CReST BOLD IDEAS
SEMINAR

Climate Change and Human Health: Prospects for the Future

Featuring
DR. RITA COLWELL
September 13, 2013

POTOMAC INSTITUTE FOR POLICY STUDIES
901 N. Stuart St. Suite 200
Arlington, VA 22203

Potomac Institute for Policy Studies
901 N. Stuart St, Suite 200
Arlington, VA, 22203
www.potomacinstitute.org
Telephone: 703.525.0770; Fax: 703.525.0299

Email: webmaster@potomacinstitute.org

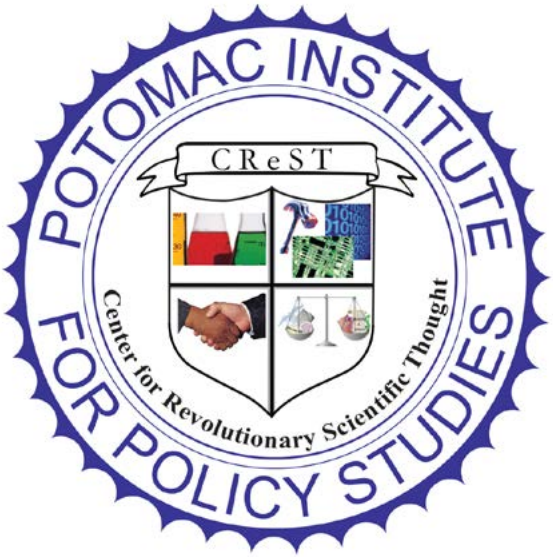
POTOMAC INSTITUTE PRESS

TABLE OF CONTENTS

CReST

The Center for Revolutionary Scientific Thought (CReST) at the Potomac Institute for Policy Studies brings together individuals from a variety of backgrounds to enable a comprehensive outlook of science and technology (S&T) futures from academic and policy perspectives. CReST intends to: 1) develop new ideas, 2) formulate strategies on how to achieve revolutionary gains in S&T, 3) provide a discussion forum to address political, ethical, legal and social issues related to S&T, and 4) inform the public and policymakers about the most pressing issues and concerns regarding the future of S&T.

The CReST mission of solving vital societal problems is enacted through research studies, products, seminars, and conferences designed to address the most trying challenges facing our society.



AGENDA

CReST Bold Ideas Seminar

Climate Change and Human Health: Prospects for the Future

MODERATOR

MICHAEL S. SWETNAM
CEO and Chairman, Potomac Institute for Policy Studies

INTRODUCTION

DR. DENNIS MCBRIDE
President Emeritus and Fellow, Potomac Institute for Policy Studies

FEATURED SPEAKER

DR. RITA R. COLWELL
Chairman, Canon U.S. Life Sciences, Inc.
Distinguished Professor, University of Maryland College Park and Johns Hopkins University Bloomberg School of Public Health
Member, Board of Regents and Senior Fellow, Potomac Institute for Policy Studies

EXECUTIVE SUMMARY

Dr. Rita Colwell's seminar, entitled "Climate Change and Human Health: Prospects for the Future," centered on the impact of infectious diseases, specifically cholera, on human health in a world undergoing climate change. Cholera, caused by the bacterium *Vibrio cholerae*, is commonly found and plays a large role in the aquatic environment throughout the world. This prevalence, unfortunately, leads to epidemics in areas with poverty, poor sanitation, and unsafe drinking water. In an effort to understand these epidemics, Dr. Colwell has researched the use of satellite imagery and modeling to predict the spread of cholera, employing chlorophyll, sea surface temperature, and rainfall data, all correlated with cholera epidemics. Furthermore, Dr. Colwell analyzed the evolution of *Vibrio cholerae*, noting that this bacterium and other vibrio human pathogens are genomically related to vibrio bacteria isolated from thermal vents 2,500 meters below sea level.

With these novel findings, Dr. Colwell evaluated the recent cholera epidemic in Haiti in January 2010. The earthquake, and the hot summer followed by record high rainfall were perfect conditions to enhance the spread of cholera. The earthquake deposited limestone into the river system, leading to a change in river pH, which in combination with the other conditions, contributed to explosive growth of the bacteria. Additionally, heavily populated areas affected by increased flooding and very high temperatures may potentially result in climate change refugee migration. The case study of cholera in Haiti is an example of the link between climate and infectious disease. Dr. Colwell's research into Yersinia pestis plague cases in Georgia and other Former Soviet Union countries provides evidence that modeling can be used to project spread of other infectious diseases. Moreover, satellite imagery and modeling can enhance the surveillance and response mechanisms of global health organizations. These advancements, along with investment in safe drinking water and sanitation, can greatly reduce the spread of enteric diseases worldwide.

SEMINAR TRANSCRIPT

Michael Swetnam: Welcome one and all to the Potomac Institute. This is the second in our series of Bold Ideas talks here at the Potomac Institute for Policy Studies (PIPS). We have embarked on a mission of finding the most enlightened, thoughtful people in our society to talk about bold ideas that can address big problems that our world and society face. This is hard to do because lots of the best people aren't trained, skilled, or have the background for thinking out of the box or about big ideas. One of the most exciting parts of my job at the Potomac Institute is being able to associate with people who have groomed themselves over a career to not solely focus on their discipline. Specifically, these people take the time to be concerned about our world and how science and technology might play a role in bettering our society. The Bold Ideas Seminars are about bringing these deep thinkers together in a room, documenting a presentation, publishing it, and helping to spread revolutionary ideas around Washington, DC and the world. Today, we have one of the broadest thinkers this town has ever seen. She has inspired me and it is my privilege to know her. As a scientist, she addresses the issues of national security from a broad perspective. She understands that science drives our national and societal security as much as anything in the world. Professor Dennis McBride, President Emeritus of the Potomac Institute will give the official introduction. But I wanted to take the time to highlight to you that Dr. Colwell has been an inspiration to the Institute and to this town. You are all in for a real treat today.

Dr. Dennis McBride: It's such an honor to introduce our featured speaker. You know they say some people don't need an introduction and Rita Colwell is one of those people. The problem is I'm Irish with a captive audience so you're going to hear an introduction. Most outstanding is her past leadership of the National Science Foundation (NSF). I do not know if NSF has ever grown or done as well as it did under her leadership. She is now Distinguished University Professor at the University of Maryland and she is also

a member of the Bloomberg School of Public Health of the Johns Hopkins University. But, Rita's depth and breadth go back quite a long way. Dr. Colwell has produced 56 PhDs, through her direct tutelage. I'm the Associate Vice President for Research at George Mason University and I don't know of any two professors that have produced that many PhDs. Three of her PhDs are members of the National Academies. The odds are that would never happen from a set of 56 tutored PhDs in your lifetime.

One day, back when she was next door at the NSF, she and I were having a conversation. She was going through some old materials and she found something that she jotted down when she accepted the job to be NSF Director. It was a checklist of all the things she wanted to accomplish during her time there. By golly if she hadn't completed everything on her list and more. As a world famous microbiologist, I cannot wait to hear what she delivers to us today. I'll close by saying that despite all the accolades you hear about Dr. Colwell, if you met her at the bookstore, you would have a pleasant conversation with her, and then you'd say, "I just met one of the nicest people ever." All this, without even knowing about her fame or about the contributions she's made to the United States and international knowledge of her specialty area. Without further ado, I turn the microphone over to Dr. Rita Colwell.

Dr. Rita Colwell: Thank you Dennis and Mike for the kind introduction. It's a pleasure to speak here at the Potomac Institute. I've been associated with it for more than 10 years and it has really been a pleasure and very exciting to learn about the studies being contemplated and the ones that have been done. I would like to talk to you today about the potential role of infectious disease influencing human health in an era of climate change. I will begin by providing some background on a disease I have studied for many years, cholera. I will give you some background facts, and genomics of the causative agent – I will then discuss how we might be able to predict cholera outbreaks based on climate events, and will include some results for cholera in Haiti and the current situation in that country.

The general background is nicely encapsulated by Hippocrates who wrote in the 4th century B.C. “Whomever wishes to pursue the science of medicine must first investigate the seasons of the year and what occurs in them.” In other words, the seasonality of diseases like cholera and influenza has a lot to do with the bacterium/virus. Very clearly the value of safe water is amply demonstrated by the effect on children; approximately 20% of children under the age of five in countries like Cambodia, Ethiopia, and Zaire who don’t have access to safe water do not survive. The result is that approximately 200 of every 1,000 children under the age of five in those countries will die from a diarrheal disease. This is a dramatic correlation, see Figure 1.

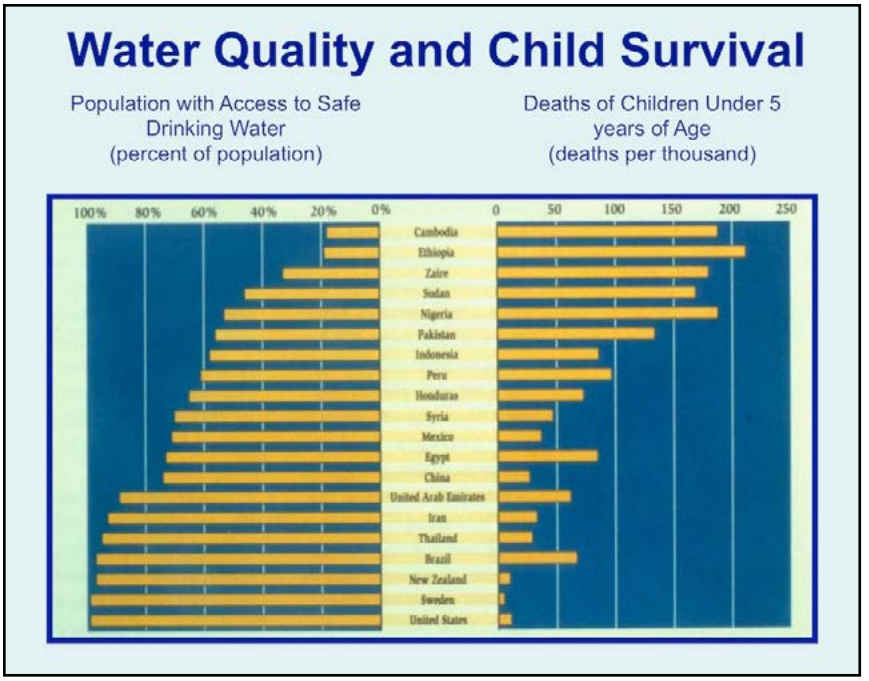


Figure 1. Water Quality and Child Survival.
Image courtesy of Rita R. Colwell.

Cholera is a global, acute, waterborne disease. We refer to cholera as occurring in pandemics, and it's cyclical – with records of outbreaks dating back to the 1800s. There were times when cholera swept through the United States (U.S.) and Europe. We refer to India and Bangladesh as the home of cholera but in the U.S., cities like New York, Washington DC, and Boston suffered cholera epidemics in 1848, 1880, and until about 1900, when introduction of safe drinking water was accomplished. More than 50 countries and about 7 million people each year are affected by this disease. As mentioned, the Bengal delta is considered the "home" of cholera but rather it is a function of the lack of universal safe water and sanitation. The work my students and I have accomplished over the last 25 years has shown that the bacterium that causes cholera exists naturally in the aquatic environment. The bacterium cannot be eradicated. It does too many things in terms of ecosystem services – fixing nitrogen in some cases, breaking down hydrocarbons. In fact, one of the Deep Horizon oil spill research findings is that there was an increase in *Vibrio* species after the spill, not surprising because many are oil degraders, playing a role in the carbon cycle of nature.

We have also discovered that the cholera bacterium has a dormant stage, allowing it to survive during the winter months. When it cannot be cultured it remains viable, persisting in the environment. *Vibrio cholerae* can be detected with molecular techniques using gene probes to test environmental samples.

The relationship of *Vibrio cholerae* with plankton has proven to be critical, another reason why it cannot be eradicated. It is part of the commensal flora of the copepod. Plankton species are globally distributed and, therefore, this bacterium is distributed with its host widely throughout the world. Several hundred cholera bacteria can be detected on a single copepod. In the spring and fall copepods respond to phytoplankton blooms and graze on phytoplankton. As copepods become abundant the numbers of vibrios increase, after which an epidemic of cholera can occur. Cholera epidemics in Bangladesh occur regularly in the spring and again in the fall.

To summarize, poverty, poor living conditions, and the lack of sanitation and safe water are associated with cholera outbreaks. When the disease occurs, it is amplified by person to person transfer, as occurred in Haiti. A model was developed, based on ground truth data from 30 years of research in Bangladesh. Temperature, salinity, nutrients, and related environmental data were included. This model showed that, as sunlight and sea surface temperatures increase in the spring months, the phytoplankton blooms that occur serve as food for zooplankton and invertebrate animals in their larval stages. Subsequently, release of vibrios into the water column occurs upon decline of the zooplankton populations. Unfiltered or otherwise untreated water then contain significant concentrations of vibrios. From the simple model developed 15 years ago, a direct correlation between predicted values of the model and actual number of cases of cholera was observed, see Figure 2.

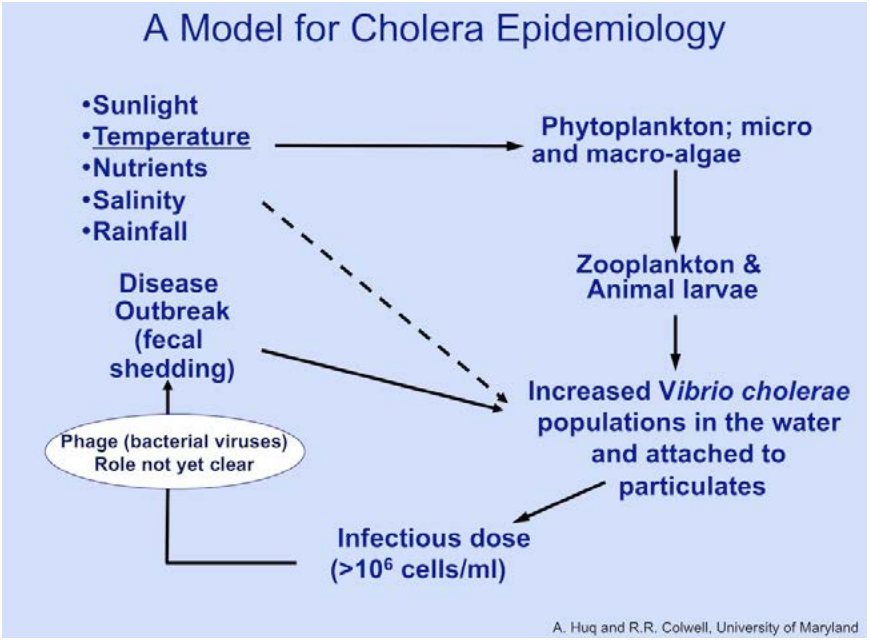


Figure 2. A Model for Cholera Epidemiology.
Image courtesy of Rita R. Colwell.

Switching to macro scale processes, rainfall, flooding, and river depth at different times of the year, coupled with sea surface temperature, salinity, and fecal contamination data permitted more sophisticated global scale models to be developed. Similarly, the 1991 and 1992 massive epidemic of cholera in South America was shown to be related to El Niño (Colwell 1996). Most of our work has been done in villages outside of Dhaka, Bangladesh, studying ponds used for drinking water, washing, and sadly, also as latrine.

Since the relationship between sea surface temperature, sea surface height, and plankton appears to drive cholera outbreaks, we used satellite sensors to measure these parameters to predict cholera epidemics. Our earlier studies with NASA focused on the Bay of Bengal, where sea surface temperature was correlated with number of cholera cases in Matlab, Bangladesh. With satellite images providing data that were coupled with ground truth data, including number of cases of cholera in the local hospitals, we found significant correlation, with results subsequently published (Lobitz, Beck, et al. 2000. Climate and infectious disease: Use of remote sensing for detection of *Vibrio cholerae* by indirect measurement. *Proc. Nat. Acad. Sci*. 97(4):1438-1443), see Figure 3.

Research carried out in both Kolkata, India, and in Matlab, Bangladesh showed very strong relationship between cholera, chlorophyll, and rainfall. In Kolkata, a one milligram per cubic meter increase in chlorophyll surface water allowed prediction of 33% increase in number of cholera cases. In Bangladesh, a millimeter increase per day of rainfall was correlated with a 7% increase in the number of predicted cases (Constantin de Magny, Murtugudde et al. 2008), see Figure 4.

Recent work has shown that spring and fall epidemics in India and Bangladesh have separate drivers. The spring epidemic is related to droughts and reduced water flow while the fall epidemic derives from monsoons and related flooding. How intense the spring epidemic will be appears to be related to the intensity of the fall ep-

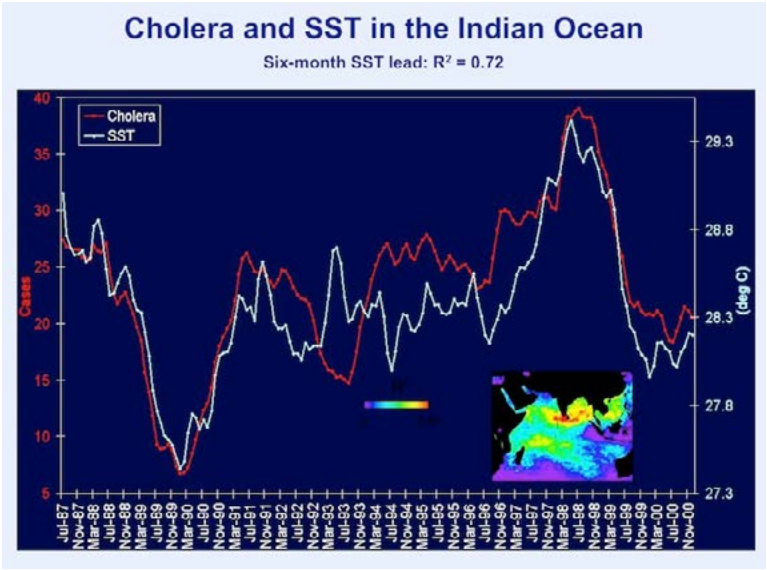


Figure 3. Cholera and SST in the Indian Ocean.
Image source: Lobitz, Beck, et al., 2000, *PNAS*.

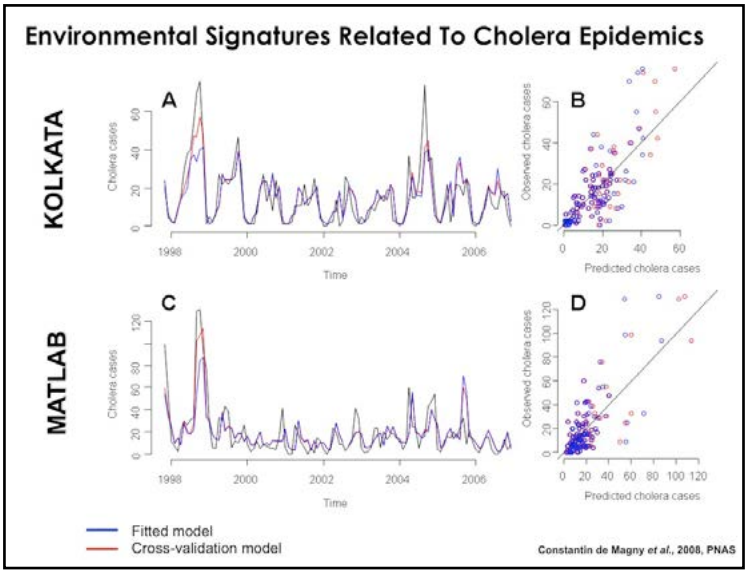


Figure 4. Environmental Signatures Related to Cholera Epidemics.
Image source: Constantin de Magney *et al.*, 2008, *PNAS*.

idemic, hence a relationship with severe weather in Bangladesh. Thus, both intensity and timing of spring and fall epidemics may be predictable, see Figure 5.

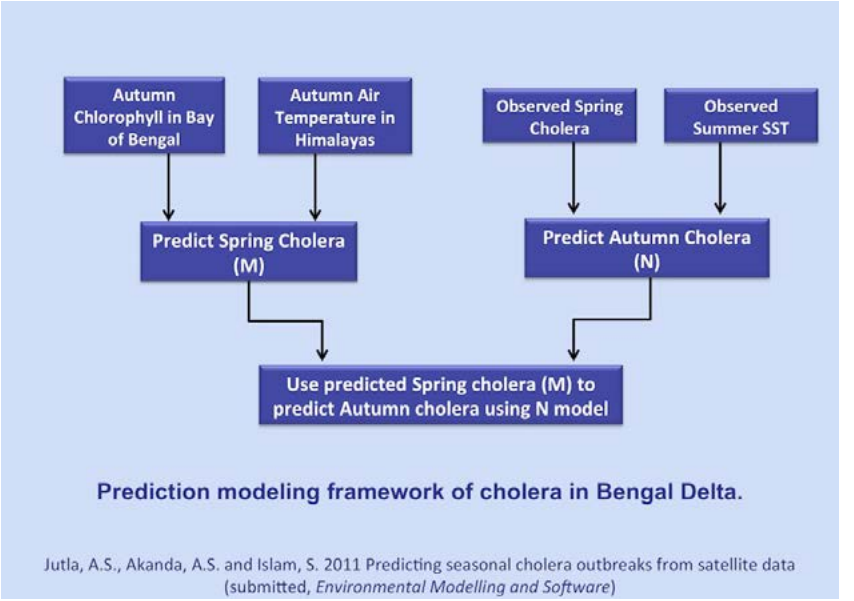


Figure 5. Prediction modeling framework of cholera in Bengal data. Image courtesy of Rita R. Colwell.

The genomics of *V. cholerae* has been studied in parallel with the ecological and climate work. Genomics is important in the context of a multidimensional and interdisciplinary understanding of cholera. In 2000 (Heidelberg, Eisen et al. 2000), the cholera bacterium was sequenced, showing that it possesses two chromosomes, a large chromosome and a smaller chromosome. We have since sequenced approximately 150 *V. cholerae* isolates from samples collected in many countries. Significant variation among strains of this single species was observed. The genomic profiles can permit tracking source of epidemics geographically, but we have found that the genomes of the cholera bacteria in individual ponds in Bangladesh will show detectible difference within and between ponds, see Figure 6.

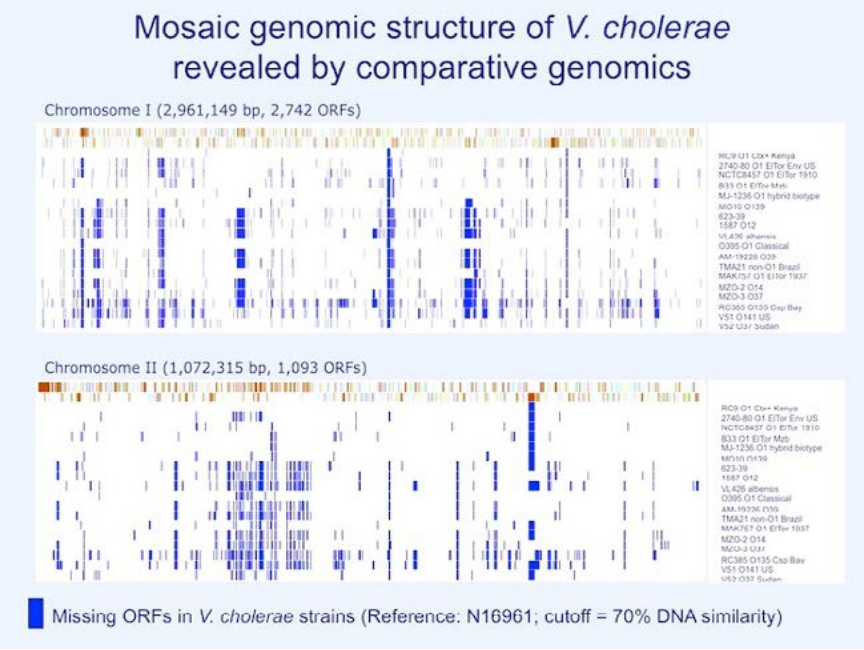


Figure 6. Mosaic genomic structure of *V. cholerae* revealed by comparative genomics. Image courtesy of Rita R. Colwell.

Evolution of the bacterium can be traced and one important discovery is that the genes coding for serotype are laterally transferred. For nearly a hundred years serology has been employed to identify the epidemic strain by serotype, but genes coding for the serotype do not represent the entire bacterium. If genes coding for serotype are mobile, perhaps it may explain some of the problems experienced in making a vaccine against cholera. We now know that up to 90% of the genes of *V. cholerae*, an ecologically versatile bacterium, can be laterally transferred.

Deep-sea copepods from thermal vents on the sea floor carry vibrios. From a water sample collected at 2500 meters deep in the East Pacific Rise, *Vibrio spp*. with many of the same genes as found in

Vibrio cholerae, *Vibrio parahaemolyticus*, and *Vibrio alginolyticus*, all of which are human pathogens, were detected. Why are these deep sea Vibrios carrying pathogenicity traits? Our conclusion is that these pathogenicity traits are better described as fitness traits for this bacterium.

Vibrio cholerae is ubiquitous in the aquatic environment. An example of this phenomenon is Iceland, where there has never been a report of cholera. Dr. Bradd Haley, while a graduate student, was awarded a Fulbright to study in Iceland. He examined geothermal sites where the water temperature can rise to 30 degrees, but cools when mixed with tidal sea water. He found *Vibrio cholerae* (the agent that causes cholera) could be isolated in Iceland. Now, what is a self-respecting *Vibrio cholerae* bacterium doing in the waters of Iceland? The conclusion is that it is a naturally occurring bacterium; it's an estuarine bacterium, and globally distributed. Many genes we consider to code for pathogenic properties are also found in the cholera bacteria in Iceland, again evidence that these genes have an environmental function.

How can we explain why there have been no reported cholera outbreaks in Iceland? First, the drinking water is essentially distilled by geothermal heating so by the time it gets to the household it has been sanitized. If Icelanders are not exposed to the cholera bacteria, why did we find so many virulence factors? The most probable reason is that these factors play a role in the natural ecology of the bacterium. An example we can draw on is that of genes coding for utilization of sialic acid, which have been related to pathogenicity in humans. Sialic acid is present in mussels growing in Iceland, which might explain why vibrios associated with the mussels have enzymes for sialic utilization.

Data from nearly 40 years of research, including genomics, satellite sensors and imagery used in prediction, and extreme weather events allowed linkages to the outbreak in Haiti. The Haitian out-

break occurred along the coast of Haiti near Port Au Prince and inland and moved very rapidly throughout much of the country. Originally reported to have been brought to Haiti by UN peace-keepers, cholera occurred essentially simultaneously throughout the country. Working with hydrographical engineers, we concluded that the river flow from the purported origin of cholera to where outbreaks also occurred was not sufficiently rapid to account for the timing of the simultaneous outbreaks, that is, hydrographically it cannot be explained as a single source, see Figure 7.

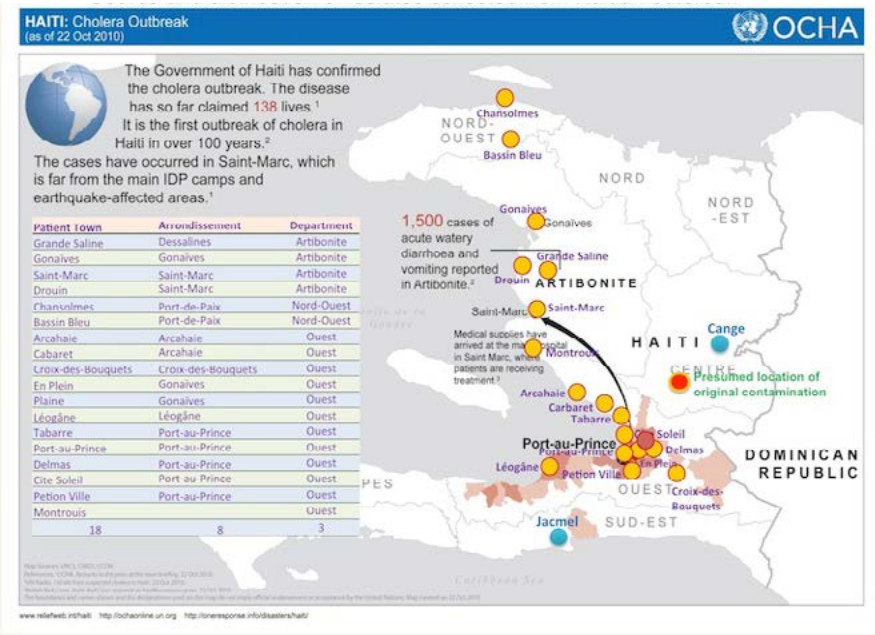


Figure 7. Source and distribution of isolates collected from Haitian outbreak, http://ochaonline.un.org. Image courtesy of Rita R. Colwell.

Within the first few weeks, stool samples from hospital admittances in Haiti were subjected to bacteriological analyses in collaboration with a local physician. The claim has been made that there has been no outbreak of cholera for the past fifty years, but tests for cholera had not been done during that time nor were there clinical laboratories to do testing for cholera bacteria. Yet hospital records of severe diarrhea cases exist but no historical records of testing for cholera. Admittedly, the extent of the current outbreak in Haiti is unparalleled. For our studies, bacteriological samples from 81 patients were shipped to the University of Maryland, College Park for analysis and confirmation. We were fortunate in our collaboration with Dr. Prosper, an attending physician, who was able to assist with isolating cultures. From each sample hundreds of colonies were isolated and screened, an intensity of analysis far more extensive than standard practice.

Using molecular analyses of the DNA isolated from the strains collected from Haiti, differences in the genomes of Haitian strains, compared to others isolated in Bangladesh, Africa, India, and elsewhere throughout the world, were detected. Principal component analysis showed Haitian strains clustering separately from the other genomes, see Figure 8.

Genomic analysis showed distinct *Vibrio* populations. Furthermore, approximately half of the patient samples did not yield *V. cholerae* O1 isolates. *V. cholerae* non-O1 serotype strains were isolated and finding only *V. cholerae* non-O1 non-O139 serotype in some of the cases led us to conclude that, while it is possible that an Asian strain was imported to Haiti, the situation was more clearly much more complicated. Strains of cholera bacteria already there in Haiti apparently were contributing to the outbreak. Furthermore, 7% of the 81 patients from whom clinical samples had been obtained did not carry *Vibrios* at all. Thus, the Haitian cholera epidemic represents a much more complex situation. Leaping to a conclusion regarding the epidemic origin, without an understanding the ecology and environmental role of the cholera bacteria, is unjustified.

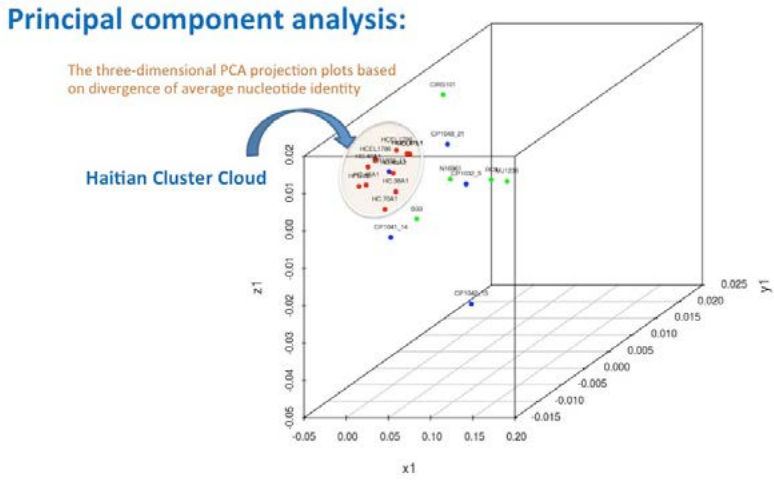


Figure 8. Principal component analysis. Image courtesy of Rita R. Colwell.

The context within which this assessment of the Haitian cholera epidemic was made is as follows. Data from India on cholera outbreaks from about 1823 until 1948 were compiled, with the excellent collaboration of Dr. Elizabeth Whitcomb, a medical doctor from New Zealand, who also earned a PhD from Oxford University studying the hydrography of India and its relationship to malaria and diarrheal diseases. She meticulously facilitated transfer of records maintained during British rule on malaria and cholera deaths from the archives in London to the computer, along with meteorological data for that period of time, including rainfall and air temperature. A clear correlation of elevated temperature for two months prior to outbreaks of cholera was noted, see Figure 9.

Furthermore, there was strong correlation between outbreaks of cholera and season of the year when they occurred. Using odds ratio analysis we found that the odds of cholera were highest when the temperature was above average for each two months prior to a

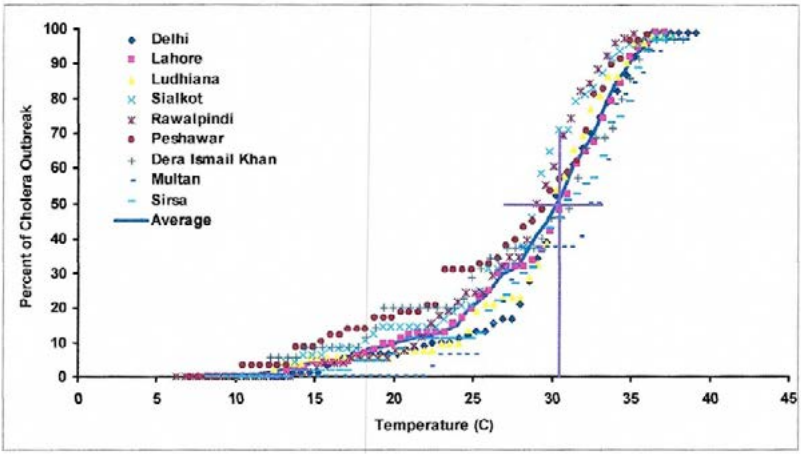


Figure 9. Relationship between cholera outbreaks and air temperatures. Image courtesy of Rita R. Colwell.

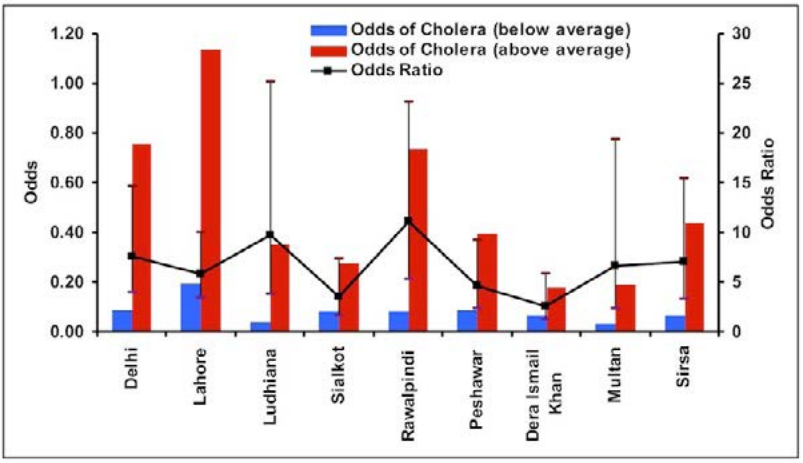
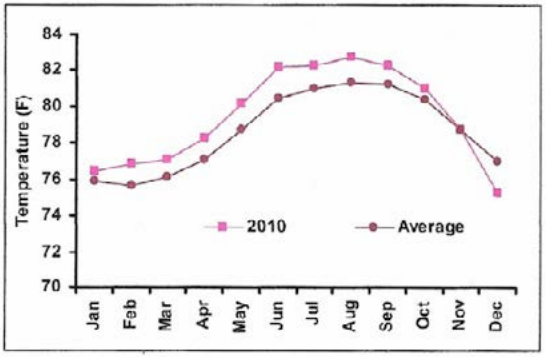


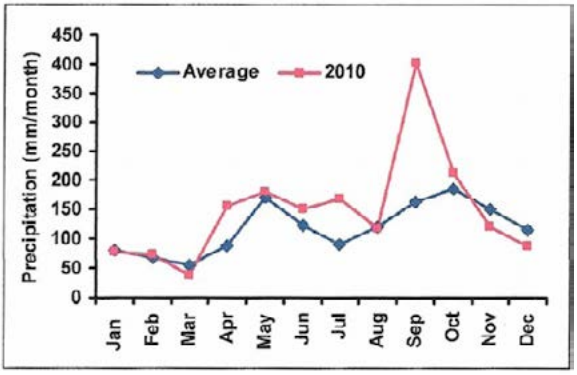
Figure 10. Odds of cholera outbreaks during above average and below average temperature and corresponding odds ratio. Image courtesy of Rita R. Colwell.

heavy rainfall and significantly lower when temperatures were low. This allowed us to tease out this relationship, establishing a significant correlation of elevated average temperature for two months before heavy rainfall, as critical predictive factors, see Figure 10.

Relating the historical evidence of cholera in India to Haiti, a massive earthquake occurred in Haiti in January of 2010, and was followed by one of the hottest summers on record and then by a 60-year record rainfall in late 2010. These events, coupled with an al-



Air temperature in Haiti in 2010 compared with historical air temperature data



Monthly rainfall in Haiti in 2010 compared with historical rainfall data

Figure 11. Historical comparison of air temperature and rainfall in Haiti in 2010. Images courtesy of Rita R. Colwell.

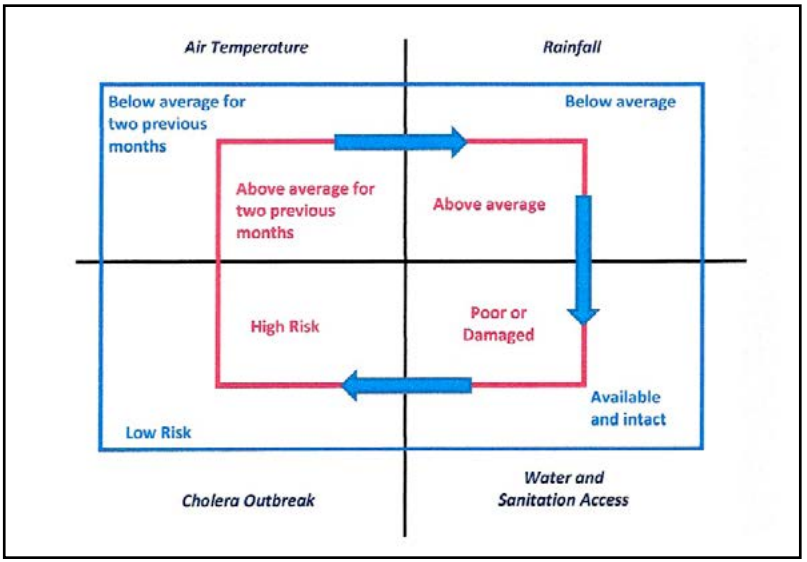


Figure 12. Theoretical framework for predicting cholera outbreaks in epidemic regions. Image courtesy of Rita R. Colwell.

ready poor and earthquake damaged sanitation system, that is, increased rainfall and above average temperature during the months prior to the cholera outbreak, significantly increased the probability of a cholera epidemic, in line with the model created using the India data. In sum, a "perfect storm" potentiated a major cholera epidemic in Haiti, see Figure 11 and 12.

The limestone geology of Haiti appears to have been another factor in the Haitian outbreak. After the earthquake, the alkalinity of the rivers was measured and the pH was alkaline, as high as 8.6 in the Artibonite River. This is significant in view of the method used to enrich for, and isolate, *Vibrio cholerae* in the laboratory, which is to place water samples being tested in alkaline solution with pH adjusted to 8.6 - 8.9, and incubate at a temperature of 35-37°. After 24 hours of incubation, selective growth of *V. cholerae* will occur.

Thus, the climate data, genomics, and meteorological data permitted development of a rational climate related hypothesis to explain the cholera epidemic in Haiti.

Returning to the Bay of Bengal, where an increase in population over the last 300 years has occurred, in the heavily populated areas in the watershed of the Brahmaputra and Ganges Delta, into which the waters of the Himalayas flow, are where the effects of climate change are predicted to be severe. With a one-meter rise in sea level, in this part of the world where 250 to 300 million people live, we can expect climate change refugees migrating to escape the flooding that is predicted. The disease potential can be expected to be high, with flooding, increased temperatures, and migrating populations.

In closing, the words of John Muir are apt, “When one tugs at a single thing in nature, he finds it hitched to the rest of the universe.”

I wish to thank collaborators at the International Center for Diarrheal Disease Research in Bangladesh, the many students and post-doctoral students, colleagues from NIH, ESRI, NASA, and the intelligence agencies that have been splendid collaborators, and co-authors in many publications, resulting from the collaboration. Thank you all so much for your kind attention, and now I will open the floor up for questions.

QUESTION AND ANSWER

Question: How do you correlate from earlier times, like the 1300 and 1400s, with disease outbreaks?

Answer: We have been working with a team from the University of Oslo, Norway studying plague, the disease caused by Yersinia pestis, which occurs in Georgia and nearby countries of Eastern Europe. The rodent host of *Y. pestis* and climate conditions associated with plague outbreaks have been included in our studies. *Yersinia pestis* and rodents have a very similar host-pathogen relationship as *Vibrio cholerae* and copepods. Some species of copepods burrow into sediment during winter months and enter into a dormant state and the bacterium, *Vibrio cholerae* most likely enters into a dormant stage then as well. Rodents do much the same in the winter, hibernating, and there is now some evidence that *Yersinia pestis* also goes into a dormant stage. We see a similar seasonal trend in outbreaks of plague as observed for cholera in cholera endemic countries like India and Bangladesh. Temperature, climate, and cases of plague in other parts of the world like China and Azerbaijan have yielded very interesting correlations. DNA samples from tissues of plague victims in earlier periods of time and recently of a victim of cholera in 1849 have provided interesting genomic information, a fascinating area of study right now.

Question: You have stated that an infectious dose greater than 10^6 cells per ml cause the disease. Has any work been done on ways to regulate ourselves and the water in the human body to have 10^6 to become a small dose?

Answer: The best way to regulate is by providing safe drinking water. The bacterium cannot be eradicated from the environment. Cholera vaccine is not routinely employed in developed countries with safe drinking water and good sanitation systems. Virulence of cholera isolates can vary. In a three-year program carried out in Bangladesh to educate women to use a simple cloth (sari cloth)

to filter water, reduction in cholera by 50% was achieved. The sari cloth filter reduced cases of cholera, because filtration removes copepods and particulate matter to which the cholera bacteria are attached but individual unattached cholera bacteria pass through the cloth filter. However, a small dose (small number of bacteria) can cause an episode of diarrhea but generally speaking, usually not the extreme cholera which we can control by treatment to provide safe drinking water.

Question: Now that we have this model, would we have been able to predict the cholera outbreak in Haiti?

Answer: My answer is a qualified yes, if we had been able to apply the models we now have. We're doing studies with colleagues in Africa, in both Mozambique and Senegal. The climate and cholera relationship has been observed in those countries as well. That is, elevated temperatures, very heavy rainfall, coupled with poor sanitation and reduced access to safe drinking water provide condtions conducive to cholera epidemics. We've been able to apply modeling to historical data (hindcast) and are now focusing on predictive models, with the intent of employing satellite-sensing as a public health tool, applicable for water-borne and vector-borne diseases.

Question: Are the World Health Organization and other global health organizations looking into this as a potential mechanism for providing healthcare where needed?

Answer: That is precisely what we are hoping will be done in the near future. That is, predict the epicenter of the disease or locales of potential outbreaks and, contain cholera, for example, by shipping in vaccines, antibiotics, and fluid rehydration therapy kits.

Question: Do animals get cholera and are there people that are naturally immune to cholera?

Answer: To the first point, how we discovered the dormant stage of *Vibrio cholerae*, was because the literature covering the search

for carriers of the cholera bacteria describes tests on cows, goats, chickens, and other domestic animals, without success. We found that between epidemics, the bacterium goes into a dormant stage and cannot be cultured. *Vibrio cholerae*, as we have amply demonstrated, is an aquatic bacterium naturally occurring in the environment and is not a disease of domestic animals.

Prevention is by provision of safe water, water properly treated for consumption. Boiling water is effective but, in a country like Bangladesh, fuel wood is in short supply. Village women collect cow and goat dung, dry it, and use it as fuel. Sari cloth filtration is inexpensive and affordable, useful to reduce the incidence and severity of cholera, especially during severe floods when safe water is even less available.

Question: Just to clarify, Mike asked if the World Health Organization and other global health organizations are using the model. Your answer was no?

Answer: Not yet on a routine basis, but studies are in progress, showing the value of satellite imagery for monitoring insect-borne diseases.

Question: This is fairly recent research so we wouldn't expect it to be adopted this quickly right?

Answer: Yes, we first reported on the use of satellite sensors to monitor cholera epidemics in the 1980s. So, it's a relatively new approach to public health.

Question: Do you have any estimate about the potential saving of lives if the models were to be employed globally using satellite sensing?

Answer: It could make a significant difference in Africa where cholera epidemics are severe and occur annually.

Question: In the last year or so, they've been talking about putting a plastic bottle with water in the sun. Is that sufficient to deal with the problem?

Answer: There are a lot of methods that can be used to reduce bacterial contamination. One is filling plastic bottles with water, leaving them in sunlight. Both heating the water and ultraviolet irradiation by sunlight act as disinfectant.

There are a variety of disinfectants that can be used. The Safe Water Network, of which the founders include the late Paul Newman and his wife Joanne Woodward, employs a business model to establish community ownership of a filtration system, which comprises kiosks to produce filtered water. The kiosk system has been deployed in India and Ghana. It is a sustainable approach, with a workable business model, and is essentially a practical philanthropy, building community ownership and pride in achievement.

Question: One thing you did not do in the presentation but you are doing somewhat in the question and answer period is answering the approaches or policy recommendations that you would make. I want to offer you the opportunity to summarize.

Answer: Safe drinking water and sanitation are key to public health. The Gates Foundation has finally begun to address sanitation as a primary problem of the developing world to be solved.

Question: How can you use new knowledge about the microbiome to treat a disease or maintain wellbeing?

Answer: *Clostridium difficile* is a common pathogen that is especially treacherous for the very young and the elderly. It is difficult to treat but a treatment now used is to introduce normal bacterial flora into afflicted individuals either via probiotics, e.g., yogurt and similar food products. Fecal transplants from healthy individuals have been effective against *Clostridium difficile*. The more we learn about the community of microorganisms in our gut, on our skin, in

our oral pharyngeal region (the microbiome), the greater the appreciation for microbiology in our lives. Thank you for inviting me to speak to you. I have enjoyed being here. You have been a terrific audience.

Michael Swetnam: Once again, ladies and gentlemen, thank you for coming. I hope that you'll come to our next CReST Bold Idea event here at the Potomac Institute. We are having another seminar on the 20th of September where we'll look at global climate change impacts of the Pacific. You're all welcome to attend. We're going to have a little reception where I hope we will continue the conversation in this room. Again, thank you for coming.

REFERENCES

Colwell, R.R. (1996). "Global climate and infectious disease: the cholera paradigm." ***Science*** **274(5295): 2025-2031.**

Abstract: The origin of cholera has been elusive, even though scientific evidence clearly shows it is a waterborne disease. However, standard bacteriological procedures for isolation of the cholera vibrio from environmental samples, including water, between epidemics generally were unsuccessful. *Vibrio cholerae*, a marine vibrio, requiring salt for growth, enters into a dormant, viable but nonculturable stage when conditions are unfavorable for growth and reproduction. The association of *Vibrio cholerae* with plankton, notably copepods, provides further evidence for the environmental origin of cholera, as well as an explanation for the sporadic and erratic occurrence of cholera epidemics. On a global scale, cholera epidemics can now be related to climate and climatic events, such as El Niño, as well as the global distribution of the plankton host. Remote sensing, with the use of satellite imagery, offers the potential for predicting conditions conducive to cholera outbreaks or epidemics.

Constantin de Magny, G., et al. (2008). "Environmental signatures associated with cholera epidemics." ***Proc. Nat. Acad. Sci. (PNAS)*** **105(46): 17676-17681.**

Abstract: The causative agent of cholera, *Vibrio cholerae*, has been shown to be autochthonous to riverine, estuarine, and coastal waters along with its host, the copepod, a significant member of the zooplankton community. Temperature, salinity, rainfall and plankton have proven to be important factors in the ecology of *V. cholerae*, influencing the transmission of the disease in those regions of the world where the human population relies on untreated water as a source of drinking water. In this study, the pattern of cholera outbreaks during 1998-2006

in Kolkata, India, and Matlab, Bangladesh, and the earth observation data were analyzed with the objective of developing a prediction model for cholera. Satellite sensors were used to measure chlorophyll a concentration (CHL) and sea surface temperature (SST). In addition, rainfall data were obtained from both satellite and in situ gauge measurements. From the analyses, a statistically significant relationship between the time series for cholera in Kolkata, India, and CHL and rainfall anomalies was determined. A statistically significant one month lag was observed between CHL anomaly and number of cholera cases in Matlab, Bangladesh. From the results of the study, it is concluded that ocean and climate patterns are useful predictors of cholera epidemics, with the dynamics of endemic cholera being related to climate and/or changes in the aquatic ecosystem. When the ecology of *V. cholerae* is considered in predictive models, a robust early warning system for cholera in endemic regions of the world can be developed for public health planning and decision making.

Heidelberg, J.F., et al. (2000). "DNA sequence of both chromosomes of the cholera pathogen *Vibrio cholerae*." *Nature* 406(6795): 477-483.

Abstract: Here we determine the complete genomic sequence of the gram negative, gamma-Proteobacterium *Vibrio cholerae* El Tor N16961 to be 4,033,460 base pairs (bp). The genome consists of two circular chromosomes of 2,961,146 bp and 1,072,314 bp that together encode 3,885 open reading frames. The vast majority of recognizable genes for essential cell functions (such as DNA replication, transcription, translation and cell-wall biosynthesis) and pathogenicity (for example, toxins, surface antigens and adhesins) are located on the large chromosome. In contrast, the small chromosome contains a larger fraction (59%) of hypothetical genes compared with the large chromosome (42%), and also contains many more genes that appear to have origins other than the gamma-Proteobacteria. The small chromosome also carries a gene capture system (the integron island) and host

'addiction' genes that are typically found on plasmids; thus, the small chromosome may have originally been a megaplasmid that was captured by an ancestral *Vibrio* species. The *V. cholerae* genomic sequence provides a starting point for understanding how a free-living, environmental organism emerged to become a significant human bacterial pathogen.

Jutla, A., et al. (2013). "Environmental factors influencing epidemic cholera" ***Am. J Trop. Med. Hyg.*** **Sep;89(3): 597-607.**

Abstract: Cholera outbreak following the earthquake of 2010 in Haiti has reaffirmed that the disease is a major public health threat. Vibrio cholerae is autochthonous to aquatic environment, hence, it cannot be eradicated but hydroclimatology-based prediction and prevention is an achievable goal. Using data from the 1800s, we describe uniqueness in seasonality and mechanism of occurrence of cholera in the epidemic regions of Asia and Latin America. Epidemic regions are located near regional rivers and are characterized by sporadic outbreaks, which are likely to be initiated during episodes of prevailing warm air temperature with low river flows, creating favorable environmental conditions for growth of cholera bacteria. Heavy rainfall, through inundation or breakdown of sanitary infrastructure, accelerates interaction between contaminated water and human activities, resulting in an epidemic. This causal mechanism is markedly different from endemic cholera where tidal intrusion of seawater carrying bacteria from estuary to inland regions, results in outbreaks.

Lobitz, Brad, et al. (2000). "Climate and infectious disease: Use of remote sensing for detection of Vibrio cholerae by indirect measurement." ***Proc. Nat. Acad. Sci. (PNAS)*****. 97(4): 1438-1443.**

Abstract: It has long been known that cholera outbreaks can be initiated when *Vibrio cholerae*, the bacterium that causes cholera, is present in drinking water in sufficient numbers to constitute an infective dose, if ingested by humans. Outbreaks

associated with drinking or bathing in unpurified river or brackish water may directly or indirectly depend on such conditions as water temperature, nutrient concentration, and plankton production that may be favorable for growth and reproduction of the bacterium. Although these environmental parameters have routinely been measured by using water samples collected aboard research ships, the available data sets are sparse and infrequent. Furthermore, shipboard data acquisition is both expensive and time-consuming. Interpolation to regional scales can also be problematic. Although the bacterium, *V. cholerae*, cannot be sensed directly, remotely sensed data can be used to infer its presence. In the study reported here, satellite data were used to monitor the timing and spread of cholera. Public domain remote sensing data for the Bay of Bengal were compared directly with cholera case data collected in Bangladesh from 1992-1995. The remote sensing data included sea surface temperature and sea surface height. It was discovered that sea surface temperature shows an annual cycle similar to the cholera case data. Sea surface height may be an indicator of incursion of plankton-laden water inland, e.g., tidal rivers, because it was also found to be correlated with cholera outbreaks. The extensive studies accomplished during the past 25 years, confirming the hypothesis that *V. cholerae* is autochthonous to the aquatic environment and is a commensal of zooplankton, i.e., copepods, when combined with the findings of the satellite data analyses, provide strong evidence that cholera epidemics are climate-linked.

SPEAKER BIOGRAPHIES

MICHAEL S. SWETNAM

CEO and Chairman, Potomac Institute for Policy Studies

Michael Swetnam assisted in founding the Potomac Institute for Policy Studies in 1994. Since its inception, he has served as Chairman of the Board and currently serves as the Institute's Chief Executive Officer.

He has authored and edited several books and articles including: *Al-Qa'ida: Ten Years After 9/11 and Beyond*, co-authored with Yonah Alexander; *Cyber Terrorism and Information Warfare*, a four volume set he co-edited; *Usama bin Laden's al-Qaida: Profile of a Terrorist Network*, co-authored with Yonah Alexander; *ETA: Profile of a Terrorist Group*, co-authored with Yonah Alexander and Herbert M. Levine; and *Best Available Science: Its Evolution, Taxonomy, and Application*, co-authored with Dennis K. McBride, A. Alan Moghissi, Betty R. Love and Sorin R. Straja.

Mr. Swetnam is currently a member of the Technical Advisory Group to the United States Senate Select Committee on Intelligence. In this capacity, he provides expert advice to the U.S. Senate on the R&D investment strategy of the U.S. Intelligence Community. He also served on the Defense Science Board (DSB) Task Force on Counterterrorism and the Task Force on Intelligence Support to the War on Terrorism.

From 1990 to 1992, Mr. Swetnam served as a Special Consultant to President Bush's Foreign Intelligence Advisory Board (PFIAB) where he provided expert advice on Intelligence Community issues including budget, community architecture, and major programs. He also assisted in authoring the Board's assessment of Intelligence Community support to Desert Storm/Shield.

Prior to forming the Potomac Institute for Policy Studies, Mr. Swetnam worked in private industry as a Vice President of Engineering at the Pacific-Sierra Research Corporation, Director of Information Processing Systems at GTE, and Manager of Strategic Planning for GTE Government Systems.

Prior to joining GTE, he worked for the Director of Central Intelligence as a Program Monitor on the Intelligence Community Staff (1986-1990). He was responsible for the development and presentation to Congress of the budget of the National Security Agency, and helped develop, monitor and present to Congress the DOE Intelligence Budget. Mr. Swetnam was also assigned as the IC Staff representative to intergovernmental groups that developed the INF and START treaties. He assisted in presenting these treaties to Congress for ratification. Collateral duties included serving as the host to the DCI's Nuclear Intelligence Panel and Co-Chairman of the S&T Requirements Analysis Working Group.

Mr. Swetnam served in the U.S. Navy for 24 years as an active duty and reserve officer, Special Duty Cryptology. He has served in several public and community positions including Northern United Kingdom Scout Master (1984-85); Chairman, Term limits Referendum Committee (1992-93); President (1993) of the Montgomery County Corporate Volunteer Council, Montgomery County Corporate Partnership for Managerial Excellence (1993); and the Maryland Business Roundtable (1993). He is also on the Board of Directors of Space and Defense Systems Inc., Dragon Hawk Entertainment Inc., and the Governing Board of The Potomac Institute of New Zealand.

DENNIS MCBRIDE

President Emeritus and Fellow, Potomac Institute for Policy Studies

Dr. Dennis McBride joined the Institute as its Executive Vice President in April 2001, a position he held until assuming the presidency from 2001 to 2009, and now serves as President Emeritus and Fellow. Dr. McBride is an affiliated professor at the Georgetown University Public Policy Institute (teaching four courses and supervising graduate research), and the Georgetown University Medical Center (teaching four courses and supervising research). He was formerly Co-Editor of the peer reviewed journal, *Technology*; he was formerly the Editor in Chief of *Review of Policy Research*.

As President of the Institute, Dr. McBride led technical programs, including significant support to the Defense Advanced Research Projects Agency (DARPA), the Office of Naval Research (ONR), the National Science Foundation (NSF), and the National Academies of Science/National Research Council (NAS/NRC), as well as to pharmaceutical and ergonomics industries. Dr. McBride was previously the Executive Director, Institute for Simulation and Training, University of Central Florida, elected by the faculty to Professor, with dual appointments in the College of Engineering and Computer Science (home of tenure), and in the Department of Psychology, College of Arts and Sciences. Professor McBride was also a member of the Burnette Honors College teaching faculty.

Dr. McBride completed a 20-year Naval career at the grade of Captain (O-6), Medical Service Corps, as a Naval Aerospace Experimental Psychologist, and flight test engineer. Earning gold wings in 1980, his tours included bench-to-management science and technology at five Navy laboratories, three major headquarters organizations (including ONR and the Navy Medical Research and Development Command), and two joint assignments. Duties took him from hu-

man engineering of extremely skilled human performance in the problem domains of anti-submarine, electronic, air-to-air, and counter-mine, to information warfare. He served as program manager at DARPA from 1989 until 1994. There, he managed national-level modeling and simulation (M&S) programs in excess of $100 million, and he initiated the first approved Office of the Secretary of Defense Advanced Concepts Technology Demonstration (ACTD), known as Synthetic Theatre of War. Dr. McBride served as acting program manager for the X-31 variable thrust-vectoring experimental test aircraft program. He directed technical components of two additional policy-driving ACTDs. He established the Department of Defense's (DoD) Joint effort in Advanced Distributed Learning (ADL), founding its Joint Co-Laboratory in 1999. He served as the head of the corps of Aerospace Experimental Psychologists as a collateral assignment from the office of the Surgeon General of the Navy.

Dr. McBride's formal education includes enrollment at the University of Georgia, University of Southern California, and the London School of Economics. He holds a Ph.D., three Master's of Science degrees, a Bachelor of Science degree, and an MPA. Trained as a flight test engineer at the University of Tennessee Space Institute under the sponsorship of the Navy's Test Pilot School, Dr. McBride was selected by the Navy as a mission specialist astronaut candidate. He was a summer resident scholar at the Santa Fe Institute. Professor McBride holds professional credentials from the Board of Certification in Professional Ergonomics, and in Professional Modeling and Simulation from the National Training Systems Association.

Dr. McBride is or has been a member of several editorial boards, including the *International Journal for Human Computer Interaction*, *Theoretical Issues in Ergonomics*, *Behavioral and Brain Science*, and reviewer for several other journals. He was formerly a Director, Board of Certification in Professional Ergonomics; Member, Executive Oversight Council, M&S Professional Certification Commission; and member of the Steering Committee, Human Systems Information Analysis Center, among other board positions,

such as Executive Advisory Panel, Institute for Creative Technology, University of Southern California. He is a member of the advisory boards for the Atlantic Legal Foundation and the Institute for Trade and Sustainable Standards Development. He has advised many universities on strategies for enhancing research portfolios, and he has provided extensive subject matter expertise in judicial matters for civil and criminal cases, to include the U.S. Supreme Court. His most recent academic product is the book, *Quantifying Human Information Processing* (Rowman-Littlefield).

Dr. McBride has received numerous awards and military decorations including Defense Superior Service Medal and the Legion of Merit. Among his civilian awards is the L.P. Coombes Medal, presented by the Australian Institution of Engineers. He has published, presented and edited more than 125 scientific articles, technical reports, and book chapters in the fields of psychobiology, experimental psychology, medical and pharmacological research, engineering science, operations research, complexity science, political science, and public policy. His works have formed the technical basis of litigation heard before the United States Supreme Court, and have been reported in a diversity of popular media, including *Business Week*, *Omni*, *Health*, *New Scientist*,*Chronicle of Higher Education*, *ABC News*, *CBS Sixty Minutes*, *New York Times*, *Los Angeles Times*, and the *Washington Post*.

RITA R. COLWELL

Distinguished University Professor, University of Maryland College Park and Johns Hopkins University Bloomberg School of Public Health
Senior Advisor and Chairman Emeritus, Canon U. S. Life Sciences
Chairman, CosmosID, Inc.

Dr. Rita Colwell is Distinguished University Professor both at the University of Maryland at College Park and at Johns Hopkins University Bloomberg School of Public Health, Senior Advisor and Chairman Emeritus, Canon US Life Sciences, Inc., and President and Chairman of CosmosID, Inc. Her interests are focused on global infectious diseases, water, and health, and she is currently developing an international network to address emerging infectious diseases and water issues, including safe drinking water for both the developed and developing world, in collaboration with Safe Water Network, headquartered in New York City.

Dr. Colwell served as the 11th Director of the National Science Foundation, 1998-2004. In her capacity as NSF Director, she served as Co-chair of the Committee on Science of the National Science and Technology Council. One of her major interests include K-12 science and mathematics education, graduate science and engineering education and the increased participation of women and minorities in science and engineering.

Dr. Colwell has held many advisory positions in the U.S. Government, nonprofit science policy organizations, and private foundations, as well as in the international scientific research community. She is a nationally-respected scientist and educator, and has authored or co-authored 17 books and more than 800 scientific publications. She produced the award-winning film, Invisible Seas, and has served on editorial boards of numerous scientific journals.

Before going to NSF, Dr. Colwell was President of the University of Maryland Biotechnology Institute and Professor of Microbiology and Biotechnology at the University Maryland. She was also a member of the National Science Board from 1984 to 1990.

Dr. Colwell has previously served as Chairman of the Board of Governors of the American Academy of Microbiology and also as President of the American Association for the Advancement of Science, the Washington Academy of Sciences, the American Society for Microbiology, the Sigma Xi National Science Honorary Society, the International Union of Microbiological Societies, and the American Institute of Biological Sciences (AIBS). Dr. Colwell is a member of the National Academy of Sciences, the Royal Swedish Academy of Sciences, Stockholm, the Royal Society of Canada, the Royal Irish Academy, the American Academy of Arts and Sciences, and the American Philosophical Society.

Dr. Colwell has been awarded 55 honorary degrees from institutions of higher education, including her Alma Mater, Purdue University and is the recipient of the Order of the Rising Sun, Gold and Silver Star, bestowed by the Emperor of Japan, the 2006 National Medal of Science awarded by the President of the United States, and the 2010 Stockholm Water Prize awarded by the King of Sweden. Dr. Colwell is an honorary member of the microbiological societies of the UK, Australia, France, Israel, Bangladesh, Czechoslovakia, and the U.S. and has held several honorary professorships, including the University of Queensland, Australia. A geological site in Antarctica, Colwell Massif, has been named in recognition of her work in the polar regions.

Born in Beverly, Massachusetts, Dr. Colwell holds a B.S. in Bacteriology and an M.S. in nGenetics, from Purdue University, and a Ph.D. in Oceanography from the University of Washington.

POTOMAC INSTITUTE FOR POLICY STUDIES

The Potomac Institute for Policy Studies is an independent, 501(c)(3), not-for-profit public policy research institute. The Institute identifies and aggressively shepherds discussion on key science, technology, and national security issues facing our society.

The Institute hosts academic centers to study related policy issues through research, discussions, and forums. From these discussions and forums, we develop meaningful policy options and ensure their implementation at the intersection of business and government.

The Institute remains fiercely objective, owning no special allegiance to any single political party or private concern. With over nearly two decades of work on science and technology policy issues, the Potomac Institute has remained a leader in providing meaningful policy options for science and technology, national security, defense initiatives, and S&T forecasting.

The Potomac Institute for Policy Studies is proud to present the Center for Revolutionary Scientific Thought (CReST).

CReST BOLD IDEAS SEMINAR

POTOMAC INSTITUTE FOR POLICY STUDIES
901 N. Stuart St. Suite 200
Arlington, VA 22203