Vector Biology, Ecology and Control

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Editor

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Springer

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ISBN 978-90-481-2457-2 e-ISBN 978-90-481-2458-9
DOI 10.1007/978-90-481-2458-9
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2009942255

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

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Introduction

Mir S. Mulla joined the faculty of the Entomology Department at the University of California, Riverside in 1956, only two years after the Riverside campus was established as an independent campus within the University of California system. Prior to his appointment, Mir received his B.S. from Cornell University and then moved to the University of California, Berkeley to pursue his graduate studies. His Ph.D. from Berkeley, awarded in 1955, completed his formal American education which was the purpose of his immigration from his native Kandahar in Afghanistan.

In his over 50 years at Riverside, Mir has made an incalculable impact on vector biology both within the United States and in developing countries throughout the world. Within Southern California, Mir's basic and applied research led to the rapid and sustainable control of mosquitoes and eye gnats in the Coachella Valley and so directly enabled this region to grow to the thriving, large community it is today. In 2006 his efforts in facilitating the development of the low desert of southern California were recognized through the dedication of the Mir S. Mulla Biological Control Facility by the Coachella Valley Mosquito and Vector Control District. His success has been so profound that it remains somewhat cryptic to the many who now reside in, visit, and enjoy, this region of California, oblivious to the insect problems that severely restrained development until Mir and his students first applied their expertise many decades ago.

Mir has taken his expertise in biological control to many developing countries throughout the world leading to the successful control of mosquitoes in regions in which vector-borne disease is endemic. His research on developing new microbial control agents and his systematic testing of formulations in the laboratory, followed by trials in simulated field conditions and then in the field continues though his "retirement", further establishing his legacy of achieving sustainable, environmentally friendly and effective control of disease vectors throughout the world. Throughout his long career Mir has provided selfless service to the World Health Organization and to the many mosquito and vector control districts throughout California.

To celebrate Mir's 50 years of service to the University of California, Riverside, and to the state of California, his colleagues from California, the United States and the rest of the world gathered in Riverside for a symposium in vector biology in his honor. His long list of graduate students now run research programs in their own countries while his many collaborators continue to employ the strategies developed by Mir at Riverside. Mir's tireless work ethic and attention to experimental detail are well known and were celebrated at this symposium as were the significant and lasting contributions he has made to global health, decades before this term enjoyed the common usage it does today.

Part I
Global Perspectives on Vector-Borne Disease

The Role of Global Climate Patterns in the Spatial and Temporal Distribution of Vector-Borne Disease

Kenneth J. Linthicum, Assaf Anyamba, Jean-Paul Chretien, Jennifer Small, Compton J. Tucker, and Seth C. Britch

Abstract Global climate variability patterns, such as those associated with the El Niño/Southern Oscillation (ENSO) phenomena, have been shown to have an impact on vector-borne infectious disease outbreaks. Evidence of the links between ENSO driven climate anomalies and infectious diseases, particularly those transmitted by insects, can allow us to provide improved long range forecasts of an epidemic or epizootic. Using satellite generated data developing climate anomalies suggested potential disease risks for 2006 and 2007. Sea surface temperatures in the equatorial east Pacific Ocean anomalously increased significantly during July–October 2006 indicating the typical development of El Niño conditions. The persistence of these conditions led to extremes in global-scale climate anomalies comparable to what has been observed during similar conditions in the past. The 2006 development of El Niño conditions had significant implications for global public health. Extremes in climate events with above normal rainfall and flooding in some regions and extended drought periods in other regions occurred. Forecasting disease is critical for timely and effective planning of operational control programs. Here we describe global climate anomalies that led to forecasts of elevated disease risks that gave decision makers additional tools to make rational judgments concerning implementation of disease prevention and mitigation strategies.

Keywords Climate change · ENSO · Disease · Vectors

Introduction

The earth's climate and ecosystems, comprising all living organisms including the disease agents of plants, animals, and humans, are intertwined in a complex association that we are attempting to better understand. Variability in global climate

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P.W. Atkinson (ed.), *Vector Biology, Ecology and Control*,
DOI 10.1007/978-90-481-2458-9_1,

patterns has been shown to have an impact on the temporal and spatial distribution of infectious diseases (Nicholls 1993; Epstein 2002). The most well-known phenomenon influencing the global climate variability at interannual time scales is the El Niño/Southern Oscillation (ENSO). El Niño is the name given to a large-scale ocean-atmosphere climate phenomenon that is linked to periodic warming in sea surface temperature in the central equatorial Pacific. The opposite phenomenon is La Niña, a cold phase of ENSO. Given the large size of the Pacific Ocean, the variability in sea surface temperatures in this basin greatly influence global atmospheric circulation with pronounced impact on global-scale tropical precipitation extending into the northern hemisphere, particularly North America.

ENSO driven climate anomalies have been linked to infectious diseases, including diarrheal diseases in Peru (Checkley et al. 1997) and cholera (Pascual et al. 2000). Outbreaks of insect transmitted diseases such as Murray Valley encephalitis (Nicholls 1986), bluetongue (Baylis et al. 1999), Rift Valley fever (RVF) (Linthicum et al. 1999), African Horse sickness (Baylis et al. 1999), Ross River virus disease (Woodruff et al. 2002), dengue (Linthicum et al. 2007), chikungunya (Chretien et al. 2006), and malaria (Bouma et al. 1996; Bouma and Dye 1997) have been associated with El Niño or other climate anomalies. To properly time and efficiently plan effective operational disease and vector control programs it is important to forecast the risk, timing, and spatial extent of ENSO related human and animal disease outbreaks when such climate anomalies emerge. It is important to understand that forecasts must be precise, accurate, and timely for decision makers to respond effectively (Kovats et al. 2003). Here we describe how global climate anomalies that developed in mid 2006 through early 2007 indicated that potential disease risks were elevated in various parts of the world, and how decision makers were able to make rational judgments concerning a large RVF outbreak in the Horn of Africa and attempt to implement a wide-range of disease mitigation strategies.

Methods

We used current and forecasted ENSO anomalies (deviations from the long term mean) as based on model forecast and observed measurements of Sea Surface Temperatures (SSTs) and compared to the 1997–1998 ENSO event to infer potential disease risks for the end of 2006 and beginning of 2007. The 1997–1998 El Niño was the largest and warmest to develop in the Pacific Ocean in the past 100 years, and serves as a milestone for seasonal forecasting. Warm ENSO events are exemplified by above normal SSTs in the eastern Pacific (EP) and sometimes above normal SSTs in the western Indian Ocean (WIO). Warm ENSO events are known to increase precipitation over most eastern Pacific Ocean islands and the Peruvian coast, the US Southwest, and equatorial East Africa, and result in severe droughts in the western Pacific region (Indonesian archipelago, Philippines), Australia, northeast Brazil, and southern Africa (Glantz 1991; Chagas and Puppi 1986; Cane 1986; Rasmusson 1991; Ropelewski and Halpert 1987).

Variability is SSTs has an impact on atmospheric circulation patterns, especially influence precipitation producing mechanisms. Changes in atmospheric circulation can be inferred from Outgoing Longwave Radiation (OLR) measurements. In simple terms OLR is an indicator of both how warm the earth's surface is and how clear the atmosphere is overhead. Warm surfaces radiate more in the longwave range, while low values of OLR are typically with cool clouds in the atmosphere. Therefore high OLR values are indicative of dry land surfaces and the atmosphere above while the lowest values can be used to infer deep convective clouds which produce rainfall. The global scale changes in precipitation described above can be indirectly derived from OLR data and displayed as anomalies. The OLR data used in this paper are generated by the Advanced Very High Resolution Radiometer sensors on board a series of National Oceanic and Atmospheric Administration (NOAA) satellites.

An unscheduled El Niño conditions advisory issued in the fall of 2006 by NOAA's Climate Prediction Center (CPC) indicated El Niño conditions would peak during the Northern Hemisphere winter of 2006–2007, followed by weakening during March–May 2007 (NOAA 2006). This advisory was used to form both the genesis of an earlier paper forecasting global and local conditions conducive for elevated disease risk (Anyamba et al. 2006) and this paper which describes some of the subsequent observed disease activities.

Results and Discussion

Development of Climatic Conditions in Fall 2006

Following the fall 2006 NOAA CPC advisory (NOAA 2006), which indicated El Niño conditions had developed in the tropical Pacific and were forecast to likely continue into early 2007, Anyamba et al. (2006) started examining global SST and OLR data sets and found that SSTs increased significantly in the EP during September (Fig. 1) and October 2006. In September (Fig. 1) and October 2006, positive OLR anomaly conditions, indicating suppressed convection and precipitation, were observed across all of Indonesia, Malaysia, and most of the Philippines, which are usually the first areas to experience ENSO-related impacts. This dryness continued for the remainder of 2006 into the early part of 2007. Negative OLR anomalies, indicating enhanced convection and precipitation, were observed eastwards between the date line and Papua New Guinea, and to the west in the equatorial WIO region extending into equatorial East Africa.

Using the SST anomalies for the 1997/98 period as a reference for the most significant ENSO event (Fig. 2) and the climate forecast for the next 3–9 months, Anyamba et al. (2006) concluded that there would be a high likelihood for drought conditions to prevail over southeast Asia, Mexico, northeast Brazil, and southern Africa, and above normal rainfall and flood conditions to occur over coastal Peru, southern California, the U.S. Gulf Coast and Florida, and eastern Africa.

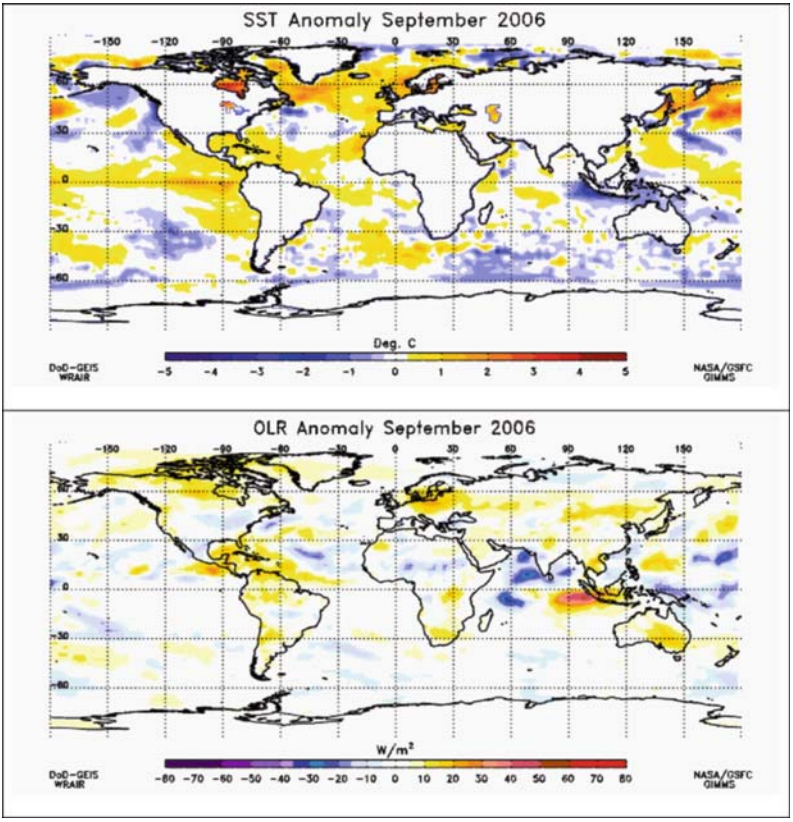

Fig. 1 Sea surface temperature (SST) anomalies for September 2006 (*top*) and outgoing long-wave radiation (OLR) anomalies for September 2006 (*bottom*). SSTs are shown in degrees Celsius and OLR is shown as watts per square meter. Positive (negative) SST anomalies in the western equatorial Indian Ocean are associated with negative (positive) OLR anomalies in East Africa. The opposite patterns occur over southeast Asia where the SSTs along the Indonesian Archipelago are cold (*blue in color*) and the OLR data depict very dry conditions (*red in color*)

Forecasted and Reported Increased Disease Outbreaks

Extremes in climatic conditions may affect vector abundance and biology in different ways, either elevating or decreasing the risk of outbreaks of various vector-borne infectious diseases (Epstein 2001). Drought conditions can suppress predators of *Anopheles* malaria vectors, enhancing populations (Gabaldon 1949; Bouma and Dye 1997), reduce populations of *Aedes* and *Culex* mosquitoes that transmit RVF in sub-Saharan Africa (Fig. 3), or elevate dengue transmission due to increased water storage habitat for *Aedes aegypti* and increased temperatures enhancing vectorial capacity (Watts et al. 1987). On the other hand, heavy rains can boost food supplies and lead to elevated rodent populations (Engelthaler et al. 1999), and create ideal

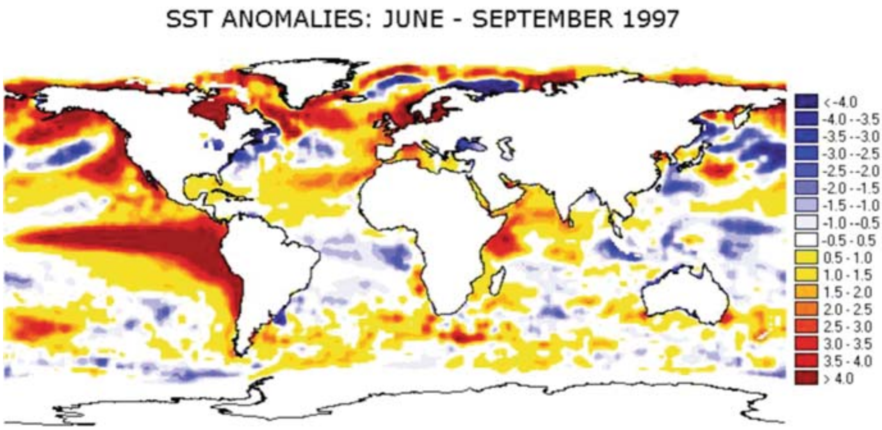

Fig. 2 Sea Surface Temperature (SST) anomalies for June through September 1997. Above normal SSTs have developed in the equatorial eastern Pacific Ocean (>3°C) and also in the equatorial Indian Ocean (~2°C) typical of warm ENSO events. The SST anomalies are computed with respect to 1982–1999 base period means

Fig. 3 Savanna grasslands in East Africa where *Aedes mcintoshi* (*left*) mosquito eggs harbor Rift Valley fever (RVF) virus during drought conditions (*center*) and adult *Aedes* and *Culex* mosquitoes transmit RVF after flooding of habitats and enhanced vegetation production during heavy rainfall periods (*right*). Note absence of clouds during drought conditions when OLR anomalies will likely be positive (*center*), and presence of clouds during especially wet conditions when OLR anomalies will be negative (*right*)

conditions for mosquito breeding and propagation of RVF virus (Fig. 3) (Davies et al. 1985; Linthicum et al. 1985).

Previous ENSO events have been strongly associated with disease outbreaks over time and space, with clusters of mosquito and rodent-borne illnesses. Based upon observations in 2006 and forecast information Anyamba et al. (2006) identified regions of North and South America, Africa, and Asia as being at increased risk for disease outbreaks (Fig. 4). A preliminary analysis of the quality of predictions of the warm ENSO phenomenon impacting various diseases throughout the world is discussed below following disease forecast information.

In Indonesia, Malaysia, Thailand, and most of the southeast Asia islands it was forecast that there would be increased dengue fever (DHF) transmission caused by

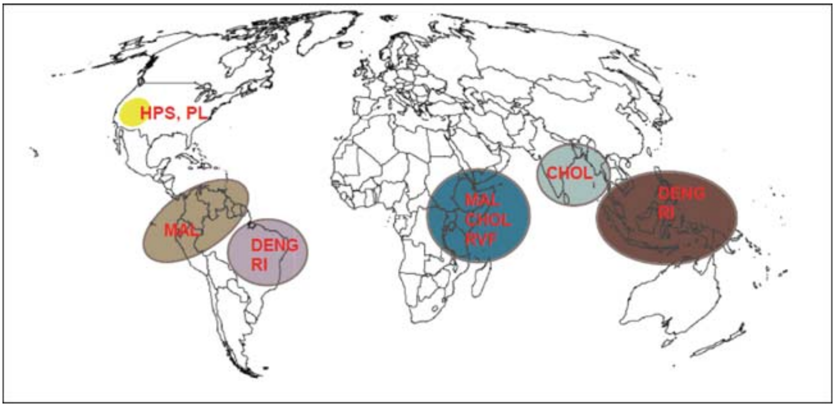

Fig. 4 Hotspots of potential elevated risk for disease outbreaks under El Niño conditions from 2006 to 2007. Diseases abbreviations as follows: DENG Dengue fever; RI Repiratory Illiness, CHOL Cholera, MAL Malaria, RVF Rift Valley fever, HPS Hanta Virus Pulmonary Syndrome, PL Plague. Adapted from Anyamba et al. 2006

drought conditions which (1) increase water storage around houses leading to elevated *Aedes aegypti* populations and (2) elevate ambient air temperatures which will reduce the extrinsic incubation period for the virus in vector mosquitoes, thus increasing vectorial capacity (Watts et al. 1987; Linthicum et al. 2007; Linthicum et al. unpublished observations). The Government of Indonesia reported in April 2007 that it considered the current DHF outbreak in early 2007 to be “an extraordinary situation.” Uncontrolled burning of tropical forests and consequent smoke haze may also result from extreme drought. Thailand reported an increase in respiratory illness and issued alerts due to such haze during extreme drought that occurred in early 2007.

In Coastal Peru, Ecuador, Venezuela, and Colombia it was forecast that there would be an increased risk of malaria due to elevated *Anopheles* vector populations which will develop when various types of immature habitats are flooded after heavy rainfall follows a period of drought (Gabaldon 1949; Bouma and Dye 1997). There had been no reports of increased malaria transmission as of mid-2007.

In Bangladesh and coastal India it was forecast that elevated risk of cholera due to elevated SSTs and of inland incursion of plankton-laden water rich in *Vibrio cholerae*, the bacterium that causes cholera (Pascual et al. 2000). In addition to elevated SSTs, heavy rains wash nutrients into waterways and may trigger plankton blooms. Cholera cases are reported to be occurring in and around Delhi at this time but there are no reports from Bangladesh or coastal India in 2007.

In the U.S. Southwest (New Mexico, Arizona) it was forecast thought that there would be increased risk for hantavirus pulmonary syndrome and plague due to elevated rodent populations caused by heavy rainfall (Engelthaler et al. 1999; Parmenter et al. 1999). There has been a report of two hantavirus pulmonary syndrome human cases in Colorado by April 2007, more than would normally be expected at this point in a normal year. New Mexico has reported a hantavirus case and deer mice rodent numbers are increasing.

In northeast Brazil it was forecast that drought conditions would lead to increased DHF and respiratory illness. Dengue transmission has been reported to be elevated in the period January through April 2007 by 20% over the same period in 2006.

In East Africa (Ethiopia, Kenya, Somalia, and Uganda) heavy rainfall in dry land areas was predicted to increase risk for RVF and malaria resulting from elevated mosquito vector populations, and increase risk for flooding-induced cholera (Loevinsohn 1994; Lindblade et al. 1999; Linthicum et al. 1999; Pascual et al. 2000;

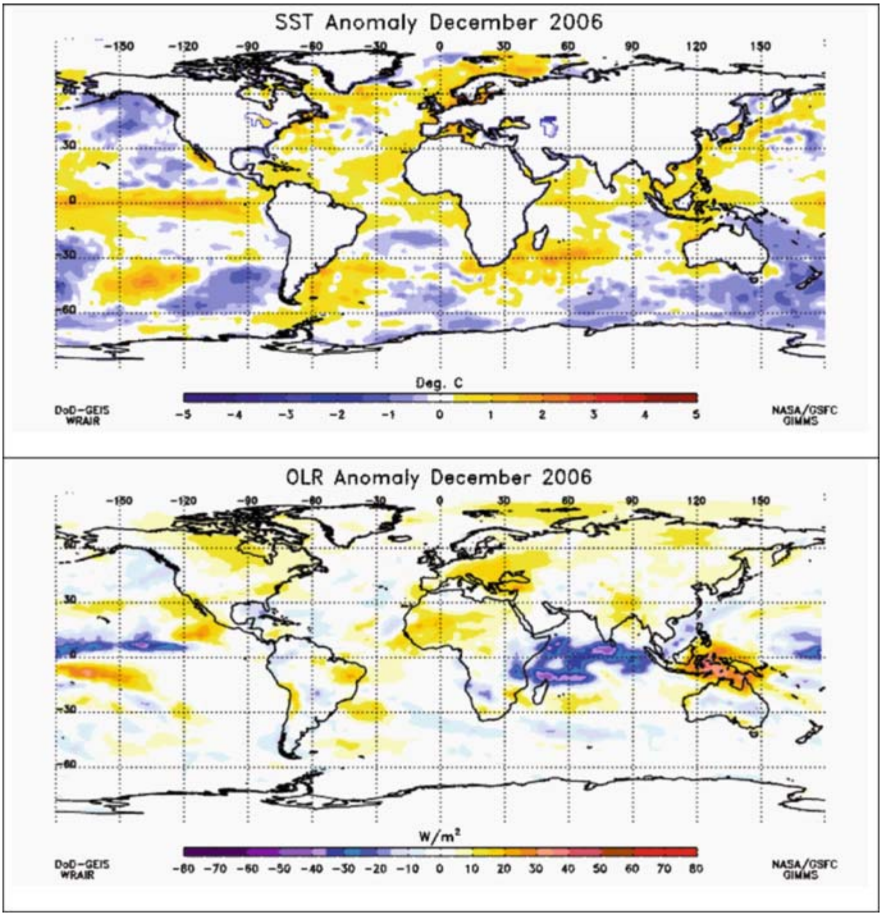

Fig. 5 Sea surface temperature (SST) anomalies for December 2006 (*top*) and outgoing longwave radiation (OLR) anomalies for December 2006 (*bottom*). SSTs are shown in degrees Celsius and OLR is shown as watts per square meter. Positive SST anomalies (depicted by *yellow-orange-red colors*) in the western equatorial Indian Ocean are associated with negative OLR anomalies (depicted by *blue colors*) in East Africa

Anyamba et al. 2002). Positive SST anomalies in the western equatorial Indian Ocean in September–October 2006 ranged from 0.3 to 0.4°C above normal and in December 2006 were almost 2°C above normal, and the warm ocean temperatures continued to produce heavy rainfall over much of the Indian Ocean and the Horn of Africa as depicted by negative OLR anomalies (Fig. 5). Anomalously high rainfall in October–December 2006 in most of Kenya and Tanzania ranged from 50 to 200 mm per month above normal. Increased levels of cholera cases were reported in Somalia, Djibouti, Kenya, and Tanzania in the first half of 2007. RVF was confirmed in patients from Garissa District in the North Eastern Province of Kenya in late December (MMWR 2007). Significant disease activity was also reported from Somalia in early 2007 and Tanzania thorough at least May 2007 (WHO Pandemic Alert and Response 2007). By February 2007 RVF cases in humans had been reported in Somalia, Kenya, and Tanzania (Fig. 6). The February 2007 RVF risk map based upon ecological studies (Anyamba et al. 2002) and published at the URL: http://www.geis.ha.osd.mil/RVFWeb/index.htm also depicted risk in Ethiopia, Sudan and Uganda but no human or animal cases were reported from these countries (Fig. 6). We observed as late as February 2007 that sheep that were allowed to graze in and around flooded mosquito habitats in savanna areas (Linthicum et al. 1984) became infected with RVF; however, cattle that were kept in feed lots several kilometers from flooded mosquito habitats remained uninfected (Fig. 7). A complete time series for the evolution of Nino 3.4 and WIO SSTs anomalies, and OLR anomalies over the Horn of Africa for the period August 2006 to May

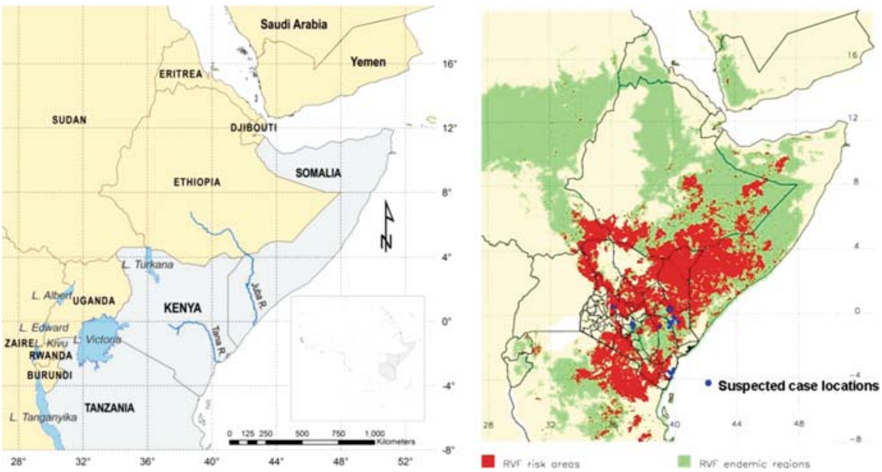

Fig. 6 Map of the Horn of Africa with countries affected by the 2006–2007 Rift Valley fever RVF outbreak depicted in gray and those countries not reporting cases depicted in beige color (*left*) and corresponding RVF risk map for February 2007. RVF endemic areas are depicted in green, and represent areas with climatological mean values that range between 0.15 and 0.4 Normalized Difference Vegetation Index (NDVI) units and receive between 200 and 800 mm/year of rainfall. Areas determined to be at risk from the RVF risk model are depicted in *red* and locations of suspected case locations in Kenya depicted by *blue dots*

Fig. 7 Sheep grazing in savanna grasslands in February 2007 in Kenya in and around flooded mosquito habitats which historically are known to be the source RVF virus (*left*), RVF infected sheep that had previously been grazing in mosquito habitats (*center*), and healthy cattle that were kept in feed lots several kilometers away from floodwater mosquito habitats (*right*)

2007 is shown in Fig. 8. It is clear that warming of SSTs in the Pacific and Indian Oceans as early as August 2006 and continuing through January 2007 quickly led to the development and maintenance of convective clouds over the Horn of Africa and the development of rainy conditions which lead to the RVF outbreak in December 2006 as described by Anyamba et al. (2009). Conversely, the cooling of the Pacific in February 2007 quickly reduced convective cloud conditions even though the Indian Ocean remained warm, resulting in the cessation in RVF transmission by mosquitoes.

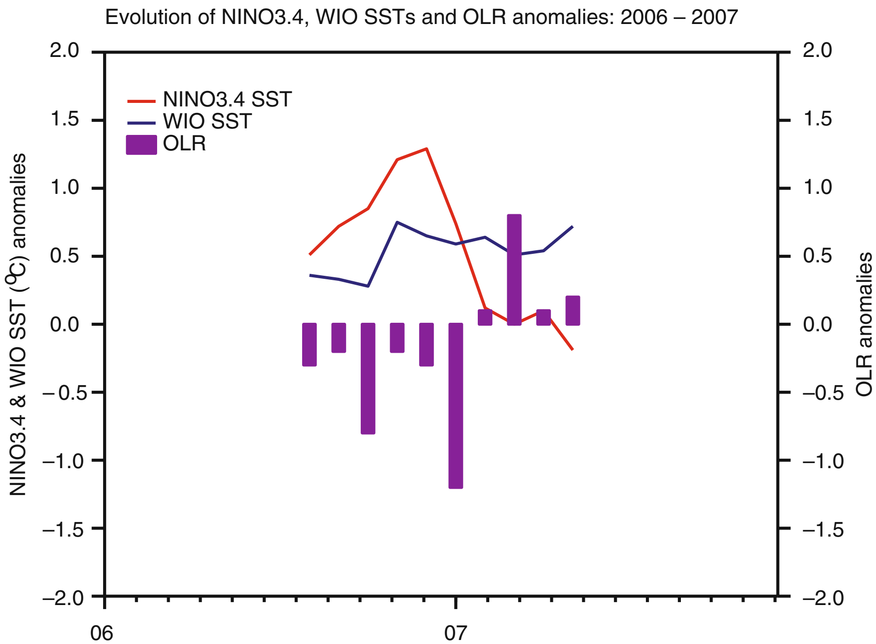

Fig. 8 Evolution of Nino 3.4 and WIO SSTs anomalies, and OLR anomalies over the Horn of Africa and the Indian Ocean for the period August 2006 to May 2007

Conclusions

Global climate analysis products including SSTs and OLR, which can serve as an indicator of rainfall, are useful in illustrating the situation of global climate anomalies with implications for public health. The fall-winter development of El Niño conditions first observed in September 2006 had important implications in early 2007 for global public health, and were similar to those observed during the large 1997/98 El Niño event and other such past events. These events have been demonstrated to have had a significant impact on vector borne diseases and their vectors. We recognize that all ENSOs do not behave alike, and climate change and warmer SSTs overall may be altering ENSOs and thus exaggerating the droughts and floods where they occur. It will be important to continue to monitor ENSO teleconnections and disease relationships in the future as climate changes. The development of El Niño conditions will continue to have important implications for global public health. The forecasting of epidemics or epizootics, like the RVF outbreak in the Horn of Africa in December 2006 to May 2007, is critical for timely and efficient planning of operational control programs if the forecast is able to precisely and accurately define the spatial and temporal range of disease outbreaks.

Acknowledgements This study was supported in part by the Department of Defense Global Emerging Infections Surveillance & Response System (DoD/GEIS). Climate forecast products and information were obtained from NOAA's Climate Prediction Center (CPC) and Columbia University's International Research Institute for Climate and Society (IRI).

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The DDT Story: Environmentalism Over Rights to Health and Life

Donald R. Roberts

Abstract The insecticide DDT proved to be a potent tool in the control of insect vectors of human pathogens and directly led to the saving of many lives throughout the world during the middle of the 20th century. Reaction to environmental concerns over the use of DDT and other insecticides led to ban on the use of DDT. The cost-benefit outcome of this decision is discussed in light of the re-emergence of many vector-borne diseases over the last several decades.

Keywords DDT · Mosquito control · Toxicology · Environment

Introduction

The modern era of insecticide toxicology was launched by discovery of the insecticidal properties of DDT. The global significance of DDT for control of major human diseases was succinctly reviewed in 1957 by de Bustamante, Brazil's national malaria control program coordinator. He stated

> Until 1945–1946, preventive methods employed against malaria in Brasil, as in the rest of the world, were generally directed against the aquatic phases of the vectors (draining, larvicides, destruction of bromeliads, etc. . ..). These methods, however, were only applied in the principal cities of each state and the only measure available for rural populations exposed to malaria was free distribution of specific drugs (de Bustamante 1957).

As described by de Bustamante, advent of DDT brought dramatic changes in how governments could control malaria and other important human diseases. Standard methods of DDT use evolved quickly. For malaria, it was applied indoors at concentrations of 2 g/m^2 of wall surface. DDT spraying, referred to as indoor residual spraying (IRS), was deployed within highly disciplined and centralized programs that also included malaria case detection and treatment.

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P.W. Atkinson (ed.), *Vector Biology, Ecology and Control*,
DOI 10.1007/978-90-481-2458-9_2,

The First Uses of IRS

Scientists in the United States began experimenting with DDT for control of malaria in 1943, and shortly thereafter, began using it operationally for malaria control in the War Areas within the U.S. However broad use of DDT did not get fully underway in developing countries until 1946. One such country was Guyana. Dr. George Giglioli supervised the trials and operational use of DDT in Guyana. The early DDT work in Guyana is elegantly described in Giglioli's autobiography, "Demerara Doctor." (Curtis 2006).

Guyana was intensely malarious. As shown in Table 1, malaria rates dropped precipitously once spray programs were initiated.

The remarkable results of the house-spraying campaign also brought dramatic reductions in infant and maternal mortalities (Table 2).

Giglioli reviewed the improvements in health and human welfare that accompanied the public health use of DDT. Particularly enlightening are the vital statistics that Giglioli compiled for Guyana Sugar Estates (Curtis 2006). He reported a 32% mortality, a 78% decrease in malaria deaths, a 50% decrease in deaths from anaemia, as well as many other improvements in health statistics.

The benefits of spraying houses were so universally high that programs were quickly initiated in many countries around the world. Those programs brought spectacular reductions in malaria and equally spectacular improvements in health. Successes of those programs eventually led to creation of the World Health

Table 1 Impact of DDT sprayed walls on malaria in Guyana (Giglioli 1951). DDT spraying began in mid-1946. Data are average values per year

	1943–45		1949–50		
Population surveyed	Spleen rate	Parasite rate	Spleen rate	Parasite rate	(%) Reduction
Rural					
279,475	33.3	37.7	7.1	0.22	99
Urban					
84,962	6.0	26.8	0.75	1.1	96

Table 2 Reductions in infant and maternal mortality in Guyana with use of DDT. DDT spraying began in mid-1946. Data are average values per year

1943–45		1949–50		
Population surveyed	Mortality per 1,000 live births	Population surveyed	Mortality per 1,000 live births	(%) Reduction
Infants				
368,498	126	408,331	77.5	39
Maternal				
368,498	12.67	408,331	5.5	56

Organization's global malaria eradication program as adopted by the 8th World Health Assembly in 1955.

Judging from official reports, the startup of organized global eradication did not get fully underway until 1959, which was the year when the first statistical reports on eradication programs began in the Americas. An estimated 300 million people had already been freed of endemic malaria even before the global program began. By end of eradication in 1969, another 600,000 million, for a total of almost one billion people, in originally malarious areas were largely freed of endemic malaria. The program brought enormous benefits to a huge proportion of the world's population. Unfortunately, neither many of the successes nor the programs themselves would survive the destructive forces that evolved during the 1960s.

Impact of the Anti-insecticide Movement

The anti-insecticide movement was one destructive force that evolved in the 1960s. The movement got its start through Rachel Carson's book, *Silent Spring*. Carson's book was published in 1962. In that book Carson described her imaginings of insidious DDT harm to wildlife. She claimed DDT was bringing the robin to the brink of extinction. This claim was false. Even in 1962 the robin was increasing in abundance, not declining at all.

Rachel Carson's book was a treatise on fear. She used such phrases as "evil spell"; "mysterious maladies"; "the cattle and sheep sickened and died"; "Everywhere was a shadow of death" to terrify and mobilize the public. Her book was devoid of scientific merit but it was, nevertheless, a publishing triumph. It changed the public's perception of DDT and other insecticides.

A fundamental premise of "Silent Spring" was the natural world had no experience or defense of DDT-like chemicals. At the time her book was written, information on natural chemicals, especially of organohalogens, was limited. Today, almost fifty years later, through the research of Gordon Gribble, Walter Vetter, and others, we know there is an abundance of natural organohalogens that are lipophilic, persistent, and accumulate in the food chain. One such chemical is Q1. It is a natural product with 7 chlorine atoms (DDT has only five). Q1 is abundant, widely distributed, accumulates in the food chain, and is even found in human breast milk.

Another example is a group of chemicals known as BC. The BCs are natual products. They contain 4 bromine atoms and are abundant, lipophilic, widely distributed, and accumulate in the food chain. Sponges produce BC compounds.

The wide distribution of natural products that are DDT-like is revealed by analysis of fat from common dolphins. One such analysis revealed the most abundant compound as BC-1, the second is Q1, the third is BC-2, the fourth is BC-3, and the fifth compound is p, p'-DDE. In this example DDE is much less abundant than the natural products, as are the PCBs.

Through decades of discovery that brought knowledge of a large world of natural and persistent chemicals, focus of the environmental movement remained largely on DDT. Ignored, but present all along, were the PCBs, dioxins, furans, a great diversity of natural chemical insecticides, repellent, irritants, anti-feedants, etc. Some of these chemicals are more toxic, persistent, accumulative and abundant than DDT.

Male euglossine bees, *Eufreisa purpurata*, harvest large quantities of DDT from sprayed house walls in the Amazon Basin. This behavior is another example of how the natural world uses and interacts with DDT and other DDT-like compounds. Remarkably, the bees are not harmed by high DDT concentrations. Specimens stored in the museum since 1980 were analyzed for presence of DDT and other chlorinated chemicals. In addition to DDT, the bees contained a group of three highly chlorinated compounds, among others. It is hypothetically possible that male bees harvest DDT in order to strip chlorines from DDT as building blocks for other compounds. How the male bees use these natural chemicals is unknown. The three new compounds found in bees contain 8 chlorine atoms and are the most highly chlorinated natural products yet discovered.

As stated above, a major premise of Carson's work is the natural world has no experience with manmade chemicals like DDT. As shown in preceding paragraphs, that fundamental premise is wrong. It is now obvious that life evolved by making, using and coping with DDT-like chemicals. Carson's attack on DDT and other insecticides was instrumental in eliminating disease control programs around the world. However, Rachel Carson's book is not singly responsible for growth in anti-insecticide activism or the demise of effective malaria control programs. Another 1960s book was written on an entirely different ideological basis and it too preached against the use of DDT in malaria control programs. The book was *The Population Bomb* by Paul Ehrlich.

In his book Ehrlich proposed that growth of human populations was endangering life on earth. Such thinking was not new as illustrated by the following quote from Garrett Hardin:

"Every life saved this year in a poor country diminishes the quality of life for subsequent generations."

It was just a small step from believing that population growth was endangering life on earth to believing that public health use of DDT was harmful because it improved conditions for growth of human populations. This belief came to maturity in Paul Ehrlich's *The Population Bomb*. His book sold almost two million copies. It, like *Silent Spring*, was a treatise on fear. He used scary predictions to mobilize public opinion against national programs to prevent diseases and save lives.

Ehrlich predicted in the prologue of his book that "In the 1970s and 1980s hundred of millions of people will starve to death in spite of any crash programs embarked upon today. At this late date nothing can prevent a substantial increase in world death rate,. . ." He said there were only two solutions to our problems, either a death rate solution or a birth rate solution. Ehrlich blamed population growth on medical science, stating that ". . .medical science was the straw that broke the camel's back. While lowering death rates in the ODCs [overly developed countries] was due in part to other factors, there is no question that 'instant death control,' exported by the ODCs, has been responsible for the drastic lowering of death rates in the UDCs [under developed countries]." In these comments, Ehrlich was mostly referring to use of DDT in national malaria control programs. He referred to use