. The precompetitive space allows resources and data to be readily shared. Private partners might include food companies, seed and chemical companies, equipment companies, universities, research institutions, commodity groups, associations, nongovernmental organizations, insurance companies, technology companies, and international development groups.

Public–private partnerships offer incentives to both the private and public sectors. Private sector incentives include meeting corporate social responsibility goals, more rapid development of

products where there are common obstacles to advancement, cost savings, direct access to important fundamental research, access to academic expertise, and access to students and trainees. Public sector incentives include an opportunity to address real-world problems, generation of research that is transferred quickly to the economy, access to resources and data that are otherwise unavailable, and access to excellent scientists. For public–private partnerships to work, partners need to have clearly defined and achievable goals and articulate clear roles, responsibilities, accountability, transparency, and rules of engagement. Objectives must meet needs of partners, and a baseline must be used to monitor progress and success. Balance among members, agreement on research objectives, and a commitment to sharing data are also needed.

### *Storytelling for effective science communication and policy*

Liz Neeley, executive director of the Story Collider, shared her expertise on the subject of storytelling in effective science communication and policymaking to help participants understand how other human beings experience their lives and the world. This understanding provides a foundation for making connections and having hard conversations about what should be done to address the complex problems the world is facing. Neeley, a marine biologist, has studied the evolution of visual color patterns of tropical reef fish from the perspective of “*umwelt*,” the world as it is experienced by a particular organism. Humans tend to assume, rightly or wrongly, that their perceptions are an accurate portrayal of reality.

“Evolution has shaped us with perceptions that allow us to survive,” said Neeley. “It guides adaptive behaviors, and shapes acceptable solutions, but not necessarily optimal ones.” As humans interpret the world through the lenses of their identities, their cultural cognition—or tendency to form perceptions of risks and facts that are consistent with their values—often results in polarized groups that distrust one another when they perceive that their way of life, their values, or their pocketbooks are at risk. In general, people do not become more concerned about a risk as their knowledge or comprehension increases, but instead they take a position consistent with their cultural predispositions. This perception of risk is a social construct driven by fears and val-

ues, which humans amplify or attenuate in the ways in which they talk to one another.

People remember and repeat facts, lots of facts, about many things. But what they believe are inferences, meaning that emotional valence—the intrinsic attractiveness or averseness of a person, object, event, or situation—is imperative. Scientists are often viewed on a cold but competent spectrum of credibility, which creates a problem in science communication. Storytelling is a powerful mechanism to communicate science by creating trustworthiness and packaging information in ways that people use to make sense of the world. People often are skeptical of storytelling; they think either of children and fairy tales or that the data are not particularly strong, so someone is trying to do a little hand-waving to distract and dazzle them. However, Neeley pointed out that fairy tales are not just for children, and the stories contain archetypes that have incredibly long and interesting evolutionary histories.

Interesting stories engage people and focus their attention. Stories transform information into an understandable language that is more effective in making people care enough to understand what is being said. Stories are more believable and persuasive than rigorous science and can be used as a lever or mechanism to help change people’s minds. Scientists and policymakers face an important balancing act between science and communication, since they have a moral and ethical obligation not to arouse people’s emotions in an effort to manipulate them.

When used benevolently, stories are successful in stimulating critical thinking, and they can connect the audience to the storyteller in a powerful way. When watching a masterful storyteller, the blink rate of an audience is often synchronized. This blink rate is an excellent indicator of a process called transportation, also known as being swept up into a story. Transportation is what allows people to imagine themselves in other people’s shoes. When people are swept up into the story world, they bring these attitudes, beliefs, and opinions back into the real world, even if they know the story is fictional.

### **Conclusions and lessons learned**

iCOMOS 2016 brought together a broad range of ideas and opinions on turning science into policy in an effort to reduce threats, both chronic and emerging, to the health of animals, humans, and the environment. The presentations and discussions

involved a diversity of knowledge, disciplines, and cultures. The common thread connecting people at each of these intersections was the key role of science and its effective communication for the development of informed health policies.

When public, private, and academic stakeholders come together for the common good, solutions to problems can occur more rapidly than when these groups work alone. For example, vaccine development in response to Africa's Ebola outbreak provides a framework for vaccine development for other emerging diseases. Models can also show changes in the distribution patterns of vector-borne diseases resulting from climate change. Models that take into account the impact of temperature and climate on the transmission of vector-borne diseases could be used in conjunction with weather forecasts to determine the risk of disease transmission at different times of the year and at different geographical locations. As a result, early warning systems can be developed to minimize or prevent the spread of vector-borne diseases.

The world is changing rapidly owing to the global movement of humans, animals, trade, and food; unparalleled environmental disruption and upheaval; climate change; and irresolvable human conflict. The iCOMOS is a forum for melding the diverse elements of science and medicine in an effort to find common ground and solutions to these challenging and complex problems. In addition to sharing scientific knowledge and stimulating thought across diverse disciplines and cultures, iCOMOS brings together scientists, medical experts, funding sponsors, and critical-need partners locally and globally for the essential purposes of networking and bidirectional communication.

Transforming science into policy occurs at multiple levels of policy formation, from global baselines to national policy to local policy and industry standards of practice. The involvement of funding sponsors, policymakers, and those who implement policy on the ground are all integral components of iCOMOS. However, consumer choice, along with ethics, values, and perceptions, are powerful influencers of public practice and policy, making communication of competent science and medicine essential. Public engagement to provide objective knowledge must be undertaken locally and globally by scientists, physicians, veterinarians, public health practitioners, and policymakers to improve the condition of humans,

animals, and the environment through evidence-based health policies.

Environmental disasters that affect human, animal, and environmental health occur on a regular basis. In 2016, major tailings from the failure of a waste pond dam in China's Henan Province resulted in two villages being buried in red mud containing toxic heavy metals. In 2016, the Peruvian government declared a 60-day state of emergency for 11 towns in the Amazon basin after officials found high levels of mercury, which can cause chronic renal and neurological disorders. In Vietnam, at least 100 tons of dead fish, apparently killed by industrial effluents, washed ashore on the central coastline in 2016. Ebola, Zika, and monkeypox outbreaks continue to occur. Violent storms that wreak havoc on health are also becoming more common owing to climate change. In Haiti, Hurricane Mathew reawakened cholera, a disease initially spread to the country in 2004 by United Nations peacekeepers who had traveled from Nepal, where the disease was flourishing.

iCOMOS provides a forum to discuss topics like these, present and weigh the objective merits of competing health priorities, and identify gaps in knowledge that threaten health security. This bidirectional communication allows major public policy implications to be discussed and eventually decided based on an underlying platform of facts. The meeting forum seeks to achieve this goal through integrative interactions across multiple platforms of knowledge and people, which will form the basis of discussions for iCOMOS 2018 and future meetings.

## Acknowledgments

The organizing committee gratefully acknowledges the funders, invited speakers, panelists, institutional partners, and student assistants. Financial support was provided by Minnesota's Discovery, Research and Innovation Economy (MnDRIVE), University of Minnesota—College of Veterinary Medicine, Office of the Vice President for Research, Academic Health Center, College of Food Agriculture and Natural Resource Sciences, Humphrey School of Public Affairs, and Institute on the Environment. We thank the staffs of the College of Veterinary Medicine Office of Research and the College of Continuing Education whose behind-the-scenes work was essential to the meeting. All authors conceived and designed the iCOMOS meeting. Manuscript roles were writing and editing (M.P.M. and P.S.) and

editing (C.J.S., S.S., N.P., and S.K.). Substantial contributions were provided by Fran Howard in collating meeting notes, and Kaylee Errecaborde for organizing student assistants and the following note takers: Aimee Hunt, Conner McLaughlin, Marie Gilbertson, Oyudari Baatartsoqt, Andrew Fang, Kaleb Fischer, Nhungoc Luong, Michael Rahe, Wenchen Wang, Fernando Lopes Leivas Leite, Katherine Worsley-Tonks, Michaela Trudeau, Amy Kinsley, Elizabeth Thompson, Marie Gilbertson, Kaushi Kanankege, Catherine McKay, Dana Boyer, Grant Stoddard, Sian Durward-Akhurst, Brittany Fox, Sylvia Wanzala, Kate Gurke, Fernanda Shoyama, Zachary Metz, Jordan Young, Derek Korpela, and Xiong Wang.

### Competing interests

The authors declare no competing interests.

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