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INVITED REVIEW

Effects of global warming on mosquitoes & mosquito-borne diseases and the new strategies for mosquito control

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Abstract

Global warming has shortened mosquitoes' lifecycle period and increased the disease transmission rates by mosquito vectors. We reviewed only three mosquito-borne diseases: malaria, dengue fever, and the Japanese encephalitis. Billions of people get infected with those diseases and millions of people die every year. Although we struggle to find the most effective way to control mosquitoes using various methods (including pesticides), mosquito-borne diseases are still among the most serious problems being faced. This paper, therefore, reviews the strategies for controlling mosquitoes. The use of pesticides to control mosquitoes might have more negative effects on humans and environments than benefits. Although the development of genetically modified (GM) mosquitoes raises new hopes for effective mosquito control, it will take longer to assess the risks to humans and environments. Furthermore, there has been concern about the possible adverse effects from the release of GM mosquitoes into the environment. The various mosquito traps may not be as effective at controlling only female mosquito populations. Therefore, new strategies for the control of mosquitoes are vital. The smart mosquito counter device was developed by Korean Centre for Disease Control (KCDC) in 2013. The mosquito pest control office is able to set up the appropriate mosquito control strategies by using quantitative mosquito information. The smart device will bring mosquito control in line with modern smart generation technology and the device will also soon be able to identify different mosquito species. This new strategy will change the methods of mosquito control and will provide beneficial effects toward sustainable nature and human health.

Key words: global warming, integrated mosquito management, mosquito-borne diseases, pesticide, smart mosquito counter, vector.

Introduction

Climate factors and mosquitoes

Changes in climate cause global warming and global warming itself has been rising due to the increase in the Earth's mean surface temperature by about 0.7°C in the last 10 decades (Revich *et al*. 2012; Bai *et al*. 2013). Scientists estimate that the average temperature of the Earth's surface will increase by 1–3.5°C by the end of the 21st century (IPCC 1995; Githeko *et al*. 2000). As a result of various human activities – burning fossil fuels, the changing of land use patterns in agriculture, deforestation, and industrialization – there have been increases in concentrations of greenhouse gases like CO_2, methane (CH_4), nitrous oxide (N_2O), and changes to the ozone, including water vapor in the atmosphere. The increase of these greenhouse gases in the atmosphere, resulting in increasing atmospheric and Earth surface temperatures, lead to global warming (IPCC 1995; Githeko *et al*. 2000; Karl & Trenberth 2003). Increasing atmospheric and Earth surface temperatures results in regional as well as global changes in climate. Global warming affects a variety of physical (Parry *et al*. 2007) and biological systems (Githeko *et al*. 2000; Parry *et al*. 2007).

Therefore, climate may play a crucial role in determining the dissemination and abundance of many arthropods and their habitats (Van Lieshout *et al*. 2004). Climatic factors like temperature, humidity, precipitation are particularly important, but wind and the duration of the daylight in combination with the above factors have also played greater roles in mosquito ecology, their survival, their behavior, development, and in the transmission rate of diseases by them (Reiter 2001). Climate change and its impacts on mosquito vector surveillance and transmission of mosquito-borne infectious diseases is a current issue. There is still not enough accurate study data and information available regarding the climate factors, such as temperature, rainfall, humidity, drought conditions, and melting snow. Continuous long-term monitoring study to ascertain the modeling of vectors and vector-borne infectious diseases in the context of climate change is required. Furthermore, it seems essential to improve our knowledge based on the availability of present information and problems regarding mosquito surveillance and mosquito-borne infectious diseases.

During the last twenty years, thirty new diseases have emerged in the world (WHO 1997; Epstein *et al*. 1998). Mosquito vectored resurgence and the redistribution of diseases such as malaria and dengue fever have occurred worldwide (Epstein *et al*. 1998; Gubler & Kuno 1998). In particular, there have been high incidences reported of Japanese encephalitis in several countries: Japan, the Philippines, Indonesia, India, Eastern Asia, and South Korea (Tellez-Rebollar 2005; Hubalek 2007). It is currently well known that humans are infected with mosquito-borne diseases like malaria, elephantiasis (filaria), encephalitis, yellow fever, dengue (dengue fever), dengue hemorrhagic fever and Japanese encephalitis through exposure to mosquito bites (Reiter 2001). Through the study of mosquito vectored diseases in the United States, it was found that the transmission season of diseases may be elongated and mosquito-borne encephalitis – like Western equine encephalomyelitis and Saint Louis encephalitis – are spreading to the northern regions of the United States and to Canada (Reisen *et al*. 1993; Reeves *et al*. 1994; Epstein *et al*. 1998). Not only are transmission seasons elongating, researchers and investigators have expressed similar views regarding the possible expansion of the geographical range of vector-borne diseases in response to climate change (Leaf 1989; Shope 1991; McMichael *et al*. 1996; Patz *et al*. 1996; Epstein *et al*. 1998).

Effects of climate factors on vectors

Increased temperatures in general increase the rate of the development of parasites (Martens *et al*. 1995). On the other hand, climate can influence vectors, pathogens, host defenses and host habits. Extreme heat kills mosquitoes, but within certain temperature ranges at which they can survive, warmer temperatures increase their blood sucking activity and reproduction (Leeson 1939). Similarly, the pathogen maturity time is shortened; thus, the maturity rate increases (MacArthur 1972; Epstein 2001). For example, *Anopheles* mosquitoes, which transmit malaria protozoa, live only several weeks; the increased temperatures allow malarial parasites to mature more quickly and mosquitoes can transmit the disease faster. Increased temperatures also expand the geographic range of mosquitoes' survival. When temperatures exceed 16°C, the transmission of *falciparum* malaria by *Anopheles* mosquitoes occurs (Martens *et al*. 1997). *Aedes aegypti* mosquitoes transfer diseases like yellow fever, dengue fever and dengue hemorrhagic fever, which are restricted when the temperature is 10°C or falls below this level. Cool temperatures such as these kill *Aedes* eggs, larvae and adults. Temperatures above 10°C favor *Aedes* for faster reproduction and disease transmission (Elias 1994; Epstein 2001). Thus, continuous warming has the potential for impact on mosquitoes and mosquito-borne diseases, which will ultimately affect human health. Higher global temperatures increase the disease transmission rates and also expand the geographic ranges. However, Reiter Paul professed that the history of malaria, yellow fever, and dengue shows us that the climate is rarely the principle determinant for the transmission of their range. Instead, human activities and the impact created by those activities at a local ecological level is a more significant factor for their dissemination (Reiter 2001).

Higher temperatures lead to an increased frequency and amount of rainfall. However, the present trend of higher rainfall increases the vector population and disease transmission by providing more breeding spaces to vectors like mosquitoes. Not all conditions of rainfall favor mosquitoes' survival and their reproduction, though. Torrential rainfall and flooding may have negative effects on increasing the density of their population because this causes runoff water and can also destroy the eggs and larvae of mosquitoes (Martens *et al*. 1995).

The climatic aspects – such as temperature, rainfall, humidity, wind – can have greater effects on various aspects of pathogen-vectoring arthropods' life cycles, including: survival, arthropod population, interactions between vector and pathogen, pathogen multiplication, behavior of the vector and their distribution. Increasing temperatures favor vectors for higher transmission potential, diminish the vector generation time, population growth rate of vector increase, decrease incubation periods and increase the length of the transmission period. Likewise, increased water conditions also increase transmission potential, larval habitats of vector, population sizes and animal host populations (Tabachnick 2009). Different researchers have different opinions about the effects of increased temperature, rainfall and rise of sea levels in vector-borne diseases. Table 1 represents the scenarios of the effects of higher and lower temperature effects, water temperature rises, higher and lower rainfall, higher and lower humidity levels and rises in sea level effects in vector and vector-borne diseases.

Conversely, Sutherst (2004) has shown a broad framework for the assessment of potential effects on vectors, pathogens, and hosts under different global change driver conditions like higher CO_2 concentrations, temperature increases, higher rainfall, urbanization, deforestation, increased irrigation and water storage, intensification of agriculture, chemical pollution, and increased trade and increased travel (Table 2).

The aims of this review are: (i) to explore the impacts of global warming on the growth, life cycle, and population distribution range of mosquitoes; (ii) to explore the distribution range of mosquito-borne diseases resulting from global warming; (iii) to analyze the increase in global problems such as malaria, dengue, dengue haemorrhagic fever, and Japanese encephalitis; (iv) to identify the most adaptive mosquito control techniques ranging from preventive methods, biological methods, genetically modified methods, chemical methods, physical methods, traps and integrated insect control methods in controlling them to minimize the problems of disease; and (v) to explore the strategies to be used for the control of mosquitoes in a sustainable way to combat the problems created by mosquito bites.

Main mosquito-borne diseases

Malaria

More than 380 species of *Anopheles* mosquito can be found worldwide. Among them, about 60 species are vectors of malaria and attracted to human beings. Among *Anopheles* mosquitoes, a number of species transmit lymphatic filariasis and viral diseases acting as a vector. They suck blood from both humans and animals. It has been determined that species which prefer feeding on human beings are more dangerous in transmitting malaria than those feeding on animals (WHO 1997).

Increased global temperatures during the last few decades has changed malaria virulence – which has similar patterns to that of double CO_2 simulations (two times CO_2; Epstein *et al*. 1998). In the last one hundred years, the surface temperature of the Earth in the Asian continent was found to have increased by 0.3 to 0.8°C and is estimated to increase by 0.4 to 4.5°C before 2070. Some of the mosquito-borne diseases like *Plasmodium falciparum* and *Plasmodium vivax* malaria, dengue fever and dengue hemorrhagic fever spread endemically in different places of tropical Asia (Watson *et al*. 1995; Githeko *et al*. 2000). Incidences of *Plasmodium falciparum* malaria increased in the Northwest Frontier Province of Pakistan which is directly associated with increases in temperature, rainfall and humidity in the area (Bouma *et al*. 1996; Githeko *et al*. 2000). Due to higher precipitation in the north-east Punjab of India, malaria epidemics have increased five-fold; due to lower precipitation than normal, the risk of malaria epidemics has likewise increased five-fold in Sri Lanka (Githeko *et al*. 2000; WHO 2000). In warmer temperatures and in situations of sufficient moisture, the frequency of mosquito bites has increased, mosquito activity is higher, mosquito populations have increased, and the extrinsic incubation period has decreased (Martens *et al*. 1997). If temperatures increase from 20–25°C then the extrinsic incubation period of malarial parasites *P. falciparum* decreases from 26 to 13 days (Macdonald 1957; Epstein *et al*. 1998). Global warming also affects transmission in different geographical ranges of many malaria vectoring species of mosquitoes (Van Lieshout *et al*. 2004).

As in the highlands of Asia, Central Africa and Latin America mosquito-borne diseases are now emerging. A slow and steady annual rise in temperature is one of the major causes for the dissemination of mosquitos and the transmission of the diseases. *P. falciparum* malarial parasite attacks is an increasing problem in the Chimbu highlands of Papua New Guinea (Rozendaal 1996; Epstein *et al*. 1998) and malaria was reported in 1997 at 2100 m altitude in the Jaya highlands of Iran (ProMED 1997; Epstein *et al*. 1998). Malaria has also been reported in the highlands of Kenya (Some 1994) and the Usamabara mountains in Tanzania (Epstein *et al*. 1998).

In 107 countries around the world, more than 3.2 billion people are under the threat of malaria transmission. Over 1 million people, mostly children, died and 300–500 million people have been found to be infected in clinical tests each year by the malaria pathogen infection, vectored by mosquito bites (WHO & UNICEF 2005). Since prehistoric times, excluding death from wars and natural disasters, 50% of all mortality of human beings has been attributed to the bites of malaria vectoring mosquitoes (Kevin 2005). Incidences of malaria are increasing rapidly throughout the world. The status of malaria around the world up to 2000AD and the possibility of extended distribution up to 2050 is given in Figure 1.

Table 1 Interactions between climatic factors and efficiency of vectors and pathogens: Changes in weather and climate that can affect transmission of vector and vector-borne diseases include temperature, rainfall, wind, extreme flooding or drought, and sea level rise

Climatic factors	Limits	Effects	References
Temperature	Effect to vector at higher temperature	– Survival can decrease or increase depending on the species.	– Reiter 1988; Reeves *et al.* 1994
		– Some vectors have higher survival at higher latitudes and altitudes with higher temperatures.	– Gubler *et al.* 2001
		– Higher transmission potential of vector; decreasing vector generation time; increasing vector population growth rate; decreasing pathogen extrinsic incubation period; increasing length of transmission period.	– Tabachnick, 2009
		– Changes in the susceptibility of vectors to some pathogens e.g. higher temperatures reduce the size of some vectors.	– Grimstad & Haramis 1984; Nasci 1986; Reisen *et al.* 1995
		– Affects their rate of multiplication in the insect.	– Gilles & Warrell 1993; Cook 1996; Reiter 2001
		– Warmer global temperatures will increase their incidence and geographic range.	– McMichael *et al.* 1996; Watson *et al.* 1996; Watson *et al.* 1998; Reiter 2001
		– Higher temperature reduces the activity of some other vectors.	– Omer & Cloudsley Thompson 1970; Reiter 1998
		– Increase the proportion of infective vectors.	– Rueda *et al.* 1990
		– Temperature above 34 °C generally has a negative impact on the survival of vectors.	– Rueda *et al.* 1990; Githeko *et al.* 2000
		– 30–32°C temperature increase the vectorial capacity and extrinsic incubation period decreased.	– Githeko *et al.* 2000
		– Changes in feeding rate and host contact (which may alter the survival rate).	– Mitchel 1989; Reisen *et al.* 1995
		– Changes in the seasonality of populations.	– Hardy *et al.* 1990
	Effect to vector at lower temperature	– Lower transmission potential; decreasing life expectancy; decreasing vector longevity.	Tabachnick 2009
		– Changes in the seasonality of populations.	– Hardy *et al.* 1990
	Effect to pathogen at higher temperature	– As temperature rises, malarial parasites and viruses complete extrinsic incubation within the female mosquito in a shorter time.	– Turell 1989
		– Temperature above 34 °C generally has a negative impact on the survival of parasites.	– Githeko *et al.* 2000
		– 1–2°C increase in temperature results in quicker and higher replication of viruses.	– Benitez 2009
		– Decreased extrinsic incubation period.	– Hurlbut 1973; Kramer *et al.* 1983; Watts *et al.* 1987; Tabachnick 2009
		– Increasing length of transmission period.	Tabachnick 2009.
		– Changes in the transmission season.	– Reisen *et al.* 1993; Reisen *et al.* 1995
		– A long term warming trend is encouraging the geographic expansion of several important infections.	– Epstein *et al.* 1998; Epstein 2001;
		– Changes in distribution	– Hess 1963
Water temperature	Effects in vector in rise water temperature condition	– The mosquito larvae take a shorter time to mature	– Rueda *et al.* 1990; Githeko *et al.* 2000
		– Greater capacity to produce offspring; digestion of blood meal faster, feed more frequently.	– Gillies 1953; Githeko *et al.* 2000
		– Disease transmission intensity increased.	– Githeko *et al.* 2000

Table 1 *Continued*

Climatic factors	Limits	Effects	References
Rainfall	Effects of higher rainfall to vector	– Increased rain may increase number and quality of larval habitat and vector population size.	– Githeko *et al.* 2000; Gubler *et al.* 2001
		– Excess rain or snowpack can eliminate habitat by flooding, thus decreasing the vector population size	– Gubler *et al.* 2001
	Effects of lower rainfall to vector	– Low rainfall can create habitat by causing rivers to dry into pools (dry season malaria).	– Gubler *et al.* 2001
		– Decreased rain can increase container-breeding mosquitoes by forcing increased water storage.	– Focks *et al.* 1995
	Epic rain effects to vector and pathogen	– Epic rainfall events can synchronize vector host-seeking and virus transmission.	– Day & Curtis 1989
	Effects of higher rainfall to vertebrate host	– Increased rain can increase vegetation, food availability, and population size; increased rain can also cause flooding and decrease population size but increase contact with humans	– Gubler *et al.* 2001
	Effects of lower rainfall to vertebrate host	– Decreased rain can eliminate food and force rodents into housing areas, increasing human contact, but it can also decrease population size.	– Gubler *et al.* 2001
Abundance of water	Effects in vector and pathogen	– Higher transmission potential in some vector and lower in others; increase in vector larval habitats; increase in vector population sizes; increase in animal host populations over time; decrease vector host interactions with increase in water sources and dispersion of animal hosts; some vector-borne disease cycles require periods of drought for pathogen amplification.	Tabachnick 2009
Humidity	Effects of higher humidity in vector	– Increased humidity increases vector survival.	– Lansdowne & Hacker 1975
	Effect of lower humidity in vector	– Decreased humidity decreases vector survival.	– Gubler *et al.* 2001
Increased sea level	Effects on selected vector-borne pathogens	– Alter estuary flow and change existing salt marshes and associated mosquito species, decreasing or eliminating mosquito breeding sites (e.g. reduced habitat for *Culiseta melanura*)	– Gubler *et al.* 2001

Dengue fever

More than 950 species of *Aedes* mosquitoes can be found in the world. Mosquitoes of the genus *Aedes* are found in diverse ecological regions of the tropics and cooler climatic zones (WHO 1997). Several *Aedes* species are responsible for transmitting dengue fever (DF). However, *Aedes aegypti* and *Aedes albopictus* are the principle vectors of DF with others playing a lesser role on the global level (Gratz 2004; Kolivras 2006). *Aedes aegypti and Aedes albopictus* transmit dengue fever, dengue hemorrhagic fever, yellow fever and other viral diseases. In some places, it has also been found that *Aedes* mosquitoes transmit filariasis. While biting both humans and animals for blood meals, virus-infected mosquitoes transmit the diseases (WHO 1997).

Changes in temperature and humidity have dramatic effects on sensitive arthropods like mosquitoes. Egyptian forest mosquitos (*Aedes aegypti*) are directly affected in terms of the rate of replication of dengue virus by increases in temperatures. The small changes in temperature enable dengue, yellow fever and other climate-sensitive vector-borne diseases to disseminate into new regions of the world – regions where no such diseases had previously been found (Patz *et al*. 1998). *Aedes aegypti* mosquitoes are the species

Table 2 Environmental effects of global change drivers pertinent to vector-borne diseases, and their potential biological effects

Global change driver	Potential effects on vector, pathogen, and host environments	Potential effects on vectors, pathogens, and hosts
Higher CO_2 concentration	– Ambient temperature and plant biomass increased; range expansion of woody plants with longer growth season with humid microclimate.	– In the same rainfall, temperature and more humid microclimatic condition vector longevity increased; humid zone vectors have chance of range expansion.
Temperature increase (regional/temporal variation)	– Warm climatic zone expansion and longer growth season; extreme high temperature frequently and less extreme low temperature.	– Due to faster development of vector and pathogen, more generation/year; short life span of vector in higher temperature; dying of vector in low temperature become reduced; expansion of range of warm-climatic vector and pathogen.
Rainfall	– Found variation region-wise and difficult to estimate; extreme rainfall frequency increased.	– Increased flooding wash out the mosquito breeding places; breeding pattern of mosquitoes changed.
Urbanization	– Human host density increased; poor cleanliness and supply of water in developing countries; develop the outer urban area near forest in developed countries.	– More vector breeding sites developed with higher diseases transmission at same vector density; Vector contact to human increased in peri-urban forested areas.
Deforestation	– Increased entrance of human towards forests; due to improved agriculture system more exposed logging water.	– Due to more vector-breeding sites, more contact between humans and vectors.
Irrigation and water storage	– Increased surface water, prevention of seasonal flooding.	– More vector-breeding sites; reduced flushing of snails and mosquitoes.
Intensification of agriculture	– Disturbance increased in land and vegetation; surface water exposed more and biodiversity reduced.	– Varieties of vector breeding sites developed with decreased predation of vectors.
Chemical pollution	– Fertilizer, pesticide, herbicide and industrial toxins cause environmental pollution and produced more endocrine-disrupting chemicals.	– Human immune systems adversely affected.
Increased trade	– Increased volume of shipped goods.	– Increased transport of vectors, leading to "homogenization" of vectors in receptive areas.
Increased travel	– Increased movement of people between North and South and East and West.	– Increased transfer of pathogens between regions of endemicity and disease-free regions, and increased exposure of visitors to regions of endemicity.

Source: Sutherst 2004. Global change and human vulnerability to vector borne diseases.

most commonly responsible for dengue transmission around the world, followed by *Aedes albopictus* (Gratz 2004). However, in the rural tropical regions of Southeast Asia, the outbreaks of *Aedes albopictus* were found to be higher (Gubler 1997; Kolivras 2006). *Aedes albopictus* was responsible for the dengue outbreaks of 1942 to 1944 in Japan (Gratz 2004; Kolivras 2006). The World Health Organization (WHO) reports that many countries in Asia suffered from high levels of dengue and dengue hemorrhagic fever. Changing weather patterns is one of the main promoting factors for them (WHO weekly epidemiological record, 1998; Githeko *et al*. 2000). The incubation period of the dengue virus was found to have been reduced from 12 days at 30°C to 7 days at 32–35°C in *Aedes aegypti* mosquitoes while conducting laboratory experiments (Watts *et al*. 1987). Around the world, 2.5 billion people live in endemically dengue affected areas and dengue infection occurs in 50–100 million people every year (WHO fact sheet 117, 2002; Kolivras 2006; WHO fact sheet 117, 2013). The dengue distribution pattern has also been witnessed to have highly increased since 1960. The distribution pattern of dengue both before 1960 and after 1960 is shown in Figure 1B.

Japanese encephalitis (JE)

Japanese encephalitis virus (JEV) is the virus most responsible for causing encephalitis. This virus belongs to the genus *Flavivirus* and the family *Flaviviridae* (Tsai 1997; Saluzzo *et al*. 2004). In the transmission cycle of this disease

A.

B.

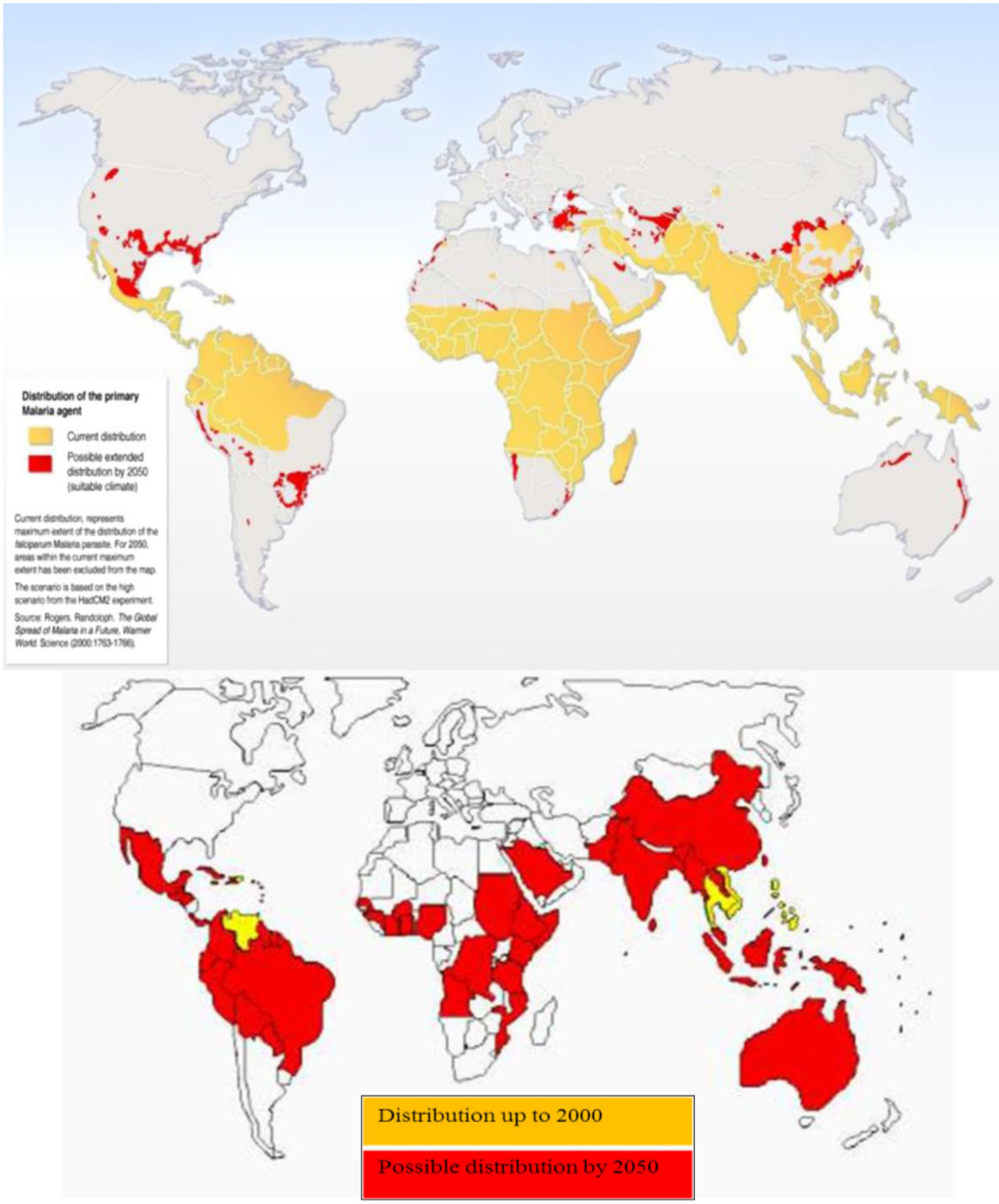

Figure 1 The distribution of malaria and dengue in the world: (A) The distribution of malaria due to climate change in the world up to 2000 AD and possible extended distribution area by 2050; (B) The emergence and distribution of the dengue/DHF in the world prior to 1960 and after 1960.

to humans, birds and animals, *Culex tritaeniorhynchus* mosquitoes are mainly involved, as well as other similar species of the genus *Culex*. Domestic pigs, water birds and humans are suitable hosts of the disease (Campbell *et al*. 2011).

In Asian countries, JE is one of the most prevalent viral diseases in generally rural and suburban areas. Areas of rice cultivation and pig farming have more pronounced disease problems (Offit 2008; Fischer *et al*. 2010). In 2013, there were 799 suspected JE events being tested, but only 14 patients were confirmed with JE patients in South Korea (Jung & Cha 2013). This disease has also occurred sporadically in northern Australia and parts of the Western Pacific

Table 3 Global status of major vector-borne diseases: (LF: Lymphatic filariasis, DF: Dengue fever, YF: Yellow fever, JE: Japanese encephalitis, Others: other arboviral diseases, Tr: Tropics, Sub: subtropics, Af: Africa, LA: Latin America, EU: Europe, SE: South Europe, NA: no estimate available)

Diseases	Population at risk (millions)†	Prevalence of infection (millions)	Present distribution	Change possibility of distribution after climate change
Malaria	2100	270.0	Tr/sub	very likely
LF	900	90.2	Tr/sub	likely
DF	1500	–	Tr/sub	very likely
YF	NA	–	Af/LA	likely
JE	NA	–	EU/SE/Asia	likely
Others	NA	–	–	likely

†Based on a world population estimated at 4.8 billion (1989). (Source: Patz JA. 2011. Global climate change and ozone depletion. In: Stellman JM (ed) Environmental health hazards, pp 1–6. International Labor Organization, Geneva).

(Campbell *et al*. 2011). This disease has been reported to cause mild fever to acute meningomyeloencephalitis and permanent neurological damage has been reported in 50% of recovered cases (Solomon *et al*. 2000) while mortality has been found to be as high as up to 25% in young children (Burke & Leake 1988). This disease was reported in 1924 (in Japan) for the first time and subsequent outbreaks of the disease occurred in 1931 and 1948 – again, both in Japan (Tsai 1997; Saluzzo *et al*. 2004). JEV has become a serious endemic over the last few decades: mostly in Southeast Asia and among the 2.4 billion people living in 16 Asian countries 50 000 clinical cases are reported annually (Mackenzie *et al*. 2001; Fischer *et al*. 2010). Due to the absence of vaccinations, 175 000 children between 0–14 years suffer from JE each year in Asia (Tsai 2000). The incidence of JE at a global level is unknown due to the intensity and varying quality of JE surveillance and available laboratory testing for diagnosis of the disease throughout the world (Paul *et al*. 1993; Campbell *et al*. 2011).

Mosquito controls

Harmful effects from mosquitoes

Along with the changes in climate and with some other human induced problems, mosquitoes and mosquito-borne diseases are increasing. At the present time, deforestation and industrialization have caused excessive increases in the range of mosquitoes. The current global warming situation also favors expansion of the geographical range of mosquitoes and increases in the incidences of malaria, dengue fever, and yellow fever. In elevated land areas, *Anopheles* mosquitoes have started to appear where they had not appeared before, and a child dies every 12 s (especially in third world countries) because of malaria. (Patel *et al*. 2012). Dengue and dengue hemorrhagic fever are some of the other most serious mosquito-borne diseases transmitted by *Aedes* mosquitoes (Gubler & Clark 1995; Brandling-Bennett & Pinheiro 1996; Briseno-Garcia *et al*. 1996; Patel *et al*. 2012). There is no special treatment or vaccine that has been developed yet against dengue and dengue hemorrhagic fever (Patel *et al*. 2012). Mosquitoes also transfer different kinds of infectious viral diseases including West Nile virus, St. Louis encephalitis virus, LaCrosse encephalitis virus, Eastern Equine encephalitis virus, and Western Equine encephalitis virus (Hill *et al*. 2013). Billions of people are affected and millions of people die each year around the world as a result of the transmission of various diseases by mosquitoes. Due to climate change, the vector-borne disease status at a global level has also been increasing. The infected population due to vector-borne diseases and their distribution in the context of climate change at global level are listed in Table 3.

Mosquitoes are annoying to human beings, livestock, and wild animals. Their bites cause itchy welts and the lives of humans and other animals become very difficult where there are increasing numbers of mosquitoes (Hill *et al*. 2013). They also decrease livestock productions (i.e. milk, meat, and eggs) in both quantity and in quality.

Due to those harmful effects of mosquitoes, mosquito control has become an indispensable subject in the present day. We should have proper mosquito control methods to minimize or to prevent excessive damage from their bites. We need the right methods and, furthermore, they must be environmentally friendly. One single effort is not enough to be able to control the mosquitoes; mass awareness and integrated efforts are required for their control (Patel *et al*. 2012).

Strategies for mosquito control

Any mosquito control strategy must focus on the use of preventive measures rather than following adaptive measures. The creation of public awareness; avoiding mosquito

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breeding sites, through the reduction of sources like stagnant water pools, stagnant water pits, water filled pots and tires around homes and settlements, and creating clean environments are the best preventative measures to control mosquitoes. The use of natural enemies and parasites is another possible method of control, and the use of genetically modified mosquitoes that cannot reproduce offspring remains a possibility. The use of mechanical traps is the best nontoxic method for the suppression of mosquitoes. Using pesticides for mosquito control is considered an alternative method because of the harmful effects that often outweigh any possible benefits; the pesticide use strategy must, therefore, be used only as a last resort alternative. The use of "Integrated Mosquito Management" (IMM) systems can effectively address and sustain mosquito control programs (Ellis 2004). The cooperative efforts of individuals, communities, government agencies and business holders are also seen to be essential for successful mosquito control.

Because mosquitoes can breed in spaces as small as a bottle cap of water, it is first essential to eliminate mosquito breeding sources if one wishes to reduce mosquito populations (Fig. 2). All water-filled containers must be removed and drained, ditches, and water pits must be eliminated. Areas may need filling with soil. If it is not possible to drain or fill the problem areas with soil, the water source should be made unusable by mosquitoes. Poorly-drained water resources support the development of vegetation and become prime areas for the laying of eggs and larval development of mosquitoes. Eliminating mosquito breeding sources might be accomplished by effective and economic methods of controlling them (Ellis 2004). According to Ellis's (2004) strategies, we can, therefore, reduce the populations of mosquitoes in backyards and other surrounding areas (Table 4).

Biological control methods

Use of bacteria

The removal of all breeding sites of mosquitoes will certainly remain difficult, and it is advisable that certain biological means of control are used. The use of *Bacillus thuringiensis israelensis* (*Bti*) products is very effective for killing mosquito larvae and the *Bti* products have low levels of toxicity to humans and wildlife. These bacterial products are Vectobac, Aquabac and Teknar. These bacteria exist in natural conditions, and their products are very lethal to the mosquitoes which ingest them (Ellis 2004). These bacteria have a toxic substance which becomes activate in mosquitoes' guts. This bacterium is toxic to mosquitoes and other flies like blackflies and nuisance chironomid midges (Ellis 2004; Lawler & Lanzaro 2005). *Bti* spray liquid, granules, and floating briquettes are manufactured for the purpose of spraying or being kept in small bodies of water to kill mosquitoes. *Bti* kills adult mosquitoes from 2–3 days to up to 3 weeks after it is applied. However, it is not effective at killing mosquito pupae or larvae in the stage of pupation because these mosquito forms will not eat anything nor eat anywhere near the required fatal dose (Lawler & Lanzaro

Figure 2 Reduction of water sources: Different stagnant water sources in which mosquito can breed and multiply. Removal of those sources helps to control mosquito.

Table 4 The strategies for reducing mosquitoes at the backyard

Mosquito sources	How to reduce mosquitoes at the backyard
Water gardens	Stock with fish or use Bt; remove excess vegetation.
Swimming pools	Keep water off the pool cover; maintain water quality at all times.
Tree holes	Fill hole with sand or mortar.
Plastic pools	Drain water when not in use, or cover so mosquitoes cannot lay eggs.
Containers	Empty water; store in an inverted position; dispose of; or cover.
Bird baths	Change water at least once a week.
Standing water	Eliminate by draining; fill in low areas.
Livestock watering troughs	Stock with fish or change water weekly.
Street gutter or catch basins	Keep litter and garden debris out of gutters; do not over water yard.
Septic tank fields	Ensure proper drainage so mosquitoes cannot lay eggs.
Roof gutters/eaves trough	Clean once a year to remove debris.
Irrigated lawns or fields	Avoid over-irrigation. Drain standing water.

Source: Ellis 2004. Municipal mosquito control guidelines. Prairie pest management. Health Canada Centre for Infectious Disease Prevention and Control.

2005). However, the application time of *Bti* is highly important and the maximum effect from the application might be obtained when it is applied during the second and third instar stages of larvae. Regarding the effect of *Bti* on non-targeted species, researchers have concluded that *Bti* has less effect on many beneficial species that are found in places where larvae of mosquitoes are found. Among the Dipterans biting flies, the poisonous effect of *Bti* is restricted to only to a few nematocerous families (Ellis 2004). According to Sinegre *et al*. (1979), the study conducted on non-targeted species in mosquito breeding sites shows that *Bti* does not cause injury or damage to the representative test organisms – water scavenger beetles, cladocerans, copepods, dragonfly larvae, brine shrimp, phantom midge larvae, mosquito fish, or oysters. The only exception was observed with chironomid larvae: they are susceptible to *Bti.* Lacey and Merritt (2004) reported that not all species of chironomid larvae are affected by *Bti*; they reported that several species of chironomid larvae have been found to be not susceptible to *Bti* – even in high strength solutions. Ellis (2004) reported that *Bti* has a much less direct and indirect effect on invertebrate species and on fish.

Likewise, another species of bacteria, *Bacillus sphaericus (Bs),* has also been found to be toxic to mosquitoes. These bacteria are effective against mosquitoes of the genus *Culex*, some *Anopheles*, *Ochlerotatus* (*Aedes*) and, *Psorophora spp* mosquitoes; however, they are not effective against all species. The bacteria also has no effect against mosquito pupae either. However, it is safe on non-targeted organisms and kills mosquitoes of up to several weeks (Lawler & Lanzaro 2005). Unfortunately, *Bacillus thuringiensis israelensis* and *Bacillus sphaericus* products are expensive and not easily found in commercial markets. The uses of bacteria for controlling mosquito larvae are shown in http://www.northlineexpress.com/how-to-kill-mosquito-larvae.html.

Use of larvivorous fish

Fishes have been used to control mosquito numbers for a long time. Larvivorous fish, like *Gambusia affinis,* have been used for more than 80 years to control mosquitoes. This fish is tolerant to different ranges of climatic conditions. They can tolerate a range of temperatures from 0.5 to 42°C and are able to establish themselves in 5–9 pH conditions (Meisch 1985; Knight *et al*. 2003). Reproduction is rapid after introduction into a new habitat or in the beginning of the summer. The rapid growth in population causes food scarcity in the habitat. *Gambusia* eats a variety of foods and its wide range of environmental tolerance makes this fish a good biological control agent of mosquitoes in wetlands and wastewater ponds. They eat the food on surface water – where mosquitoes' larvae are mostly found (Knight *et al*. 2003). The strength of larvivorous fishes decrease in areas of thick vegetation (Coykendall 1980; Knight *et al*. 2003). The use of mosquito-eating fishes for the control of mosquitoes has, however, become debatable because they adversely affect other local fishes and other fauna by diminishing both their populations and diversity (Gamradt & Kats 1996; Rupp 1996; Knight *et al*. 2003).

Other biological control means

Other different biological means are in use for the suppression of mosquito populations. Fresh water crustaceans, fungi and nematodes, for example, are also used, but these are also not available on commercial scales for the purpose of mosquito control. Natural control of mosquitoes achieved using natural predators – bats, dragonflies and damselflies – is another means of biological control, but to date multiplication work of those natural predators still does not occur; furthermore, it is not available in larger quantities and is unable to achieve certain targets. These natural methods of control are also not effective at achieving a reduction of mosquito populations in sufficient quantity to break down mosquito-borne disease cycles and to reduce their annoyance level. Consequently, these biological measures have not been widely-used for adult mosquito control (Lawler & Lanzaro 2005).

Genetically modified (GM) mosquitoes

Sterile insect technique (SIT) of GM mosquito

The sterile insect technique (SIT) is a species-specific and environmentally-friendly method for insect population control (Knipling 1955; Phuc *et al*. 2007; Wilke & Marrelli 2012). The SIT technique consists of mass rearing, radiation mediated sterilization, and the release of a large number of such male insects in desired target areas (Reiter 2007; Wilke & Marrelli 2012). In this technique, the successful mating of a female insect with a sterile male insect will produce no progeny. Adequate numbers of sterile male insect production and release will help in decreasing or eliminating harmful insect populations (Knipling 1955; Wilke *et al*. 2009), and, therefore, help to decrease vector-borne disease transmission (Pates & Curtis 2005; Wilke & Marrelli 2012).

This method has important benefits over the other mosquito control methods mentioned – insecticide use, biological control, and breeding site removals – as the males seek females of the same species and the population of targeted species is then reduced (Alphey 2002; Alphey *et al*. 2008; Wilke *et al*. 2009; Wilke & Marrelli 2012). The SIT is ecofriendly, species specific, ensures no toxic agents are released in to the environment and released organisms cannot replicate themselves (Hendrichs *et al*. 2002; Wilke & Marrelli 2012). Along with the beneficial aspects of SIT, there are also several difficulties regarding its implementation. First, this procedure must be repeated frequently. SIT needs large numbers of sterile insects and mass rearing of insects produces both male and female sex insects; this requires the necessary separating and removal of females before release (Alphey 2002; Fu *et al*. 2010). Bisexual releases of insects are not effective and will not decrease the population (Wilke & Marrelli 2012). SIT is also expensive and has operational difficulties of irradiation (Pates & Curtis 2005; Alphey 2007). During transit and release, there is a high possibility that the produced sterile mosquitoes will suffer damage (Thomas *et al*. 2000; Phuc *et al*. 2007; Alphey *et al*. 2008).

Release of GM male mosquitoes

The system of a GM male mosquito carrying a dominant lethal gene (RIDL) was developed by Oxitec (Thomas *et al*. 2000). This system consists of introducing a lethal dominant gene which is under the control of a female specific promoter (Wilke & Marrelli 2012). After introducing a lethal dominant gene, the lethal gene is inactivated by the treatment of tetracycline and allows the mosquitoes to grow into a colony. When preparing for the separation of male and female mosquitoes, tetracycline is removed from the systems, and then the lethal gene is expressed which causes the death of all females (Alphey 2007; Wilke & Marrelli 2012). The genetic control in the RIDL system favors males locating and mating with wild females of the same species (Wyss 2000; Wilke & Marrelli 2012). Homozygous males for the lethal gene will produce heterozygous progeny, and in such situations only males will survive; all females die in larval stages and this ultimately leads to the suppression of mosquito populations (Heinrich & Scott 2000; Thomas *et al*. 2000; Wilke & Marrelli 2012).

In the progeny (F_1 generation) of RIDL males and wild females, a dominant female specific lethal gene is inherited. So, F_1 female progeny will all die, but the males remain viable and fertile. This creates a mechanism for releasing only males. This condition helps reduce the production potential of wild mosquitoes (Alphey 2002; Wilke & Marrelli 2012). The RIDL system is, therefore, an improved system of sterile insect technology (SIT) (Wilke & Marrelli 2012).

Oxitec (Milton Park, UK) has been conducting an experiment following the RIDL system for the control of wild mosquitoes. Oxitec has released millions of genetically modified (GM) male mosquitoes in Brazil – they have also undertaken small experiments conducted in the Cayman Islands (UK) and in Malaysia. The Release of insects carrying a dominant lethal genetic system (RIDL) was Oxitec's patented technique for genetically modifying insects. Experiments were done in the OX513A strain of the *Aedes aegypti* mosquito (yellow fever mosquito), which is genetically engineered to contain a red fluorescent marker and the RIDL "conditional lethality" trait. In the study, it was hoped that Oxitec's male OX513A GM mosquitoes would mate with wild females and produce offspring, which may die in the larval stage. However, at the time of writing, the company has not yet published any results or information in any scientific journals. Information from the public suggests, though, that RIDL is not effective for the suppression of wild mosquitoes (Wallace 2013).

Oils and monomolecular films (MMF)

The use of diesel oils in small water sources to kill mosquito's larvae and pupae by creating suffocation in breathing is another old practice. However, the use of diesel oil not only kills mosquitoes, but also kills other unwanted aquatic animals and plants which find the oils equally toxic. Instead of diesel oil, another oil product called Golden Bear Oil is used to control mosquitoes. Golden Bear Oil is less toxic to other non-targeted organisms and produces less persistent effects on the environment (just for a few days). This oil is not available commercially anywhere except in California, USA. The oils act as a barrier against breathing on all aquatic insects and animals and also hamper the air breathing of predators of mosquitoes. Oils have also been shown to contain some other demerits: they cause bird feathers to mat and mated feathers hinder young birds from keeping warm and dry in winter. This method of biological control has limitations: it cannot be used in places where young birds are found.

Monomolecular films (MMFs) are also used to control mosquitoes and other insects. Two MMFs, Arosurf and Agnique, have been commercialized for the purpose of controlling mosquitoes. The active ingredient found in Arosurf is poly (oxy-1, 2-ethanediyl), a-Isooctadecyl-w-hydroxyl, an ethoxylated alcohol which is made from plant oils. The active ingredient in Agnique MMF is the same as Arosurf, poly (oxy-1, 2-ethanediyl), a-Isooctadecyl-w-hydroxyl. When it is applied to water, it spreads over the surface. Petroleum oil and MMFs work in the same way, though a larger amount of petroleum oil is needed. MMFs are found in spray form as well as in the form of tablets which can be put into water (Fig. 3A) If the MMF is in spray form, then 2–10 liters of MMF is required per hectare, whereas 10 time more petroleum oil is required for the same area (Stark 2005). MMF films kill both the larvae and pupae of mosquitoes in much the same way oil does: by coating the breathing tube or by passing into the blood. The effectiveness of this method is, however, not widely accepted and cannot be used in areas where dense concentrations of plants are found. It also cannot be used on windy days or in windy places because holes are formed due to vegetation and wind: thus, it does not kill larvae in such places (Lawler & Lanzaro 2005).

Use of pesticides

Impacts of pesticides on human health

Pesticides are chemical substances that are used to kill or to repeal the insects. Insecticides are poisonous substances manufactured to create effects on the nervous system, reproductive system or the immune system in order to kill insects. There are countless pesticides used for the control of

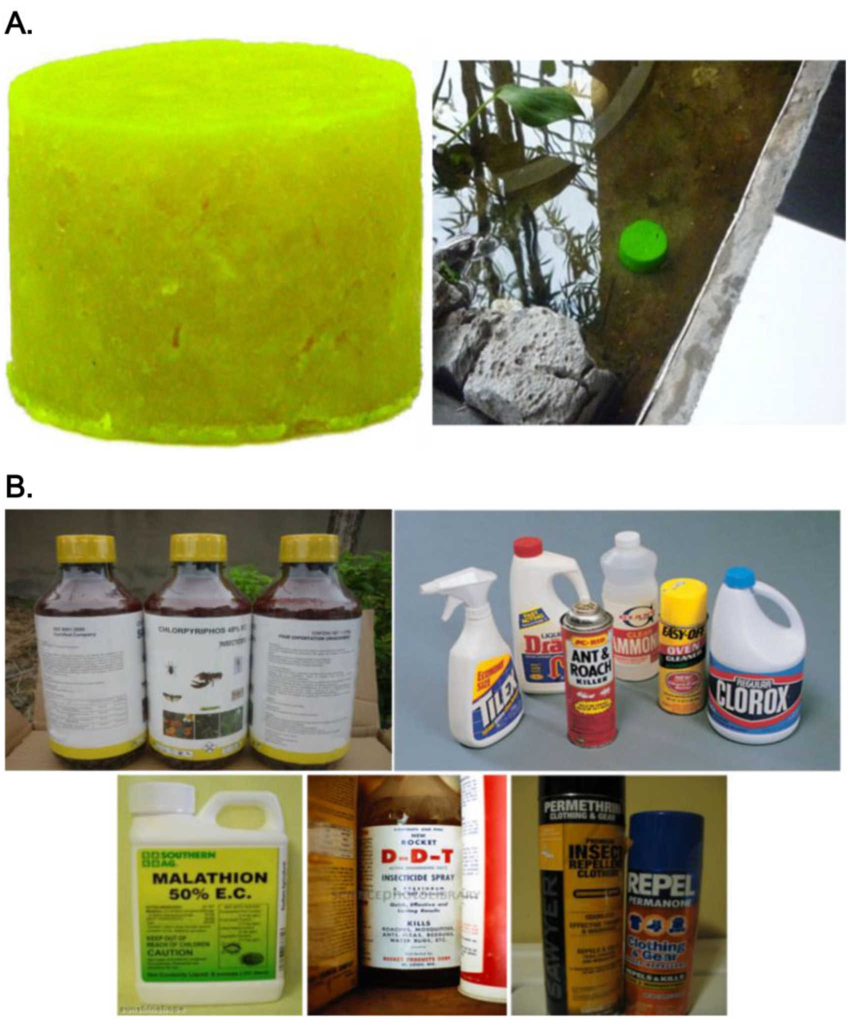

Figure 3 (A) Use of monomolecular film: α-isooctadecyl-w-hydroxyl poly (oxy-1, 2-ethanediyl) for control of mosquito larvae and pupae in small source of water. (B) Use of pesticides for mosquito control: Pyrethroid, chlorine & organophosphorous containing pesticides are under use for control of mosquitoes, they kill mosquitoes by bringing problem in respiratory, circulatory, nervous or in digestive system.

mosquitoes. Generally, scourge, anvil, permethrin and malathion (the trade name of pesticides) are used for the killing of mosquitoes. Scourge, anvil, and permethrin are pyrethroid insecticides, and malathion is an organophosphate (Stahl 2002) (Fig. 3B). For many years, different chemicals have been used to control different pests of crops, nuisance pests to humans, and animals (FCCMC 2009). Arsenic sulfide is used by the Chinese to kill insects (Pimentel & Lehman 1993). Florida, USA, used an arsenic compound (Paris green) for larval control during the 1960s. The Swiss Chemist Paul Muller discovered the insecticidal property of the organochlorine pesticide dichlorodiphenyl-trichloroethane (DDT). The laboratory of United States Department of Agriculture (USDA) in Orlando then advanced it to use in the field. Likewise, many other synthetic pesticides were developed by scientists for the control of insects and other pests in agriculture and in many circumstances associated with human health. In the early years of manufacture, the effectiveness of the insecticides was highly praised because of the decreased occurrences of human illness and death through the use of chemicals (FCCMC 2009).

The use of pesticides, however, increases the number of detrimental effects on human beings rather than the benefits. Many people regarded them as an amazing development while others had a much more pessimistic view about the widespread use of pesticides. At the time of the development of pesticides, there were research papers related to the hazardous effects on human health from those substances (FCCMC 2009). The harmful effects or risks involved in using pesticides became a mass issue after Rachel Carson published a book in 1960 called “Silent Spring” which detailed the harmful effects of pesticides (Carson 1962). Since then, public awareness has been raised toward the various harmful effects of pesticides – including acute and chronic impacts on humans, wildlife, and environments. The persistence effects of some pesticides on the environment and the transport of pesticides outside the targeted areas may cause unwanted environmental damage. The chemical control of mosquitoes contributes to human health problems (Lyon & Steele 1998) because they have been known to be especially used in human settlement areas (FCCMC 2009). Pesticides have very damaging effects on humans – especially on children. They are directly associated with the development of certain cancers, leukemia, sarcomas, and brain tumors, particularly in children. Experiments have shown that some classes of pesticides adversely affect the development of the nervous systems of some animals. Some other dangerous effects of using pesticides to control mosquitoes and other pests are birth defects and harmful effects on the immune systems of children and infants (Stahl 2002). Organophosphates (e.g. malathion) and carbamates (containing carbon compounds) are toxic to the nervous system (Blondell 1997) and some of the pyrethroids (e.g. permethrin) are believed to be toxic to the reproductive system and disruptive to endocrine functions (Garey 1998; Stahl 2002). Moreover, pyrethroid insecticides have long-lasting poisoning effects like asthmatic breathing, sneezing, nasal stuffiness, headaches and nausea (Stahl 2002). Furthermore, pesticide resistance in mosquitoes shows that they have become 12 times stronger and shown increased tolerance over the past 20 years (Kevin 2005). Researchers have further found that 56 anopheline and 39 culicine species of mosquitoes are resistant to pesticides (WHO 1992; Brogdon & McAllister 1998). Due to use of pesticides, the environment has become more polluted and the number of natural enemies has decreased; this has caused more problems in the attempted control of mosquitoes (Lee & Yu 1999). Serious effects on humans also remain with exposure to pesticides resulting in skin problems and birth abnormalities in children.

Impacts of pesticides on environment and water resources

The impact on the environment created by pesticides is often seen as greater than the intended benefits. More than 98% of insecticides reach air, water, bottom sediments in water reservoirs, and food (Miller 2004). Some pesticides contribute to global warming and the exhausting of the ozone layer (Reynolds 1997). Likewise, the application of pesticides also affects water resources. Leaching, runoff and drift are the major leading factors for carrying the pesticides up to water sources (States of Jersey 2007). One of the studies conducted by the UK government showed that the concentration of pesticides has been found at levels higher than that of allowable amounts in some samples of river water and ground water; this meant that the water tested had been made unsafe for drinking (Bingham 2007). If the use of pesticides is continuously carried out, it will accumulate in water resources (Pesticide Action Network North America 1999).

Effects of pesticides on terrestrial and aquatic ecosystems

The pesticides have big impacts on terrestrial and aquatic ecosystems through the eradication of other non-targeted species and, therefore, create big problems in the food chains of those ecosystems (Federighi 2008). Pesticides may also affect the beneficial insects, including bees, in terrestrial ecosystems. Organophosphate pesticides extensively kill bees and generally cause a decline in hive vigor and result in the loss of feeding ability (Atkins 1975), which hampers crop pollination. Probably 65% of flowering plants pollinated by different insects are adversely affected by the use of pesticides (FCCMC 2009). Aerial use of permethrin, pyrethrin and malathion has been found to have had significant effects on night flying insects and the reduction of non-targeted species has been observed (Jensen *et al*. 1999). Other animals – birds, bats, spiders, and dragonflies – depend on insects for their food and they have also been shown to suffer from adverse effects (FCCMC 2009). Every year, 72 million birds are killed as a result of the use of different pesticides in the United States alone (Fimrite 2011). Due to the use of pesticides, 116 species of birds are now under threat in Europe (Kerbs *et al*. 1999).

Pesticides also affect aquatic ecosystems. Harmful results include the killing of zooplanktons – which are the major food source of young fishes (Pesticide Action Network North America 1999). Amphibians like frogs and aquatic animals like fishes may adversely suffer from food shortages due to reductions in population sizes of plankton and aquatic invertebrates (Boone & Bridges 2003). Pesticides kill the aquatic insects on which fish rely and further increase the vulnerability of exposure to predators while they travel longer distances in search of food (Helfrich *et al*. 1996). A study in Canada showed that organochloride pesticides like endosulfan kills the tadpoles of frogs and causes behavioral and growth abnormalities if they are sprayed in nearby fields (Raloff 1998).

Impacts of pesticide on soil and soil dwellers

Soil and soil animals are also affected by the application and use of pesticides. Soils that contain no chemicals have been shown to maintain a higher quality compared to soils in which chemicals have been used. The use of pesticides decreases soil biodiversity (Johnston 1986). Studies have shown that chemical pesticides are likely to have harmful effects on the growth and reproduction of earthworms; consequently, this further affects the food chain of birds and small mammals and, thereby, affects their number (Yasmin & Doris 2010).

In soils, small soil dwellers are found. Those soil dwellers stir up the soil and perforate it so that air and water can enter. They chew up dead plants into tiny peaches, so fungi and bacteria can break down those materials more easily. They also feed on bacteria, fungi, and protozoa, and help release the nutrients found in them for plants to use. Nematodes are very small worms and their waste is rich in nutrients; those nutrients are, in turn, used by plants. In soils, microscopic protozoans are also found, and they also help to release the requisite nutrients required for plants. A teaspoonful of top soil contains approximately 50 million one-celled bacteria. Those bacteria also help to break down dead plants and animals. During decomposition they release nutrients which are utilized by small animals, plants & other microbes. Nitrogen fixing *Rhizobium bacteria* which are found in leguminous plants roots can absorb nitrogen from the air and convert it into a form that plants can use to grow. If pesticides are used in the soils or in plants, all those small animals die and also affect microbes. This disturbs the natural system and chain of nutrient cycles, which ultimately affects plants and large animals, too. So, the use of pesticides is harmful to both soils and soil animals.

Mosquito traps

Light traps, black hole light traps, New Jersey light traps, Mega Catch mosquito traps, mosquito magnets, homemade mosquito traps, Dyna traps, Dragonfly II, Koolatron traps, and Mos-hole traps (Fig. 4) are some examples of the mechanical traps available in the market. The purpose of all the traps is based on attracting blood sucking female mosquitoes around the trap, capturing and killing them. Some mosquito traps – like Mos-hole traps and homemade mosquito traps – work on the principle of the emission of CO_2 or together with scents, lactic acid, octanol, heat and water vapor (Okumu *et al*. 2010). Some other new mosquito attractant traps have additional properties such as those that emit certain sounds. In Mega-Catch mosquito traps, sophisticated light systems are used which flash and project both visible and invisible light spectrums to attract mosquitoes. The Dragonfly II trap, a night light trap, and Koolatron and Dyna traps use blue light. Mega-Catch traps, Dragonfly II traps, Koolatran traps and Mosquito Magnet traps use some type of fragrance strip or lure. CO_2 might be used as an additional component in Mega-catch traps. Mosquito magnets and Koolatron traps burn propane to release CO_2. Pure CO_2 is used in Dragonfly II traps. Mos-hole traps use pure CO_2 and octanol for mosquito attraction. Homemade brown traps also operate on the release of CO_2 to attract mosquitoes. Most of the brands focus on the release of some amount of heat to attract and trap mosquitoes. The others release some water vapor to increase the humidity along with the heat. The heat and humidity system is confined near the intake system of the traps. In some mosquito traps, a powerful fan is attached in the traps. Attractants lure the mosquitoes while a fan sucks them and holds them in a catch bag or in a liquid catch container containing a mixture of water, dish soaps, and non-diet soda. The liquid holder has benefits which are twofold: holding the mosquitoes, and helping to add more humidity and sweet smells. Mosquito Magnets use a vacuum and a catch net, while Koolatron uses a capture cup, Mos-hole traps and CDC light traps mostly use catch bags. In the Dragonfly II trap, mosquitoes are vacuumed into a collection tray where they cannot escape, and within a couple of hours die of dehydration due to air being blown over them. Mechanical traps also kill significant amounts of mosquitoes, but their efficiency in certain places depends on the sizes and species of the mosquito population as well as the types and locations of breeding habits. Most of the mechanical traps used for trapping mosquitoes have been found to be inefficient in killing mosquitoes/female mosquitoes selectively: large numbers of

Figure 4 Different kinds of traps used for trapping mosquitoes: (A) Homemade brown sugar trap produce CO_2 for attraction of mosquitoes; (B) MOS-hole trap based on release of attractant like CO_2, heat, humidity for attraction of mosquitoes; (C) Dyna light trap based on light system for attraction of mosquitoes; (D) Megha-catch trap is also based on use of spectrum of light and certain fragrance or lure for attraction of mosquitoes.

non-targeted species are also killed in the traps. Those mechanical traps are effective, however, for specimen collection studies to find out the mosquito species prevalent in an area. The depletion of large numbers of mosquitoes using only those mechanical traps is not possible.

A smart mosquito counter device

The mosquito digital monitoring system (DMS) is a mechanical smart counter device which can count number of female mosquitoes caught (Fig. 5, Table 5) as well as send the number of mosquitoes by code division multiple access (CDMA) module to the mosquito control office. This system was developed by the Korea Centers for Diseases Control and Prevention (KCDC) in 2013. The device is made of steel, PVC and acrylic (high strength power coating). This DMS device is 1080 mm in height, 560 mm in width and 320 mm in diameter. It consumes 30-watts of power during operation. It contains CO_2 cylinders of 10-liter capacity along with a pressure regulator to measure the CO_2 emission. It emits CO_2 at a rate of 300 mL/min. It is based on the principle of animals' respiration process. The device is equipped with infrared beam area sensors along with software for censoring mosquitoes in the area (the detail of DMS specification is shown in Fig. 5C). The DMS communicates through the CDMA module placed on the system. There is a mosquito catch bag inside the device. The device can attract and catch the mosquitoes around 30 m (0.7 acre) from the place of installation (ETND 2003). This system also monitors mosquitoes at the field level and requires less human labor for the monitoring and counting of mosquitoes. Most mosquito traps require the mosquito samples to be separated and counted manually. This is, of course, very time-consuming work. The DMS automatically counts the mos-

Table 5 The differences of insect composition and abundance between a light trap and a DMS for capturing mosquitoes

Description	Light trap	DMS
Female mosquitoes	7	82
Male mosquitoes	10	0
Other insects	6117	12
Total	6134	94
Capture efficiency for only mosquito/night	0.10%	87%

Source: Yi HB, Yu JS, Park K, Kim S, Shin E, Lee W, Park M (2013) Development of the Smart Mosquito Counter & Its Capability: Can We Measure the Mosquito Population? In: The Korean Society of Entomology 2013 , Seoul, Korea. Abstract P163. Department of Bio and Environmental Technology, Seoul Women's University, Korea [Research area: Gwangju-city, Gyeonggi-Do, Korea (N 38°.08′.64″/E 127° 40′.63″)].

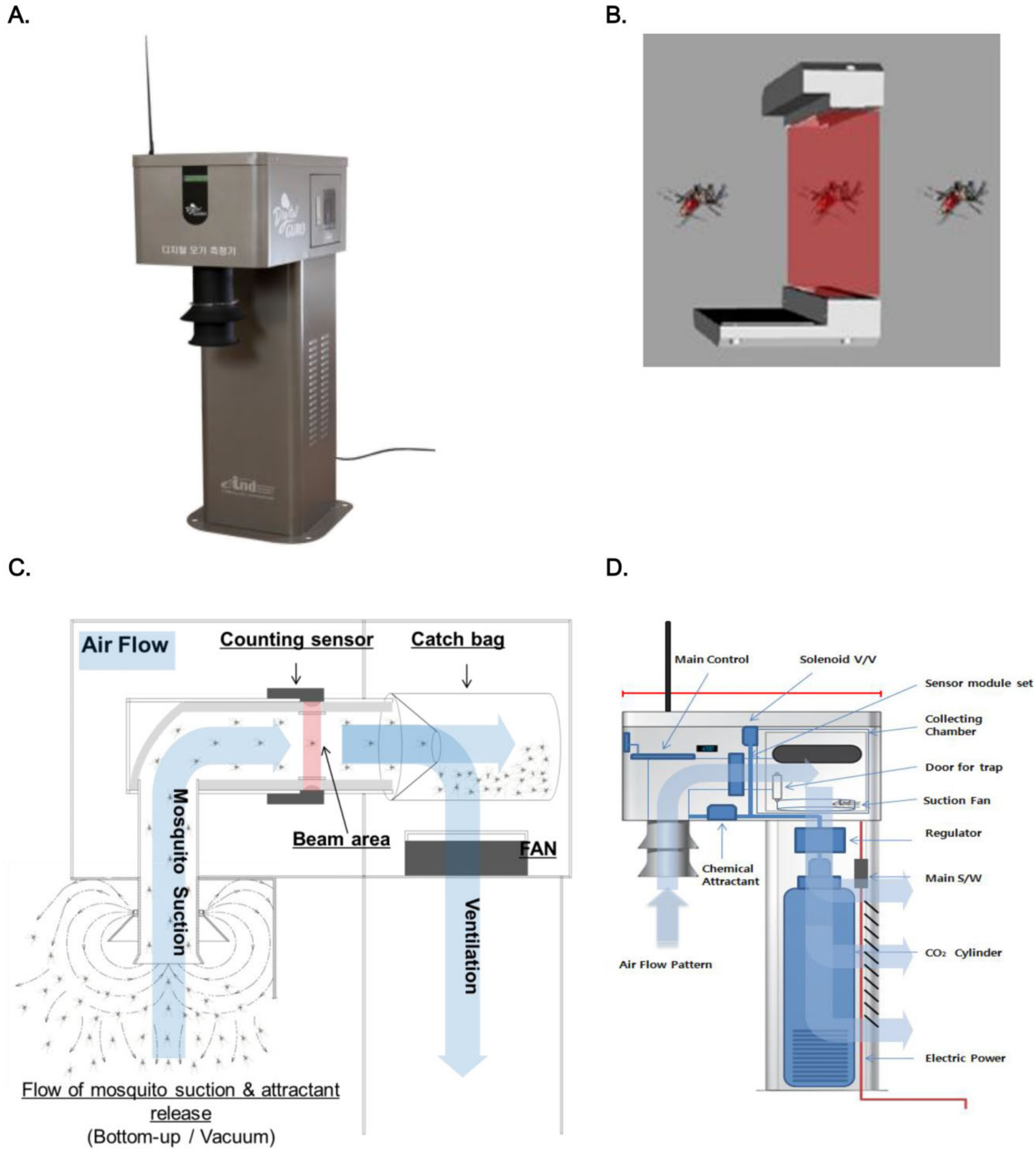

Figure 5 Digital mosquito monitoring system: (A) External appearance of DMS device; (B) DMS with mosquito counting sensor; (C) Specification of digital mosquito monitoring system; (D) Internal appearance of DMS device.

quitoes and can send the data via the CDMA communication module (Fig. 6). Through this information, the mosquito control office can control mosquitoes more efficiently and use a method which is more environmentally friendly. Using this device as a method of mosquito control will prove effective in parks, recreational areas, and conservation areas and cause little to no harm. Furthermore, the device can play a vital role in aiding the depletion of infectious mosquitoes' population at every installed site, thereby helping in reducing disease transmission also.

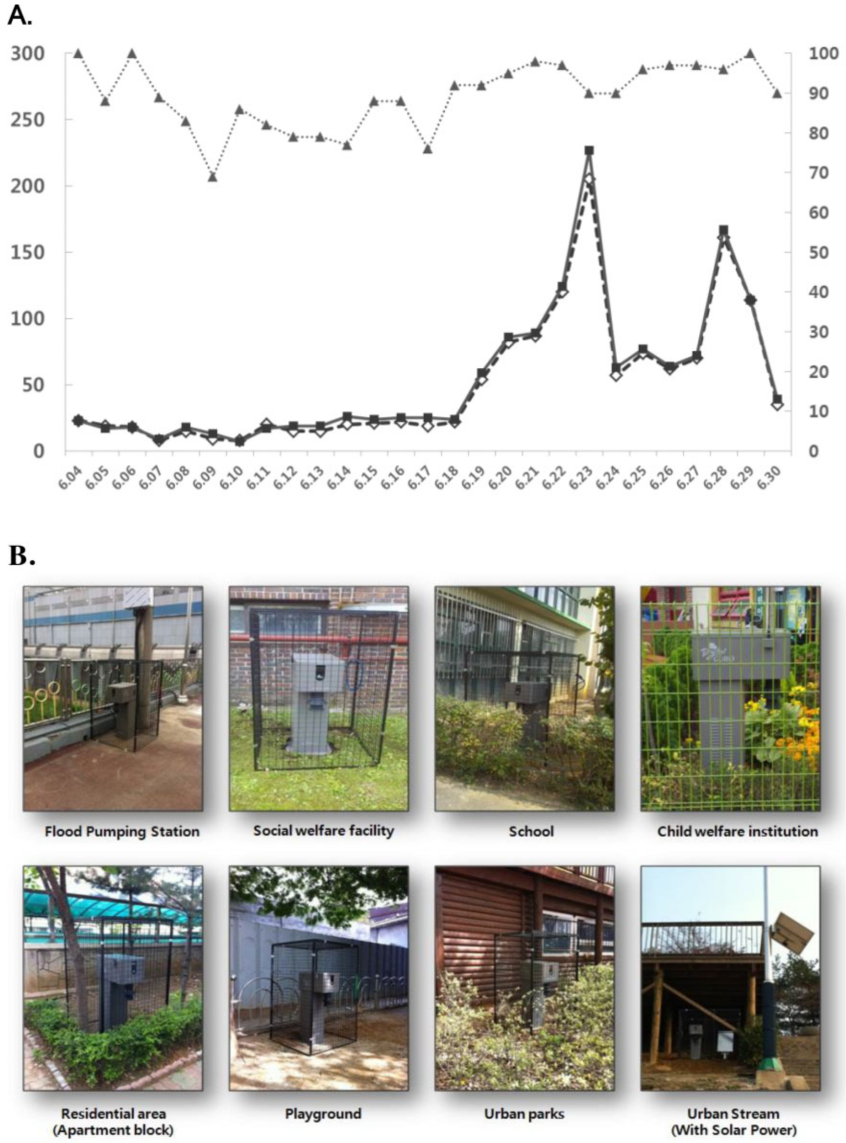

Figure 6 (A) Compare of the real number of mosquito and automated capture and counting Data using by DMS, (B) Use of DMS to control mosquito in different places of Youngdeungpo-gu areas of Seoul city. –◇– Transmission Data; –■– Real number of mosquito; ···▲··· Accuracy of count.

During tests, the device has been used to control mosquitoes in flood pumping stations, social welfare facility centers, schools, children's welfare institutions, residential areas, playgrounds, urban parks, and an urban stream around the Youngdeungpo-gu area of Seoul city in the Republic of Korea for three years (Fig. 6). The device has been used to test the identification of mosquito species with reference photos as well as the further effectiveness of the systems in different environmental and geographic conditions.

Conclusion

The history of mosquitoes and mosquito-borne diseases is a long and complicated one. Because of climate change, the life cycle of mosquitoes has shortened, their distribution has expanded, and disease transmission rates by mosquito vectors have increased. The problems of mosquito-borne diseases and the mosquito control are vague issues. From the past to present, trends of mosquito-borne disease are continuously increasing at a global level. The control vectors and vector-borne diseases have become a big issue and, consequently, a big challenge in the last few decades.

The reduction of mosquito populations can be achieved through the reduction of their habitats, by using biological control methods, using mechanical traps or, by using pesticides – but due to the harmful effects of pesticides outweighing the benefits, pesticide use is becoming a critical issue among scientists, researchers and the general public. Whereas biological methods, the use of many other traps and, habitat reduction are not sufficiently effective at decreasing mosquito populations in intended places, methods like biological means require the commercial production of bio-organisms to use which are still not available in commercial form.

For the control of vector and vector-borne diseases, only the vector control measures are insufficient for the control of diseases. More study should be undertaken in the use of biological methods and the use of integrated mosquito management practices might be the most advisable and must sustainable solution for the suppression of mosquito populations and to minimize the problems brought about by them. Appropriate plans and strategies must be created, but these control plans must not be environmentally hazardous. Furthermore, the plans should not affect non-targeted beneficial species and should be economically viability. They must also be robust. Rather than the chemical use, biological and mechanical control measures must be the priority. Therefore, the control of mosquito populations through DMS, developed by KCDC in South Korea in 2013, is vital. This method promises good results through the use of DMS traps for the control of mosquitoes. The DMS is a very selective, efficient, and quantitative device. It will bring a new smart generation to mosquito control and the device will also introduce the time-saving power and ability to identify mosquito species. This new strategy will change the methods of mosquito control and provide welcome sustainable benefits to both nature and human health.

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