Ann Ist Super Sanità 2016 | Vol. 52, No. 3: 397-405
DOI: 10.4415/ANN_16_03_11

Climate change, vector-borne diseases and working population

Nicoletta Vonesch[1], Maria Concetta D'Ovidio[1], Paola Melis[1], Maria Elena Remoli[2], Maria Grazia Ciufolini[2] and Paola Tomao[1]

[1]Dipartimento di Medicina, Epidemiologia, Igiene del Lavoro e Ambientale, Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL), Monte Porzio Catone (Rome), Italy
[2]Dipartimento di Malattie Infettive, Parassitarie e Immunomediate, Istituto Superiore di Sanità, Rome, Italy

Abstract
Introduction. Risks associated with climate change are increasing worldwide and the global effects include altered weather and precipitation patterns, rising temperatures and others; human health can be affected directly and indirectly. This paper is an overview of literature regarding climate changes, their interaction with vector-borne diseases and impact on working population.
Materials and methods. Articles regarding climate changes as drivers of vector-borne diseases and evidences of occupational cases have been picked up by public databank. Technical documents were also included in the study.
Results. Evidences regarding the impact of climate changes on vector-borne diseases in Europe, provided by the analysis of the literature, are presented.
Discussion. Climate-sensitive vector-borne diseases are likely to be emerging due to climate modifications, with impacts on public and occupational health. However, other environmental and anthropogenic drivers such as increasing travelling and trade, deforestation and reforestation, altered land use and urbanization can influence their spread. Further studies are necessary to better understand the phenomenon and implementation of adaptation strategies to protect human health should be accelerated and strengthened.

Key words
- climate change
- vector-borne diseases
- human health
- occupational health

INTRODUCTION

Climate changes: definition, main impacts

Climate change is any significant variation in temperature, precipitation, wind or other type of weather that lasts for decades or longer, caused by natural processes and human activity that modify atmospheric conditions. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) each of the last three decades has been successively warmer than any preceding decade since 1850. Over the period 1880-2012, the globally averaged combined land and ocean surface temperature data show a warming of 0.85 °C [1]. In Northern Europe the warming is likely to be highest in winter, and temperature increases are likely to be seen in the Mediterranean Region during the summer period; annual mean precipitation will increase in the northern parts of Europe and will decrease in the south [2] and extreme events (drought, heavy rainfall) will be more frequent [3, 4]. The impacts of climate change on human health are multifaceted and depend on many factors such as local environmental conditions, vulnerability assessment and the existence of adaptation strategies by public health systems. Though an influence of weather and climate on the incidence of infectious diseases has been recognized since the time of Hippocrates, understanding the linkage between climate and disease has increasing urgency. In fact, the global warming is unequivocal and the transmission of the infectious diseases depends on many factors including social, economic and ecological conditions, human susceptibility and access to care [3, 5].

Climate changes and vector-borne diseases

Vector-borne diseases (VBDs) refer to infections transmitted by the bite of blood-sucking arthropods such as mosquitoes, ticks and sandflies. It is recognized that climatic change influences the emergence or re-emergence of vector-borne diseases by altering their rates, ranges, distribution and seasonality. In fact, VBDs are dynamic systems with complex ecology, which tend to adapt continually to environmental changes. Although climate is only one of the several factors that influence the distribution of these diseases, together with environmental and socioeconomic aspects such as intercontinental human mobility and trade, it seems to be a major driver able to modify their epidemiology.

Address for correspondence: Nicoletta Vonesch, Dipartimento di Medicina, Epidemiologia, Igiene del Lavoro e Ambientale, INAIL, Via Fontana Candida 1, 00078 Monte Porzio Catone (Rome) Italy. E-mail: n.vonesch@inail.it.

Weather conditions, in particular temperature, humidity and precipitation, affect reproduction rates and survival of the vectors, their habitat suitability, distribution and abundance; climatic factors impact intensity and temporal activity of the vectors throughout the year and influence the rates of development, reproduction and survival of pathogens within the vectors. Insects are poikilotherms and their internal temperature varies considerably with ambient temperature that affects their physiology and directly exposes pathogens they carry to thermic variation. The infectious agents are also sensitive to environmental conditions in terms of survival, reproduction and multiplication [6-8].

The aim of our study is to present an overview of the published scientific literature regarding climatic changes, their interaction with VBDs and the possible consequences on the working population.

METHODS

Technical publications and articles regarding climate changes as drivers of VBDs and evidences of occupational cases connected to this problem have been picked up from the databank of PubMed (www.ncbi.nlm.nih.gov/pubmed*)* with the following key words: "climate changes", "vector-borne disease", "infectious diseases", "human health", "Europe" alone and/or in combination with "employees", "workers", and "occupational". Abstracts were reviewed, and applicable articles were obtained. Main internet sources included the following web sites: World Health Organization (WHO, www.who.int/en/), Centers for Disease Control and Prevention (CDC, www.cdc.gov/), European Centre for Disease Prevention and Control (ECDC, http://ecdc.europa.eu/), Intergovernmental Panel on Climate Change (IPCC, www.ipcc.ch/ipccreports/tar/wg2/index.php?idp=358).

RESULTS

We focused our attention on VBDs in Europe. In 2010 the ECDC published a technical document to assess and manage changes in the risk of infectious diseases transmission posed by climate change [2]. *Table 1* summarizes tick-, mosquito- and other arthropod-borne diseases and pathogens that may be affected in the European countries.

Tick-borne disease

The geographical distribution of tick-borne diseases has changed since the early 1980s: ticks are now found at higher latitudes and altitudes where the seasons were previously too short or cold for their survival [2, 9-12]. *Ixodes ricinus*, a three-host tick species which is free-living with brief feeding periods between the different tick stages (larvae, nymph and adult) transmits protozoal, viral and bacterial pathogens, several of which are zoonotic [13]. It requires a relative humidity of at least 80% to survive during its off-host periods, and the habitat is restricted to areas of moderate to high rainfall, with vegetation that retains a high humidity. *I. ricinus* occurs throughout Europe, and the effects of climatic change have been reported. Studies from North-Central Sweden have shown northward expansion of ticks along the Baltic Sea coastline and new establishments around larger bodies of water in the north. These changes have been statistically correlated in time and space with recent changes in climate, represented by the number of days with temperatures demonstrating milder winters [14]. *I. ricinus* distribution in the mountainous region of the Czech Republic has been studied in the same locations since 1950s. Tick collection from the early 1950s and 1981 have shown that ticks were not present higher than 700 meters above sea level. When the same places were studied in 2001, 2002 and 2003, ticks were prevalent as high as 1250 meters [15]. Nevertheless the effects of climate change on ticks are often controversial. In fact, other studies have stated that although climatic changes could influence the life cycle of *I. ricinus*, clear evidence for a consistent association between tick abundance and a warmer and wetter climate are lacking. Other environmental variables such as landscape characteristics and abundance of hosts are also important in the dynamics of tick population [13, 16]. Regarding hosts, it needs to keep in mind that each active stage (larvae, nymphs, and adults) of *I.ricinus* feeds on a range of animal hosts, and the presence and abundance of these large hosts often determine the survival of tick populations [14].

Lyme borreliosis (LB), the most common vector-borne disease in the EU region (about 100 000 cases each year, probably underestimated), and tick-borne encephalitis (TBE) are transmitted by *I. ricinus* and, in North-Eastern Europe (Finland and the Baltic States), by *Ixodes persulcatus*. The widespread occurrence of LB and the risk of secondary complications can cause morbidity and economic losses. In endemic areas currently characterized by long winter seasons, climate changes will lengthen the risk season of both LB and TBE. In Southern Europe vector density, and thus LB and TBE risks, may decrease when locations become too dry for tick survival [2, 17]. There was a marked rise in TBE cases from the 1970s in Central and Eastern Europe. Spring-time daily maximum temperatures grew in the late 1980s, sufficient to encourage transmission of the TBE virus [18]. In the Czech Republic, between 1970 and 2008, there were signs of lengthening transmission season and higher altitudinal range in association with warming [19]. The presence of TBE virus in Italy has been reported for the first time in 1975 in Tuscany Region. Isolation of the virus from ticks and 12 sporadic cases between 1975 and 1991 occurred. Further foci were reported in the 1990s in two regions of northern Italy, Trentino-Alto Adige and Veneto (Belluno Province), both near the Austrian border, with the isolation of virus strains from ticks and the diagnosis of several cases of human disease [20].

Another tick-borne disease found in Europe and possibly affected by climate change include Human Granulocytic Anaplasmosis (HGA), caused by *Anaplasma phagocytophilum*, a bacterium usually transmitted to humans by *I. ricinus*. In Europe, the disease was known to cause fever in goats, sheep, and cattle until it emerged as a disease in humans in 1996 and now is widely recognized as an emerging zoonotic tick-borne disease [21]. The prevailing distribution of *I. ricinus* in

Table 1
Vector-borne infectious diseases that may be affected by climate changes in Europe. Modified from [2]

Tick-borne		Mosquito-borne		Other insect-borne	
Disease	**Vector**	**Disease**	**Vector**	**Disease**	**Vector**
Lyme Borreliosis	*Ixodes ricinus (I.persulcatus in north-eastern Europe)*	Chikungunya fever	*Aedes albopictus*	Leishmaniasis	Phlebotomine sandflies
Tick-borne encephalitis	*Ixodes ricinus*	Malaria*	*Anopheles*	Chandipura virus	Sandflies and mosquitoes
Human ehrlichiosis	*Ixodes*	West Nile virus	*Culex*	Sandfly fever Sicilian (SFS) virus	*Phlebotomus papatasi*
Crimean-Congo haemorrhagic fever*	*Hyalomma*	Tularemia	*Aedes, Culex, Anopheles*	Tularemia	*Chrysops* spp.
Tularemia	*Amblyomma, Dermacentor, Haemaphysalis, Ixodes, Ornithodoros*	Yellow fever*	Mosquitoes	Toscana virus	*P. perfiliewi* and *P. perniciosus*
		Sindbis virus	*Culex*	Sandfly fever Naples (SFN) virus)	*P. papatasi*
		Tahyna virus	Mosquitoes		
		Dengue	*Aedes albopictus Aedes aegypti*		

*Disease not prevalent in the European Union.

Norway corresponds to the distribution of *Anaplasma phagocytophilum* [13].

Crimean-Congo haemorrhagic fever (CCHF) is a severe viral disease, caused by a virus belonging to the Bunyaviridae family and transmitted by *Hyalomma* spp. ticks to domestic and wild animals. The virus is present in the Eastern Mediterranean, where a series of outbreaks in Bulgaria in 2002 and 2003 have been reported, and in Albania and Kosovo in 2001. Milder weather conditions, favoring tick reproduction may influence the incidence of the disease. For example, an outbreak in Turkey was linked to a milder spring season (a substantial number of days in April with a mean temperature higher than 5 °C) in the year before the outbreak. However, other factors such as land use and demographic changes have also been implicated [21, 22].

Mosquito-borne disease

Among the arthropods vectors of human diseases, mosquitoes appear to be the most susceptible to climatic changes, being part of their life dependent on the availability and quality of the water. During the early part of the 21st century, an important change in the status of VBDs in Europe has occurred. In fact, invasive mosquitoes widely established across the continent, with subsequent transmission and outbreaks of Dengue and Chikungunya virus; malaria re-emerged in Greece, and West Nile virus (WNV) has appeared throughout parts of Eastern Europe. These changes are partly due to globalization, since intercontinental air travel and shipping transport have created new opportunities for invasive vectors and pathogens, and partly to modifications in land and environment use. *Aedes albopictus* (the tiger mosquito) has been reported in 25 different European countries and has become widely established in large parts of the Mediterranean Basin. Since 2007, *Ae. albopictus* has been implicated in the transmission of Chikungunya (> 200 human cases in Italy) and Dengue (isolated cases in France and Croatia), after these non-native mosquitoes acquired infection by blood-feeding from infected travellers. In 2014, *Ae.albopictus* was implicated in local transmission of Dengue and Chikungunya in Southern France. *Ae. albopictus* is abundant in most of Italy, along the Croatian coast, on the Cote d'Azur, and along the Spanish Mediterranean coast. This species continues to expand rapidly along road networks. However, the occurrence of autochthonous cases would depend on local climate conditions controlling the abundance of mosquitoes, and thus the rates of mosquito biting, and the virus circulation [4]. Moreover, climate changes may affect disease transmission by shifting the vector's geographic range and shortening the pathogen incubation period [23]. In Italy, *Ae. albopictus* was first recorded in Genoa in the late summer of 1990, while the first established populations were identified in Padua (Veneto Region) in 1991, probably introduced from the United States in used tires. The tiger mosquito has subsequently spread throughout the peninsula, with populations now established in almost all regions of Italy. In the Province of Trento, *Ae. albopictus* was found for the first time in 1996 in a used tire depot near Rovereto (30 km south of Trento), and has now been recorded in other municipalities localized in a mountainous region. The European Alps are considered particularly sensitive and vulnerable to meteorological and climate impacts caused by global warming. In fact, there has been a mean annual temperature increase in the Alps since 1890 of 1.1 °C [24]; a positive trend in mean temperature of about 1 °C per century in Italy was also demonstrated [25]. Another potential vector of arboviruses is the *Culex pipiens*, an autochthonous mosquito species which is the main component of the Italian local insect fauna. The distribution of this species cover all temperate regions and comprises two distinct forms, *pipiens* and *molestus*, that differ in several behavioural and ecological characteristics affecting their vector competence to several viruses [26] Although the members of the *Culex pipiens* complex have been implicated as vectors of a number of arboviruses including St. Louis encephalitis, Sindbis, and Rift Valley fever viruses, this species has been repeatedly implicated as an important vector of WNV in continental Europe [27] and North America [28], habitually biting both humans and birds, so that it serves as a bridge vector of infection from birds to humans.

WNV, belonging to the family *Flaviviridae*, is an emerging zoonotic arthropod-borne virus (arbovirus) widely distributed throughout the world and with considerable impact on veterinary and human health. Human cases have been reported from Romania since the 1960s, and limited sporadic outbreaks have occurred in several European countries in the past 15 years. In Italy the first outbreak of WNV appeared in 1998 in Tuscany (Fucecchio/Cerbaie), in a nesting site for migratory birds that act as a reservoir of the virus, with a few cases of equine encephalitis [6]. In 2010 an unprecedented increase in the numbers of WNV cases was recorded in Europe: temperature deviations from a third year average during the summer months correlated with a WNV outbreak of over 1000 cases in South-Eastern Europe, starting from Greece. Evidences show that climatic conditions favoring high population densities of both birds and vectors in a location preceded major outbreaks [23, 29, 30]. Increased temperatures cause an upsurge in the growth rates of vector populations, decrease the interval between blood meals, shorten the incubation time from infection to infectiousness in mosquitoes, accelerate the virus evolution rate and increase viral transmission efficiency to birds. However it is important to note that, in some cases, extremely high temperatures begin to slow down mosquito activity. Regarding precipitation, above-average precipitation might lead to a higher abundance of mosquitoes and increase the potential for disease outbreaks in humans: heavy rainfall increases the standing water surface, is necessary for mosquito larval development. A pattern of a positive association with rainfall in the months preceding disease outbreaks has been demonstrated for WNV [8].

In summer 2007, an unexpected outbreak of Chikungunya fever, an arbovirus belonging to the Alphavirus genus, caused more than 200 human cases in the Emilia-Romagna Region of Italy; most of the cases were recorded in the Province of Ravenna. The tropical virus was introduced by a man from Kerala (an Indian state affected by a large Dengue outbreak) and sustained by local mosquitoes *Ae. albopictus*, which transmitted the infection to other persons [31]. This was the first Chikungunya outbreak on the European continent [21]. The tiger mosquito is now ubiquitous with a distribution predominantly stratified along the coastal areas, inland below 600 m, and in the north is already present up to the Alpine regions. The species could see a reduction of its presence in the southern regions where the temperature increase was not accompanied by abundant rainfall during the warmer months [6]. The epidemic was the result of the globalization of vectors and humans, which occurred through a two-step process: the introduction and adaptation of *Ae. albopictus* to a new environment and the introduction of Chikungunya virus in an infection-free country because of population movement. Whether climate change created a favorable ground for the spread of the infection is a matter of debate, though this hypothesis has been widely confuted; in fact, the Italian climate has always been suitable for *Ae. albopictus* to flourish during the warm season. The time-limited capacity of the vector to sustain infection transmission after the hot season and appropriate control measures determined a rapid containment of the outbreak [31]. Why WNV infection occurred in 2008 in Italy almost in the same area that had been affected by the Chikungunya outbreak of 2007 and what factors were involved remain undefined. Climate change, which can have hardly explained the Chikungunya outbreak, is certainly not to blame for the WNV outbreaks [2, 31, 32].

Dengue is the most rapidly spreading mosquito-borne viral disease, showing a 30-fold increase in global incidence over the past 50 years [33]. Each year about 390 million Dengue infections happen worldwide, of which about 96 million manifest with symptoms [34]. The first sustained transmission of Dengue in Europe since the 1920s was reported in 2012 in Madeira, Portugal [35]. Autochthonous transmission has occurred repeatedly in France and Croatia, due to travel importation [36]. *Ae. aegypti* and *Ae. albopictus* are the principal vectors for Dengue and both are climate sensitive. Over the last 2 decades, climate conditions have become more suitable for *Ae. albopictus* in some areas (*e.g.*, over Central North-Western Europe) but less suitable elsewhere (*e.g.*, over Southern Spain) [2, 18, 37]. *Ae. albopictus* is now established in southern Europe and is better adapted to lower temperatures than the primary vector (*Ae. aegypti*) of the Chikungunya and Dengue viruses. *Ae. albopictus* is likely to spread further in Europe with climate change. However, the potential areas for future transmission of Chikungunya and Dengue viruses are more restricted than areas with possible vector occurrence [2].

Malaria is caused by one of the species of the *Plasmodium* parasite, transmitted by female *Anopheles* spp. mosquitoes. Historically malaria was endemic in Europe, but it was eliminated in 1975. Recent studies investigated the recurrence of malaria in Italy [38-40]. The risk is currently considered low and unlikely: sporadic and isolated cases of *Plasmodium vivax*, along with small and localized outbreaks, may occur in rural areas of our country, where the climatic conditions and the density of the vector are favorable. The historic vector *Anopheles labranchiae* is present mainly in Tuscany, Northern Lazio, Puglia, Calabria and large islands [29]. The potential for malaria transmission is linked to meteorological conditions, such as temperature and precipitation [21]. The influence of temperature on malaria development appears to be nonlinear, and is vector specific [41]. But malaria is very sensitive to socioeconomic factors and health interventions, and the generally more conducive climate conditions have been offset by more effective disease control activities [18]. Projections of malaria under future climate change scenarios are limited in Europe; while climatic factors may favor autochthonous transmission, increased vector density, and accelerated parasite development, other factors (socioeconomic, land use, treatment, capacity of health-care system, etc.) limit the likelihood of climate-related re-emergence of malaria in Europe [21].

Other insect-borne disease

Other insect-borne diseases have been considered influenced by climate changes: the visceral form of leishmaniasis (VL) is the most serious of the sandfly-borne diseases in Europe and is caused by a parasite present mainly in dogs. Most VL cases are currently reported south of the 45°N latitude in Europe, but both sandflies and a few autochthonous cases have been recently found in mid-Western Germany [2]. VL is a typical rural and peri-urban disease, present along the areas of the Tyrrhenian coast, the coast of the Adriatic Sea and islands; cases are reported in many regions of south-central, but the areas most affected are in Campania and Sicily. The average increase in atmospheric temperature may determine the increase of cases in the regions where it is already present in endemic form, and the expansion of the transmission of leishmaniasis to northern latitudes [42]. This phenomenon has been studied in some areas of Northern Italy, and comparison between recent entomological data with those available for the years 1960 and 1970 revealed that some species of sandflies have expanded their geographic distribution northward [29, 43, 44].

Nematodes of the genus Dirofilaria are currently considered emerging agents of parasitic zoonoses in Europe. Climatic changes and an increase in the movement of reservoirs (mostly infected dogs) have caused an increase in the geographical range of these parasites from the traditionally endemic/hyperendemic southern regions, and the risk for human infection has increased. In the last several years, forecast models have predicted that current summer temperatures are sufficient to facilitate extrinsic incubation of Dirofilaria in many areas of Europe. The global warming projected by the Intergovernmental Panel on Climate Change suggests that warm summers suitable for Dirofilaria transmission in Europe will be the rule in the future decades, and if the actual trend of temperature increase continues, filarial infection should spread into previously infection-free areas [45].

Impacts on working population

Considerable research and planning with regard to climate change has dealt with public health and the environment, but little has been focused on workers. The challenge would be to investigate and characterize how climate events may influence workers health and safety and to establish plans for mitigating, responding to and anticipating health impacts. Schulte, *et al.* [46] tried to represent the link between global climate change and occupational safety and health through a framework, derived from two models used by WHO for assessing the relationship between environmental health and policy action [47, 48]. A synthesis of the framework focused on VBDs is shown in *Figure 1*. The model asserts that the climate changes affect workers' health together with other contextual factors, such as population growth, energy policies, local conditions/socioeconomic circumstances and increasing urbanization/deforestation. All these factors act increasing the magnitude and severity of known hazards and result in a higher number of workers potentially exposed to them. The hazards can be included in seven categories: increased ambient temperature, air pollution, ultraviolet (UV) radiation, extreme weather, expanded vector habitats, industrial transitions and emerging industries, and changes in the built environment. Exposure to these hazards trigger different outcomes on workers' health. *Figure 1* shows the impact of the climate changes and the other contextual factors on vector-borne pathogens and host habitats, the main effect on the occupational health and

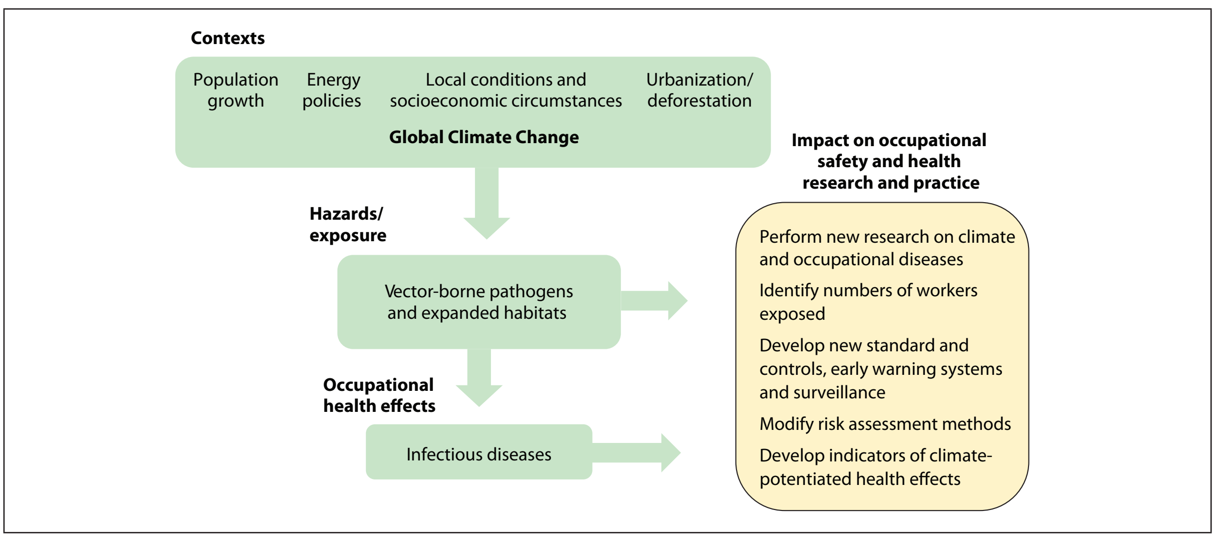

Figure 1
Relationship between climate change and occupational safety and health. Modified from [46].

the implications in terms of future research and plan. In fact, modifications in research and practice should adequate to new scenarios and/or to more frequent exposure to a specific hazard.

The occupational category mainly affected by VBDs is represented by outdoor workers, which include farmers, foresters, landscapers, groundskeepers, gardeners, painters, roofers, pavers, construction workers, laborers, mechanics, and any other worker who spends time outside. Industry sectors with outdoor workers include the agriculture, forestry, fishing, construction, mining, transportation, warehousing, utilities, and service sectors. Emergency responders and healthcare workers who deal with infected subjects are also at risk of exposure. Outdoor workers are exposed to many different hazards depending on the type of work, the geographic site, the season, and the duration of time they spend outside. Physical hazards may include extreme heat, extreme cold, noise, and sun exposure; biological hazards involve exposure to tick, mosquitoes and other vectors in enlarged habitats. Due to climate modifications, workers may be exposed to vector-borne diseases in areas and at times where transmission was previously impossible. Moreover, changes in daily work activities caused by increased heat, *i.e.* longer rest periods in the middle of the day and increased work at dawn and dusk, could correspond to period when vectors are most active, therefore increasing the risk of disease transmission [49]. Other factors associated with vector-borne diseases include host factors such as population susceptibility, insecticide resistance, primary healthcare, land use patterns, and subtle alterations in microenvironments [46]. In literature studies regarding occupational exposure to vector-borne diseases are numerous [50-56], however uncertainty persists in attributing the increasing of some diseases to climate change.

DISCUSSION

Vector-borne pathogens can cause massive suffering to human and animals, and a lot of them are increasing their range into new areas such as Zika, a tropical virus spread by mosquitoes, suspected of causing severe birth defects, whose proliferation reinforce the assumption that arboviruses continually evolve and adapt within ecologic niches perturbed directly or indirectly by humans [57]. Investigating infectious disease outbreaks is a complex and dynamic process involving biological, environmental, social, and economical factors. Vector-borne diseases are also gaining wider socioeconomic impacts since the burden of climate-sensitive diseases is greater for the poorest populations [58]. They varies markedly by pathogens and by location, resulting more frequent in the tropical climates of many developing countries, and also because of low levels of socioeconomic development and coverage of health services in underdeveloped areas. More than ten years ago, Harvell, *et al.* [59] reviewed the potential for infectious diseases to increase with climate change. Since then, a lot of researches have been published in theme of climate-disease interactions, as demonstrated by a study of Altizer *et al.*, showing that papers referencing a climate-disease link in the title has doubled in the period 1990-2012 [60].

Naturally-occurring climatic events, such as disasters and disease outbreaks, have often occurred in the past in response to extreme climatic cycles, such as the El Niño Southern Oscillation (ENSO) cycle. Nowadays, the situation has become more complicated, since human activities may influence natural climate cycles, amplifying for example the natural "greenhouse effect", thereby increasing Earth temperature [61]. Impacts of climate change vary by regions, depending on the change intensity and the vulnerability of the area. It is recognized that during recent decades Europe has warmed up: temperature has grown especially in the north and in the mountains of the Mediterranean region. Climate changes are represented not only by modifications in temperature but also in humidity and precipitation. Rainfalls have shown variable trends across Europe: annual precipitations increased of 10-40% during the 20th century in the north and decreased of up to 20% in the south. The Mediterranean region has become warmer with an increase in the frequency, intensity and duration of "heatwaves" and a decrease in total precipitation [8].

The life-cycle and transmission of many infectious agents are inextricably linked to climate, and there is little doubt that climate changes will affect VBDs [57]. In general, it has been observed that increased temperatures and humidity favor the growth of mosquito populations, but paradoxical effects, such as the link between drought and the emergence of Chikungunya along coastal East Africa, have been also reported [62]. Extreme weather conditions are one of the consequence of climatic changes. Drought is known to contribute to outbreaks of the WNV in North America: as wetlands dry, the remaining pools become hubs of birds activity which, together with the increase in abundance of mosquitoes developing in nutrient-rich waters, increases animal-vector interface that permits virus transmission. Flooding creates additional aquatic habitats, thereby contributing to mosquito-borne disease risk [4]. Climatic factors in Italy may have favored the extension of vectors now ubiquitous as the tiger mosquito at higher altitudes or the shift to more northern latitudes of vectors already considered endemic (*i.e.* sandfly vector of leishamania), or the appearance of cases in areas generally considered exempt [6]. Nevertheless, it should be emphasized that climate change is not the unique factor able to change the epidemiological picture of vector-borne disease. Others include socioeconomic development, urbanization, land-use change, migration, and globalization. Rezza, *et al.* sustains that the impact of climatic changes on VBDs has been sometimes overemphasized: the debate following the Chikungunya outbreak in Italy tended to attribute a role to climate change, without considering that the Italian climate has always been suitable for the vector *(Ae. Albopictus)* to flourish during the warm season [62]. Many existing and emerging zoonotic diseases can be traced back to human-induced ecological disturbances. Deforestation, road construction, water control system and human settlements disrupt the natural habitat of infectious agents, their host and vectors: workers involved in these activities are on the front line to contract novel infections. The emergence of Nipah virus in Malaysia in the late 1990s after large tracts of rain forest were cut for commercial forestry is an example of disease outbreak caused by ecological modification. Projected increasing in the frequency and severity of ENSO under future climate change, associated with modification in ambient and food supplies for animals, can increase the risk of new interaction between animals and human activities [50].

Quantification of the effect of climate change on VBDs and the subsequent risk to public and occupational health is very difficult to assess [4]. If and in which direction changes in the global climate will have an impact on human health is largely debated: scientists assert that most of the health impact of climate change would be adverse [61]. Consideration must be given to the capacity of public health systems worldwide to respond and adapt to the infectious diseases, and in particular to vector-borne diseases, that might result from climate change [4]. In general, an effective public health response should include disease control strategies and methods to mitigate effects of epidemics, and an optimally allocation of resources. Exposure prevention through vector control and suitable protection measures are essential actions of effective public health and occupational practice. Monitoring environmental and climatic precursors of the diseases through early warning systems are also very important to predict the introduction and spread of VBDs [36, 56].

The EU Commission at various level and jointly by different Directorates has promoted actions to affront climate changes related health problems through: 1) strengthening cooperation between the services of human, animal, and plant health; 2) developing action plans to face extreme weather conditions; 3) collecting reliable information on the risks of climate change by international cooperation, in particular with the WHO; 4) looking for additional effort to identify the most effective measures; 5) improving the surveillance and the control of the infectious diseases circulating among humans and animals [23, 63, 64]. The gaps in adaptation strategies to climate change between different countries are evident, as also shown in recent study conducted in the Mediterranean basin [65]. Stakeholders should develop and implement guidelines and standards in order to protect workers health under climate change conditions [66].

In conclusion, climate change is an important phenomenon in a changing world and, though its influence on infectious diseases has been recognized, its real impact and long term effects need further studies and investigations.

Author's contribution statement

Nicoletta Vonesch and Paola Tomao conceived and designed the study; Nicoletta Vonesch wrote the paper; Maria Concetta D'Ovidio, Maria Grazia Ciufolini, Maria Elena Remoli, Paola Tomao additional manuscript editing and corrections; Paola Melis acquisition of the bibliography.

Acknowledgements

This paper is part of a monographic section dedicated to Climate change and occupational health, edited by Maria Concetta D'Ovidio, Carlo Grandi, Enrico Marchetti, Alessandro Polichetti and Sergio Iavicoli and published in the same issue: *Ann Ist Super Sanità* 2016;52(3):323-423.

Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

Submitted on invitation.
Accepted on 12 April 2016.

REFERENCES

1. Intergovernmental Panel on Climate Change. Pachauri RK, Meyer LA (Eds). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC; 2014.
2. European Centre for Disease Prevention and Control. *Climate change and communicable diseases in the EU Member States*. Stockholm: ECDC; 2010. DOI: 10.2900/27967
3. James N, Mills JN, Gage KL, Khan AS. Potential influence of climate change on vector-borne and zoonotic diseases: A review and proposed research plan. *Environ Health Perspect* 2010;118(11):1507-14. DOI: 10.1289/ehp.0901389
4. Medlock JM, Leach SA. Effect of climate change on vector-borne disease risk in the UK. *Lancet Infect Dis* 2015;15(6):721-30. DOI: 10.1016/S1473-3099(15)70091-5
5. Semenza JC, Sudre B, Oni T, Suk JE, Giesecke J. Linking environmental drivers to infectious diseases: the European environment and epidemiology network. *PLoS Negl Trop Dis* 2013;7(7):e2323. DOI: 10.1371/journal.pntd.0002323
6. Castellari S, Venturini S, Ballarin Denti A, Bigano A, Bindi M, Bosello F, Carrera L, Chiriaco MV, Danovaro R, Desiato F, Filpa A, Gatto M, Gaudioso D, Giovanardi O, Giupponi C, Gualdi S, Guzzetti F, Lapi M, Luise A, Marino G, Mysiak J, Montanari A, Ricchiuti A, Rudari R, Sabbioni C, Sciortino M, Sinisi L, Valentini R, Viaroli P, Vurro M, Zavatarelli M. *Rapporto sullo stato delle conoscenze scientifiche su impatti, vulnerabilità ed adattamento ai cambiamenti climatici in Italia.* Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma; 2014.
7. Parham PE, Waldock J, Christophides GK, Hemming D, Agusto F, Evans KJ, Fefferman N, Gaff H, Gumel A, LaDeau S, Lenhart S, Mickens RE, Naumova EN, Ostfeld RS, Ready PD, Thomas MB, Jorge Velasco-Hernandez J, Michael E. Climate, environmental and socio-economic change: weighing up the balance in vector-borne disease transmission. *Philos Trans R Soc Lond B Biol Sci* 2015;370(1665)pii:20130551. DOI: 10.1098/rstb.2013.0551
8. Paz S. Climate change impacts on West Nile virus trans-

mission in a global context. *Philos Trans R Soc Lond B Biol Sci* 2015;370(1665)pii:20130561. DOI: 10.1098/rstb.2013.0561
9. Lukan M, Bullova E, Petko B. Climate warming and tick-borne encephalitis, Slovakia. *Emerg Infect Dis* 2010;16(3):524-6. DOI: 10.3201/eid1603.081364
10. Tokarevich NK, Tronin AA, Blinova OV, Buzinov RV, Boltenkov VP, Yurasova ED, Nurse J. The impact of climate change on the expansion of Ixodes persulcatus habitat and the incidence of tick-borne encephalitis in the north of European Russia. *Glob Health Action* 2011;4:8448. DOI: 10.3402/gha.v4i0.8448
11. Estrada-Peña A, Ayllón N, de la Fuente J. Impact of climate trends on tick-borne pathogen transmission. *Front Physiol* 2012;27(3):64. DOI: 10.3389/fphys.2012.00064
12. Jaenson TG, Jaenson DG, Eisen L, Petersson E, Lindgren E. Changes in the geographical distribution and abundance of the tick *Ixodes ricinus* during the past 30 years in Sweden. *Parasit Vectors* 2012;5:8. DOI: 10.1186/1756-3305-5-8
13. Jore S, Vanwambeke SO, Viljugrein H, Isaksen K, Kristoffersen AB Woldehiwet Z, Johansen B, Edgar Brun E, Brun-Hansen H, Westermann S, Larsen IL, Ytrehus B, Hofshagen M. Climate and environmental changes drives *Ixodes ricinus* geographical expansion at the northern range margin. *Parasit Vectors* 2014;7:11. DOI: 10.1186/1756-3305-7-11
14. Lindgren E, Tälleklint L, Polfeldt T. Impact of climatic change on the northern latitude limit and population density of the disease-transmitting European tick *Ixodes ricinus*. *Environ Health Perspect* 2000;108(2):119-23. DOI: 10.2307/3454509
15. Materna J, Daniel M, Danielová V. Altitudinal distribution limit of the tick *Ixodes ricinus* shifted considerably towards higher altitudes in central Europe: results of three years monitoring in the Krkonose Mts. (Czech Republic). *Cent Eur J Public Health* 2005;13(1):24-8.
16. Medlock JM, Hansford KM, Bormane A, Derdakova M, Estrada-Peña A, George JC, Golovljova I, Jaenson TGT, Jensen JK, Jensen PM, Kazimirova M, Oteo JA, Papa A, Pfister K, Plantard O, Randolph SE, Rizzoli A, Santos-Silva MM, Sprong H, Vial L, Hendrickx G, Zeller H, Van Bortel W. Driving forces for changes in geographical distribution of *Ixodes ricinus* ticks in Europe. *Parasit Vectors* 2013;6:1. DOI: 10.1186/1756-3305-6-1
17. Ostfeld RS, Brunner JL. Climate change and *Ixodes* tick-borne diseases of humans. *Philos Trans R Soc Lond B Biol Sci* 2015;370(1665)pii:20140051. DOI: 10.1098/rstb.2014.0051
18. Smith KR, Woodward A, Campbell-Lendrum D, Chadee DD, Honda Y, Liu Q, Olwoch JM, Revich B, Sauerborn R. Human health: impacts, adaptation, and co-benefits. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M,. Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (Eds). *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* 2014. Cambridge, UK and New York, USA: Cambridge University Press; 2014. p. 709-54.
19. Kriz B, Maly M, Benes C, Daniel M. Epidemiology of tick-borne encephalitis in the Czech Republic 1970-2008. *Vector Borne Zoonotic Dis* 2012;12(11):994-9. DOI: 10.1089/vbz.2011.0900
20. Cinco M, Barbone F, Ciufolini MG, Mascioli M, Anguero Rosenfeld M, Stefanel P, Luzzati R. Seroprevalence of tick-borne infections in forestry rangers from north-eastern Italy. *Clin Microbiol Infect* 2004;10(12):1056-61. DOI: 10.1111/j.1469-0691.2004.01026.x
21. Semenza JC, Menne B. Climate change and infectious diseases in Europe. *Lancet Infect Dis* 2009;9(6):365-75. DOI: 10.1016/S1473-3099(09)70104-5
22. World Health Organization. *A global brief on vector-borne diseases*. Geneva: WHO; 2014.
23. Bezirtzoglou C, Dekas K, Charvalos E. Climate changes, environment and infection: facts, scenarios and growing awareness from the public health community within Europe. *Anaerobe* 2011;17(6):337-40. DOI: 10.1016/j.anaerobe.2011.05.016
24. Roiz D, Neteler M, Castellani C, Arnoldi D, Rizzoli A. Climatic factors driving invasion of the Tiger Mosquito (*Aedes albopictus*) into new areas of Trentino, Northern Italy. *PLoS One* 2011;6(4):e14800. DOI: 10.1371/journal.pone.0014800
25. Brunetti M, Maugeri M, Monti F, Nanni T. Temperature and precipitation variability in Italy in the last two centuries from homogenized instrumental time series. *Int J Climatol* 2006;26:345-81. DOI: 10.1002/joc.1251
26. Vinogradova AB. *Culex pipiens pipiens mosquitoes: taxonomy, distribution, ecology, physiology, genetics, applied importance and control.* Sofia Pensoft; 2000.
27. Hubálek Z. European experience with the West Nile virus ecology and epidemiology: could it be relevant for the New World? *Viral Immunol* 2000;13(4):415-26.
28. Apperson CS, Harrison BA, Unnasch TR, Hassan HK, Irby WS, Savage HM, Aspen SE, Watson DW, Rueda LM, Engber BR, Nasci RS. Host-feeding habits of *Culex* and other mosquitoes (*Diptera*: *Culicidae*) in the Borough of Queens in New York City, with characters and techniques for identification of Culex mosquitoes. *J Med Entomol* 2002;39(5):777-85. DOI: 10.1603/0022-2585-39.5.777
29. Semenza JC, Zeller H. Integrated surveillance for prevention and control of emerging vector-borne diseases in Europe. *Euro Surveill* 2014;19(13)pii:20757.
30. Epstein PR. West Nile virus and the climate. *J Urban Health* 2001;78(2):367-71. DOI: 10.1093/jurban/78.2.367
31. Rezza G. Chikungunya and West Nile virus outbreaks: what is happening in north-eastern Italy? *Eur J Public Health* 2009;19(3):236-7. DOI: 10.1093/eurpub/ckn135
32. European Centre for Disease Prevention and Control. *Mission report. Chikungunya in Italy. Joint ECDC/WHO visit for a European risk assessment, 17-21 September 2007.* Stockholm: ECDC; 2007.
33. World Health Organization. *Vector-borne diseases. Dengue*. WHO. Available from: www.who.int/mediacentre/factsheets/fs387/en/index2.html.
34. Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, Drake JM, Brownstein JS, Hoen AG, Sankoh O, Myers MF, George DB, Jaenisch T, Wint GRW, Simmons CP, Scott TW, Farrar JJ, Hay SI. The global distribution and burden of dengue. *Nature* 2013;496(7446):504-7. DOI: 10.1038/nature12060
35. Sousa CA, Clairouin M, Seixas G, Viveiros B, Novo MT, Silva AC, Escoval MT, Economopoulou A. Ongoing outbreak of dengue type 1 in the Autonomous Region of Madeira, Portugal: preliminary report. *Euro Surveill* 2012;17(49)pii:20333.
36. Semenza JC. Prototype early warning systems for vector-borne diseases in Europe. *Int J Environ Res Public Health* 2015;12(6):6333-51. DOI: 10.3390/ijerph120606333
37. Caminade, C, Medlock JM, Ducheyne E, McIntyre KM, Leach S, Baylis M, Morse AP. Suitability of European climate for the Asian tiger mosquito *Aedes albopic-*

tus: recent trends and future scenarios. *J R Soc Interface* 2012;9(75):2708-17. DOI: 10.1098/rsif.2012.0138
38. Di Luca M, Boccolini D, Severini F, Toma L, Barbieri FM, Massa A, Romi R. A 2-year entomological study of potential malaria vectors in central Italy. *Vector Borne Zoonotic Dis* 2009;9(6):703-11. DOI: 10.1089/vbz.2008.012
39. Romi R, Boccolini D, Menegon M, Rezza G. Probable autochthonous introduced malaria cases in Italy in 2009-2011 and the risk of local vector-borne transmission. *Euro Surveill* 2012;17(48)pii: 20325.
40. Boccolini D, Toma L, Di Luca M, Severini F, Cocchi M, Bella A, Massa A, Mancini Barbieri F, Bongiorno G, Angeli L, Pontuale G, Raffaelli I, Fausto AM, Tamburro A, Romi R. Impact of environmental changes and human-related factors on the potential malaria vector, *Anopheles labranchiae* (Diptera: Culicidae), in Maremma, Central Italy. *J Med Entomol* 2012;49(4):833-42. DOI: 10.1603/ME11252
41. Alonso D, Bouma MJ, Pascual M. Epidemic malaria and warmer temperatures in recent decades in an East African highland. *Proc Biol Sci* 2011;278(1712):1661-9. DOI: 10.1098/rspb.2010.2020
42. Maroli M, Rossi L, Baldelli R, Capelli G, Ferroglio E, Genchi C, Gramiccia M, Mortarino M, Pietrobelli M, Gradoni L. The northward spread of leishmaniasis in Italy: evidence from retrospective and ongoing studies on the canine reservoir and phlebotomine vectors. *Trop Med Int Health* 2008;3(2):256-64. DOI: 10.1111/j.1365-3156.2007.01998.x
43. Maroli M, Feliciangeli MD, Bichaud L, Charrel RN, Gradoni L. Phlebotomine sandflies and the spreading of leishmaniases and other diseases of public health concern. *Med Vet Entomol* 2013;27(2):123-47. DOI: 10.1111/j.1365-2915.2012.01034.x
44. Rossati A, Bargiacchi O, Kroumova V, Garavelli PL. Malattie trasmesse da vettori e cambiamenti climatici in Europa. *Infez Med* 2014;22(3):179-92.
45. Genchi C1, Kramer LH, Rivasi F. Dirofilarial infections in Europe. *Vector Borne Zoonotic Dis* 2011;11(10):1307-17. DOI: 10.1089/vbz.2010.0247
46. Schulte PA, Chun H. Climate change and occupational safety and health: establishing a preliminary framework. *J Occup Environ Hyg* 2009;6(9):542-54. DOI: 10.1080/15459620903066008
47. Corvalan C, Briggs D, Kjellstrom T. Development of environmental health indicators. In: Briggs D, Corvalan C, Nurinen M (Eds). *Linkage methods for environment and health analysis: General guidelines*. Geneva: UNEP, USEPA, WHO; 1996.
48. Morris GP, Beck SA, Hanlon P, Robertson R. Getting strategic about the environment and health. *Public Health* 2006;120(10):889-903. DOI: 10.1016/j.puhe.2006.05.022
49. The National Institute for Occupational Safety and Health. *Safety and health topic. Hazards to outdoor workers*. NIOSH. Available from: www.cdc.gov/niosh/topics/outdoor/
50. Bennett CM, McMichael AJ. Non heat-related impacts of climate change on working population. *Glob Health Action* 2010;3:5640. DOI: 10.3402/gha.v3i0.5640
51. Chmielewska-Badora J, Moniuszko A, Żukiewicz-Sobczak W, Zwoliński J, Piątek J, Pancewicz S. Serological survey in persons occupationally exposed to tick-borne pathogens in cases of co-infections with *Borrelia burgdorferi*, *Anaplasma phagocytophilum*, *Bartonella* spp. and *Babesia microti*. *Ann Agric Environ Med* 2012;19(2):271-4.
52. Jurke A, Bannert N, Brehm K, Fingerle V, Kempf VA, Kömpf D, Lunemann M, Mayer-Scholl A, Niedrig M, Nöckler K, Scholz H, Splettstoesser W, Tappe D, Fischer SF. Serological survey of *Bartonella* spp., *Borrelia burgdorferi*, *Brucella* spp., *Coxiella burnetii*, *Francisella tularensis*, *Leptospira* spp., *Echinococcus*, Hanta-, TBE- and XMR-virus infection in employees of two forestry enterprises in North Rhine-Westphalia, Germany, 2011-2013. *Int J Med Microbiol* 2015;305(7):652-62. DOI: 10.1016/j.ijmm.2015.08.015
53. Richard S, Oppliger A. Zoonotic occupational diseases in forestry workers – Lyme borreliosis, tularemia and leptospirosis in Europe. *Ann Agric Environ Med* 2015;22(1):43-50. DOI: 10.5604/12321966.1141368
54. Di Renzi S, Martini A, Binazzi A, Marinaccio A, Vonesch N, D'Amico W, Moro T, Fiorentini C, Ciufolini MG, Visca P, Tomao P. Risk of acquiring tick-borne infections in forestry workers from Lazio, Italy. *Eur J Clin Microbiol Infect Dis* 2010;29(12):1579-81. DOI: 10.1007/s10096-010-1028-6
55. Santino I, Sessa R, Pantanella F, Tomao P, Di Renzi S, Martini A, Nicoletti M, Del Piano M. Detection of different *Borrelia burgdorferi* genospecies in serum of people with different occupational risks: short report. *Int J Immunopathol Pharmacol* 2009;22(2):537-41.
56. Barzon L, Squarzon L, Cattai M, Franchin E, Pagni S, Cusinato R, Palù G. West Nile virus infection in Veneto region, Italy, 2008-2009. *Euro Surveill* 2009;14(31) pii:19289.
57. Fauci AS, Morens DM. Zika virus in the Americas – Yet another arbovirus threat. *N Engl J Med* 2016;374:601-4. DOI: 10.1056/NEJMp1600297
58. Cambell-Lendrum D, Manga L, Bagayoko M, Sommerfeld J. Climate change and vector-borne diseases: what are the implications for public health research and policy? *Philos Trans R Soc Lond B Biol Sci* 2015;370(1665)pii: 20130552. DOI: 10.1098/rstb.2013.0552
59. Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD. Climate warming and disease risks for terrestrial and marine biota. *Science* 2002;296(5576):2158-62. DOI: 10.1126/science.1063699
60. Altizer S, Ostfeld RS, Johnson PTJ, Kutz S, Harvell CD. Climate change and infectious diseases: from evidence to a predictive framework. *Science* 2013;341(6145):514-9. DOI: 10.1126/science.1239401
61. Rezza G. Re-emergence of Chikungunya and other scourges: the role of globalization and climate change. *Ann Ist Super Sanit*à 2008;44(4):315-8.
62. Rezza G. Dengue and chikungunya: long-distance spread and outbreaks in naïve areas. *Pathog Glob Health* 2014; 108(8):349-55. DOI: 10.1179/2047773214Y.0000000163
63. Lindgren E, Andersson Y, Suk JE, Sudre B, Semenza JC. Monitoring EU emerging infectious disease risk due to climate change. *Science* 2012;336(6080):418-9. DOI: 10.1126/science.1215735
64. Commission of the European Community. *Adapting to climate change: toward a European framework for action. COM (2009) 147 final*. Brussels: Commission of the European Community; 2009.
65. Negev M, Paz S, Clermont A, Pri-Or NG, Shalom U, Yeger T, Green MS. Impacts of climate change on vector borne diseases in the Mediterranean Basin – implications for preparedness and adaptation policy. *Int J Environ Res Public Health* 2015;12(6):6745-70. DOI: 10.3390/ijerph120606745
66. Nilsson M, Kjellstrom T. Climate change impacts on working people: how to develop prevention Policies. *Glob Health Action* 2010;3:5774. DOI: 10.3402/gha.v3i0.5774