Zoonosis y Entomología Médica: revisión

Mosquitoes: disease vectors in context of climate change in Chile.

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Summary

Mosquitoes are a remarkable group of epidemiological interest, for their large numbers and the number of diseases they transmit to humans and animals. There are studies in which climate change can affect mosquito populations, mediated by changes in temperature, rainfall, relative humidity and water level changes etc., and it has been suggested that climate change may affect their disease transmission to vertebrates. Changes in populations of Culicidae could be responsible for the emergence and re-emergence of diseases such as encephalitis, West Nile virus and dengue, considered today to be emerging vector-borne diseases in the world. This has become evident in Chile by the introduction of dengue in Easter Island due to travel in the Pacific islands, an expression of globalization. The effect of climate change on animal populations including vectors and reservoirs of zoonotic potential is now a latent issue that requires a great deal of interdisciplinary research.

Keywords: Mosquito, Culex, climate change, vector-borne diseases.

Introduction

Climate change is a global problem, with a potential impact on animal and public health. The average increase in atmospheric temperature near the Earth's surface and troposphere may contribute to changes in global weather patterns (Bernardi 2008). Recently, the Intergovernmental Panel on Climate Change (IPCC) estimated that this increase in global temperature is at least 0.8 °C above preindustrial levels and projected a further increase of 1.1 to 6.4 °C by the year 2100 (Meehl et al. 2007).

Despite scientific debate on climate change and its potential impact on diseases, there is a relationship between human and animal infections and global environment. Climate change has signified the enhancement of intensity of certain diseases, particularly those transmitted by blood-sucking vectors (Genchi et al. 2009). It is postulated that climate change can affect the behavior of blood-sucking vectors, and thus may alter the distribution and temporal patterns of diseases transmitted by bite of these vectors (Rogers & Randolph 2006).

Blood-sucking insect vectors are responsible for hundreds of millions of cases (Gubler 2009) of diseases in humans and animals each year. In last thirty years there has been a global resurgence of infectious diseases in humans and animals in general, and diseases transmitted by blood-sucking insect vectors in particular, with high transmission rates and expansions in geographical distribution. Most vector-borne diseases occur in the tropics, usually in areas where resources are quite limited and survival is poor. High mobility of animals and humans due to air travel and trade (globalization) has made these diseases not a problem only of tropics; they present a large health problem for the world community and are a threat to economic security. This highlights the need for physicians and veterinarians in non-endemic areas to take into consideration the vector-borne diseases, to learn about where they occur, how to recognize and treat them (Gubler 2009).

The medical importance of mosquitoes around the world is known. They are vectors of many diseases, viruses, protozoa, filarias etc.; well-known and serious illnesses such as yellow fever, malaria and dengue are examples. Malaria and dengue were present in Chile but were eradicated (Atías 1998, Laval 2003). However, dengue reappeared on Easter Island causing an epidemic in 2002, although it had been considered likely that *Aedes aegypti* would appear in the north of Chile. This threat still exists; global change could lead to re-entry of *Aedes aegypti* and the increase and extension of populations of *Anopheles* sp. Climate change can dramatically alter the situation in coming years, with results such as the entry of viruses that have not been seen in Chile such as the West Nile virus and other encephalitis viruses whose vectors are mosquitoes of the genus *Culex*. In spite of this threat, Culicidae are one of least studied insect groups in Chile. The Ministry of Health and the Public Health Institute (ISP) monitored continuously some populations, but knowledge about the variation of relevant epidemiological parameters is insufficient. The aim of this paper is to review the main factors influencing diseases transmitted by blood-sucking insects, specifically by mosquitoes, and their relation to climate change.

Current status of problem

Global change

Global change refers to changes in the global environment that may alter the Earth's capacity to sustain life and human activities (GCRA 1990). This includes changes in climate, atmospheric chemistry, oceans and other aquatic resources, topography of the land surface, biological productivity and ecological systems, including the goods and services they provide (Burkett et al. 2011).

Major environmental changes are the depletion of stratospheric ozone layer, increasing world population, loss of biodiversity, land degradation worldwide, freshwater depletion and other changes such as disruption of elementary cycles of nitrogen and sulfur and global spread of persistent organic pollutants. All this has important implications for the sustainability of ecological systems, food production, human health and economic activity (McMichael 2003). Climate change is only one of a large set of long-term destabilizing environmental changes that are already in progress (McMichael 2003).

Global warming

Global warming is defined as an average increase in the temperature of atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns (Bernardi 2008). Currently there is scientific consensus on four points: i) global warming is happening, ii) it is largely attributed to human emissions of greenhouse gases, iii) the effects are observable today, and iv) warming will continue to progress (Bernardi 2008). For the scientific community, the progressive increase in the temperature of the Earth is unequivocal. Eleven of the 12 years of the 1995-2006 period were among the warmest since 1850 according to instrumental records of global surface temperature. The consequences of this process have been documented; it is reflected in an accelerated melting of permanent snow cover and consequent increased mean sea level (IPCC 2007).

Since climate is an important component of many ecosystems, any great variation would affect other components, including microorganisms, insect vectors, animal reservoirs and susceptible humans, producing a change in the incidence and distribution of numerous pathologies, mainly infectious ones (Cerda et al. 2008).

Climate change

For the IPCC, term "climate change" denotes a change in state of climate identifiable (for example, by statistical analysis) following a change in the mean and/or the variability of its properties that persists for an extended period, typically decades or longer periods. This refers to any change in climate over time, whether due to natural variability or as a consequence of human activity (IPCC 2007).

This meaning differs from that used in the United Nations Framework Convention on Climate Change (UNFCCC), which defined climate change as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (IPCC 2007).

Climate change is a global problem with potential impact on animal and public health, manifested in different ways in different parts of the world, from the tropics to temperate regions (Bernardi 2008). One of its manifestations is a global increase in the average ocean and air temperatures and rising of the average sea level, which have become the main problems affecting regional and global natural ecosystems (Pinto et al. 2008).

In the recently published IPCC (2014) indicates that without additional efforts of mitigation (for RCP8.5, scenario with very high greenhouse gas emissions), the emissions of greenhouse gases will continue to grow, and will cause an increase in global average surface temperature of 2.6 °C to 4.8 °C for the end of the 21st century. It will require strong reductions in greenhouse gas emissions to limit the global warming to 0.3°C to 1.7 °C (for RCP2.6, stringent mitigation scenario), which will pose a major challenge technological, economic, and institutional behavior. Global mean sea level rise will continue during the 21st century, very likely at a faster rate than observed from 1971 to 2010. The rise will likely be in the ranges of 0.26 to 0.55 m for RCP2.6, and of 0.45 to 0.82 m for RCP8.5 (IPCC 2014). Other current and projected manifestations include contraction of the surface covered by permanent snow, ocean acidification, increased extreme events, increased heat waves, heavy precipitation at high latitudes, increasing intensity of tropical cyclones, poleward shift of extra-tropical storms and less rainfall in dry regions at mid-latitudes and in the tropics. Many semi-arid areas will also experience a decrease in their water resources, producing vast droughts (Meehl et al. 2007).

Influence of climatic condition on blood-sucking insect vectors

Much of the impact of climate on vector-borne diseases can be explained by the fact that the insect vectors of these diseases are poikilothermic and therefore are subject to the fluctuating effects of temperature on development, reproduction, behavior, and population dynamics (Shope 1991, Gage et al. 2008). Although arthropods can regulate their internal temperature by changing their behavior, they cannot do so physiologically and therefore are totally dependent on the climate for their survival and development (Lindsay & Birley 1996). Both the infectious agent (protozoa, bacteria, virus) and the associated vector organism (mosquito) have minimal thermoregulatory physiological mechanisms and thus both their temperature and fluid levels are determined by behavioral plasticity (behavioral thermoregulation) and local climate (ectothermic organisms). Therefore there is a limited range of climatic conditions in which infectious and vector species can survive and reproduce. Climate is thus one of the factors that influence the incidence of infectious diseases, although there are other social and demographic components: migration and transport, drug resistance, nutrition, deforestation, agricultural development, etc. (Hales et al. 2003). Among the climatic aspects that most affect blood-sucking vector populations are the following:

Temperature: Changes in temperature can modify the incidence and prevalence of these vector-borne diseases, for example by modifying bite rates, vector population dynamics and human contact rates (Gubler et al. 2001). Temperature also can change the length of the season in which this transmission occurs. These vectors can adapt to changes in temperature by changing their geographic distributions, and there is evidence that some have produced genetic adaptation to increasing temperatures (Patz et al. 2003). Increase in temperature also causes a decrease in generation time, longevity and life expectancy and increases the growth rate of vector populations, as well as decreasing the extrinsic incubation period and increasing the length of the pathogen transmission period (Patz et al. 2003).

Precipitation: Increased rainfall may promote development of favorable habitats for insect vectors (larval habitats or feeding) (Patz et al. 2003), thus favoring population growth (Gubler et al. 2001). Seasonality and amount of precipitation in an area can also affect strongly the availability of mosquito breeding sites; climatic variables can affect the distribution and abundance of vertebrate host species, which may in turn affect the population dynamics of the vector and transmission of its disease (Gage et al. 2008). A greater amount of rainfall may produce a greater abundance of food and may imply that the populations of vectors and vertebrate hosts increase and disperse, causing a decrease in host-vector interactions. On the other hand, floods can have the opposite effect, reducing vector populations (Gubler et al. 2001, Patz et al. 2003); excessive rainfall can have catastrophic effects on a local population of vectors by constant washing of soil by flooding (Epstein 2004).

Humidity: Higher humidity can increase mosquito survival (Gubler et al. 2001). A decrease in humidity can adversely affect mosquitoes since they desiccate easily; survival rates decrease in dry conditions (Patz et al. 2003). But in other geographical areas, drought can turn rivers into a succession of ponds favorable to vector reproduction; therefore, opportunistic vectors reproduction can create epidemic conditions (Meléndez-Herrada et al. 2008).

Climate change may cause changes in the geographical distribution of these vectors; some places may cease to be endemic areas while areas that were not endemic may be able to harbor these vectors, thus new human populations would be exposed to the diseases they transmit (Rogers & Randolph 2009, Haines et al. 2006). Extreme weather events can create conditions that lead to outbreaks of infectious diseases; an example is the heavy rains that leave adequate sites for mosquito breeding (Haines et al. 2006), increasing their population and the probability of human contact. Insects tend to be more active at warmer temperatures and there is scientific evidence to suggest that due to climate change, infectious diseases have already been introduced in geographical areas not previously affected (Shuman 2010).

Mosquitoes

The main group of insect vectors of pathogens to man are Diptera, and within this taxon the family Culicidae (Foster & Walker 2002). Mosquitoes belong to the suborder Lower Brachycera which is composed of 37 families, one of which is the Culicidae. Mosquitoes are divided into 2 subfamilies (Anophelinae and Culicinae) and 44 genera, the most common are *Anopheles, Culex, Aedes, Ochlerotatus, Sabethes, Mansonia, Culiseta, Psorophora, Wyeomyia, Coquillettidia, Haemagogus* and *Armigaeres* (Harbach 2007). They are found throughout the world except Antarctica. They develop in an extremely wide range of biotic conditions: Arctic tundra, boreal forest, high mountains, plains, deserts, tropical forests and oceanic coasts (Foster &Walker 2002, Lehane 2005).

Mosquito species such as *Anopheles gambiae, Anopheles funestus, Anopheles darlingi, Culex quinquefasciatus and Aedes aegypti* are responsible for the transmission of serious parasitic diseases (Rueda et al. 1990); for example, *Anopheles* are transmitters of the malaria; *Aedes aegypti* is a transmitter of yellow fever, Chikungunya and the main vector of dengue. In America vectors are associated with viruses such as the West Nile virus and Venezuelan equine encephalitis virus (primarily *Culex* spp.), Eastern equine encephalitis (*Culiseta*, *Ochlerotatus*, *Culex* and *Coquillettidia* spp.) and Western equine encephalitis (*Ochlerotatus* and *Culex* spp.) (Lehane 2005).

In Chile 14 species of mosquitoes have been described: *Aedes (Stegomyia) aegypti, Ochlerotatus albifasciatus, Anopheles pseudopunctipenni, Anopheles pictipennis, Anopheles atacamensis, Culex acharistus, Culex annuliventris, Culex apicinus, Culex articularis, Culex curvibrachius, Culex dolosus, Culex plicatus, Culex pipiens* and *Culex quinquefasciatus*. Their distribution includes almost all the national territory except Chilean Antarctic, including Easter Island in the case of *Aedes aegypti* (González & Mac-Lean 2008, González & Sallum 2010).

Culex is a cosmopolitan genus of mosquitoes (Harbach 2011); it is the most common genus in Chile. Several mosquito species have specific larval habitat requirements (Lehane 2005); for example, *Culex pipiens* exploits a variety of breeding sites, often artificial containers and small or medium-sized pools of stagnant water. The presence of immature stages has been linked to shaded environments and contaminated water with high organic matter content (Fischer & Schweigmann 2004). In contrast, *Culex dolosus* breeds in temporary and permanent ponds with aquatic plants, grass or no vegetation in urban areas; this species is mainly associated with clean uncontaminated water (Fischer & Schweigmann 2004). Male mosquitoes usually do not disperse more than 100 meters from the larval site, however females travel farther to find food and new larval sites to colonize. It is likely that under tropical field conditions male mosquitoes live for about seven to ten days and females more than one month. Females live two or more months in temperate regions, and adults who hibernate survive up to eight months (Lehane 2005).

Adult mosquitoes are small (usually about 5 mm long), delicate, with slender bodies, long and elongated legs projecting towards the mouthparts. At rest, mosquitoes keep their single pair of wings on the abdomen like a closed pair of scissors. In most Anophelines wings have a mottled appearance due to alternating blocks of dark and light scales, unlike most culicines not have such distinctive marks on the wings (Lehane 2005). These traits are important to determine, to differentiate species and detect the possible introduction of new populations of disease-carrying mosquitoes in previously unaffected areas.

Parasites isolated from adult mosquitoes are of three types: conidia of the form-class Hyphomycetes and nematodes of the families Onchocercidae and Mermithidae (Maciá et al. 1997). Parasites isolated from *Culex* larvae have been: *Geotrichum candidum* (Fungi: form-class Hyphomycetes), *Smittium morbosum* var. *Rioplatenses* (Fungi: Trichomycetes), *Coelomomyces* sp, *Achlya* sp. (Chromista: Pythiistea), *Amblyospora dolosi* (Archeozoa: Microsporida) and *Strelkovimermis spiculatus* (Nematoda: Mermithidae).

Factors affecting mosquito borne-diseases

The discovery of some diseases transmitted to humans by an invertebrate vector is relatively recent, in the last decades of the 19th century. Most of these diseases are caused by viruses, bacteria, protozoa, and filarial worms which are transmitted by a vector insect competent to vertebrate hosts (Romi 2010).

Mosquitoes transmit many of the most debilitating diseases in humans, including malaria, sleeping sickness, filariasis, leishmaniasis, dengue and encephalitis, for example. Furthermore, these insects cause major economic losses in agriculture by direct damage to livestock or as a result of veterinary diseases, such as different trypanosomiases (Lehane 2005). The factors that influence disease transmission by mosquito vectors are survival, reproductive rate, bite rate, the time of year and level of vector activity, and rate of development and reproduction of the pathogen within the vector (OSMAN 2012).

The mosquito-borne pathogens are particularly sensitive to climate, and it has been reported that anthropogenic climate change may increase the incidence and intensity of their transmission, and it can alter the common patterns of transmission of diseases transmitted by these vector insects (Khasnis & Nettleman 2005, Greer et al. 2008, EASAC 2010). Temperature can affect the development of pathogens within vectors (Epstein 2004) and interact with humidity, influencing vector survival and thus mosquito vectorial capacity. It has been postulated that extreme temperatures are often lethal for the survival of mosquito pathogens, but an increase in temperature can have several effects; if the vector lives in an environment where the average temperature is at the limit of physiological tolerance of a pathogen, a small increase could be lethal. But if vector lives in an environment where the average temperature is low, a small increase may result in an increase in the development, incubation and replication of pathogen (Lindsay & Birley 1996). Pathogen survival outside its host (mosquito) depends on the characteristics of its particular environment, including exposure to sunlight, salinity and pH. Therefore, climatic variations may result in an increase or decrease in the incidence of mosquito-borne diseases (Meléndez-Herrada et al. 2008).

Other climatic factors that may affect the transmission of infectious vector diseases are ambient humidity, alteration of precipitation patterns, soil humidity and sea level. It is complex to determine which of these factors have greater importance in the risk of mosquito-borne diseases, because in addition to climatic factors, incidence and geographical distribution of these diseases is influenced by social and demographic factors (Semenza & Menne 2009).

Situation in Chile

The projections for Chile based on new scenarios: RCP8.5 and RCP2.6 was obtained for two periods: 2011-2030 and 2031-2050, based on the historical baseline 1961-1990. Temperature rise across the country, with a gradient from high to low, from north to south and from Cordillera to Ocean it is projected. Notably, the average warming in Chile is less than the global average warming. Between 2011 and 2030, increases in temperature range from 0.5 °C to south and 1.5 °C for Large North and high Andean plateau. For the period between 2031 and 2050, the warming trend continues, but with higher values. The RCP8.5 scenario projects higher concentrations of CO2, with increasing temperature reaches 2 °C. The RCP2.6 scenario, which involves strong climate mitigation policies, slows the rise in temperature to a global average of 2 °C. It is expected that further warming is verified on the Large North and height, on the Andes Mountains.

Between 2011 and 2030, projected decreases in rainfall between 5 and 15% to latitude 27 °S to 45 °S, that is, from the Copiapo River basin and Aysen River basin. To the South, between 38 °S and 42 °S, approximately Biobio river basin and the southern boundary of the region of Los Lagos, the decrease in precipitation signal is more robust, i.e., exists coincidence between the results of several models that project this decline. No other significant changes were projected onto the rest of the territory. For the period 2031-2050, it remains and intensifies the decrease in rainfall. It is noted that the area between 35 °S and 45 °S, approximately Mataquito River basin and the Aysen River, shows a fairly strong signal of reduced rainfall. In the region of Magallanes, the models simulate an increase in rainfall, with very little variation. The provision and quality of drinking water for the population.

In relation to extreme weather events, it was found a marked increase in the probability of drought events, especially from the second half of this century. 70% of the models projected that by the end of the century, such events occur more than 10 times in 30 years. Moreover, although the number of extreme precipitation events tend to decrease in much of the country, the occurrence of events of high rainfall on days with high temperatures increases relative to the base situation. This has important implications, because the increase of the height of the zero isotherm, during the calls warm storms, has the effect of substantially increasing the flow of rivers. This generates major disasters due to floods, landslides and alluviums. These events can cause the loss of human lives and negatively impact the provision and quality of drinking water for the population. These same events also generate serious impacts on irrigation infrastructure and affect water quality, due to the drag of materials, which can alter the chemical and organoleptic composition of water, as also affect irrigation works (PANCC, 2014).

Most of the agricultural regions of the country (Atacama to Los Lagos) will suffer aridity as a result of rainfall decline together with the trend to increasing temperature; in addition to these primary modifications, it is possible that other secondary characteristics may be modified such as wind patterns, cloud cover and frequency of critical events in relation to extreme temperatures. This condition could displace the current climate zones southward (AGRIMED 2008).

Decrease in rainfall in southern Chile, southeastern Argentina and southern Peru has contributed to water scarcity. The projected average warming to South America for the end of this century could affect biodiversity through increasing the risk of species extinction by replacement of tropical forest by savanna in eastern region of the Amazon, causing changes in the habitat of insect vectors (Meehl et al. 2007, Pinto et al. 2008).

The response of insect vectors to climatic change has been poorly studied in Chile (Pino et al. 2015). In Chile malaria was endemic in the North, between parallels 18º and 21º S, however, it was eradicated in the antimalaria campaign between 1937 and 1945 (Atías 1998). The existence of dengue in Chile was reported prior to 1889, although *Aedes aegypti* was eradicated from continental Chile in 1915 (Laval 2003). However, *Aedes aegypti* and dengue reappeared, not where it was expected, but instead on Easter Island in 2002 (Olea 2003). For this reason, mosquitoes of genera *Culex*, *Anopheles* and *Aedes*, must be under permament surveillance, the first as possible vectors and the second as proven vectors of infectious diseases of known gravity.

Dengue as a paradigmatic example

Dengue is a disease caused by an arbovirus of family Flaviviridae, transmitted by bite of certain mosquito species of the genus *Aedes* (*Stegomyia*), mainly *Aedes aegypti*, *A. albopictus* and *A. ochlerotatus*; currently at least 22 vector species are recognized in different biogeographic regions (González & Mac-Lean 2008, Acha & Szifres 2003). The virus has four serotypes, DENV-1 to DENV-4, associated with two main medical profiles: classic dengue, mainly associated with DENV-1, and dengue hemorrhagic fever (DHF) associated with other serotypes (Valero et al. 2007). Although classic dengue is a benign medical profile, DHF can reach mortalities ranging between 1 and 5% (Labraña 2011).

Dengue is the mosquito-borne disease which causes the greatest morbidity and mortality in the world (Martínez-Vega et al. 2006) and one of the most frequent causes of hospitalization in endemic areas; it is the tenth cause of death due to infection in the world. It affects tropical and subtropical countries of Asia, Pacific Islands, Caribbean Islands, Mexico, Africa and Central and South America (Seijo 2001). It is somewhat more frequent in women and in endemic areas the most affected group is that of age 13-14 years (Acha & Szifres 2003).

It is estimated that there are 2.5 billion people at risk, with 50 - 100 million cases annually of dengue fever and 250-500 thousand cases of DHF with about 30 000 deaths (Seijo 2001). Today it is considered an emerging infectious disease and a global health problem (Acha & Szifres 2003) which has significantly increased its range and number of cases (Valero et al. 2007, Martínez-Vega et al. 2006, Rojas et al. 2007), especially in America in Brazil, Colombia, Cuba, Ecuador, Peru, Paraguay, Venezuela, Colombia and Bolivia (Martínez-Vega et al. 2006); this has been attributed to population growth, unplanned urbanization, inadequate water supply, difficulties in collecting solid waste and increased travel (Valero et al. 2007). This adds to difficulties in managing populations of *Aedes* sp., whose eggs, which can be transported in practically anything remain viable for months; also their immature stages develop in small water bodies, containers, cans, barrels, tires, vases etc. (González & Mac-Lean 2008). However, the effect of climate on their vectors and pathogens cannot be ignored, therefore it is important to take into account the history and changes in distribution of this disease in world. For example, climate change may be a limiting factor in epidemics by appearance of more cold weather. *Aedes aegypti* dies quickly in freezing temperatures; 62% of adults die when exposed to 0 °C for 1 hour and most larvae die when the average weekly temperature of the soil drops to 8.8 °C (Shope 1991). On the other hand, development of a mosquito larva is faster in warmer climates, which will become an adult transmitter earlier. The extrinsic incubation period of the dengue virus is also temperature dependent. Within a wide temperature range, warmer ambient temperature reduces the incubation period from the moment when mosquito ingests infected blood until it is able to transmit the virus by a bite. The implication of climate change from point of view of rising temperatures not only would be an increase in distribution and acceleration of the metamorphosis of the insect; the extrinsic incubation period of the dengue virus would be shortened and therefore its cycle within the mosquito would be faster. And a faster cycle would increase the speed of spread of epidemic (Shope 1991).

In continental Chile there were populations of *Aedes aegypti* whose latest reports date back to 1961 (Laval 2003). Until 1953, in continental Chile the domiciliary infestation was from sea level to 1320 m in the oasis of Pica (69°18'W / 20°28'S) and from Arica to Caldera (71°00'W / 27°15'S) reaching a maximum of 45.2% domiciliary infestation in Taltal (Neghme 1950, Neghme et al. 1953). There were reports of dengue cases (classic dengue apparently) in Iquique in 1889 (Laval 2003). Until 1999 recurrence of the vector and disease had not been detected. However unexpectedly, since the main concern was the north of Chile, in 2000 populations of *Aedes aegypti* were detected in Easter Island (Olea 2003). On March 13, 2002 the first case of indigenous dengue was confirmed that surely originated from infected travelers, because the virus was circulating in Tahiti and Hawaii in 2001 and the nucleotide sequence is closely related to genotype DENV-1 of the Pacific (Olea 2003, Labraña 2011, Cáceres et al. 2008). In 15 weeks 636 confirmed cases were reported, (17% of the population), producing the classical medical profile and corresponding to the DENV-1 serotype in 100% of the cases (Labaraña 2011). Dengue reappeared in 2006, 2007, 2008, 2009 and 2011 with 3, 27, 25, 25, and 1 cases, respectively. Mathematical models predict future outbreaks of decreasing size, but caution that the main danger lies in DHF epidemics resulting from the introduction of other serotypes (Canals et al. 2012).

Concluding remarks

Climate strongly affects agriculture and livestock production, and also influences animal diseases, vectors, pathogens and their habitats. It is likely that the global warming trend, predicted in South America in the IPCC2007 report will modify the temporal and geographic distribution of infectious diseases, including mosquito-borne diseases such as West Nile fever (Pinto et al. 2008), malaria and dengue. Factors involved in disease spreading are highly complex and the consequences for human health are difficult to predict, but it is assumed that climate change will exacerbate diseases transmitted by blood-sucking insects (DG 2011). The answer to the question of which of these factors may have greater effect on the risk of these diseases cannot be determined clearly, since demographic and social factors of human populations must be included (Semenza & Menne 2009).

The geographical distribution of mosquito populations is related to temperature patterns, precipitation and humidity. Increased temperature speeds up the metabolic rate of mosquitoes, increasing spawning and feeding frequencies (Epstein 2004) as well as increasing the population growth rate; however, it has a detrimental effect on longevity and life expectancy. Increasing feeding frequency causes a greater likelihood of acquiring and transmitting diseases, increasing the temperature would decrease the extrinsic incubation period of pathogens within the mosquito which would live a short time, because their life expectancy is shortened (Patz et al. 2003).

However, the effect of precipitation on vector metabolic behavior is difficult to predict. Rainfall has an indirect effect on vector longevity; humidity creates a series of favorable habitats, increasing the geographical distribution of mosquitoes with seasonal abundance, and may also have short and long-term effects on their habitas by creating new breeding sites. Increased rainfall and vegetation density can increase the number and quality of breeding places of mosquitoes, affecting the availability of resting sites, shelter (Githeko et al. 2000) and feeding (Patz et al. 2003), but host-vector interactions decrease due to greater dispersion (Gubler et al. 2001). This is debatable, since excessive rainfall causing floods can have a lethal effect on mosquitoes (Epstein 2004, Paaijmans et al. 2007) and larval survival, and preclude the colonization of new breeding sites. Moreover, there are cycles of some mosquito-borne diseases of the genus *Culex*, such as the West Nile virus or St. Louis encephalitis virus which require dry periods and heavy rainfall to multiply (Tabachnick 2010).

The effect of climate change and global warming are potentially important for the dynamics of disease vectors; however it is unclear exactly how mosquitoes will respond under changing climate conditions, due to complex relationships between mosquito life cycles and climate (Morin & Comrie 2010).

The increased incidence of mosquito-borne diseases is more easily detected in areas close to the geographical limits of their distribution (Tirado 2010). Several of these diseases occur in countries bordering Chile but have not yet invaded it, such as malaria and dengue in Peru, Bolivia and Argentina (Canals et al. 2012), which produces an imminent risk of the entrance of these diseases into Chile. A shocking projection is that if there is an increase in global temperatures of 2-3 °C, the population at risk for malaria will increase between 3-5%, which means there will be millions of new infections each year (Shuman 2010). The estimates according to research conducted by the University of Chile predicted an increase between 2 and 4 °C in severe scenario emissions (CONAMA 2006), which could cause a change in the distribution of vectors.

Knowledge of how climate and weather can influence the mosquito vectors of disease at multiple time scales is vital to mitigate and adapt to impacts of climate change on disease (Morin & Comrie 2010), since knowing their phenology and bioclimatology in different seasons will allow the creation and establishment of potential strategies for the control of larvae or adults of transmitter mosquitoes of emerging and reemerging disease in Chile. Each species of vector mosquito requires specific climatic conditions to be sufficiently abundant and perpetuate itself over time, which is why any climate variation will cause an effect on the vectors. Climatic variations may affect reproduction, development, population dynamics and behavior of mosquitoes, such as their ability to transmit infectious agents. For example, if warmer and wetter conditions facilitate mosquito multiplication, they will also increase the spread of diseases transmitted by this type of vector.

In general, scientists agree that climate change will impact mosquito-borne diseases, yet these effects are uncertain due to complex interactions between climatic factors and phenology of each disease-transmitting mosquitoes. The frequency of emerging and re-emerging diseases has accelerated in recent times as a result of factors that allow rapid multiplication and spread of infectious agents. An example of these factors is that of temperature on mosquitoes; its increase shortens the life cycle, increases foraging frequency and allows favorable replication of pathogen it harbors. Coupled with an increase in rainfall which increases the number of breeding sites, it causes a decrease in transmission times by increasing the chances of human exposure to mosquito-borne diseases. For this reason, due to projections of different scenarios of climate change in Chile, it is essential to monitor mosquito populations, determine bioclimatic parameters and estimate epidemiological parameters of importance in the transmission of their diseases, and with these resources perform studies of potential changes as a result of climate change.

Support for evidence-based implementation, monitoring and information systems is essential in order to be better able to detect infections and improve control measures, effectively reducing cases of mosquito-borne diseases. Development of more accurate and adjusted models (with better spatial resolution) of future climate variability in Chile in different scenarios and surveillance models is vital to predict or detect outbreaks of disease and to act as an early warning system. Because emerging and re-emerging diseases (for example, dengue) generally have high mortality, they need to be identified quickly and be a source of local and international reporting, to develop preventive and therapeutic measures as quickly as possible, strengthening health systems to cope with the expected changes.

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