Current procedures of the integrated urban vector–mosquito control as an example in Cotonou (Benin, West Africa) and Wrocław area (Poland)[1]

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ABSTRACT. Current strategy of Integrated Vector Management (IVM) comprises the general approach of environmentally friendly control measures. With regard to mosquitoes it includes first of all application of microbial insecticides based on *Bacillus thuringiensis israelensis* (*Bti*) and *B. sphaericus* (*Bs*) delta-endotoxins as well as the reduction of breeding habitats and natural enemy augmentation. It can be achieved thorough implementation of the interdisciplinary program, i. e., understanding of mosquito vector ecology, the appropriate vector-diseases (e. g., malariometric) measurements and training of local personnel responsible for mosquito abatement activities, as well as community involvement. Biocontrol methods as an alternative to chemical insecticides result from the sustainability development concept, growing awareness of environmental pollution and the development of insecticide-resistant strains of vector-mosquito populations in many parts of the world. Although sustainable trends are usually considered in terms of the monetary and training resources within countries, environmental concerns are actually more limiting factors for the duration of an otherwise successful vector control effort. In order to meet these new needs, increasing efforts have been made in search of and application of natural enemies, such as parasites, bacterial pathogens and predators which may control populations of insect vectors. The biological control agent based on the bacterial toxins *Bti* and *Bs* has been used in the Wrocław's University and Municipal Mosquito Control Programs since 1998. In West-Africa biocontrol appears to be an effective and safe tool to combat malaria in addition to bed-nets, residual indoor spraying and appropriate diagnosis and treatment of malaria parasites which are the major tools in the WHO Roll Back Malaria Program. IVM studies carried out 2005–2008 in Cotonou (Benin) as well those in Wrocław Irrigated Fields during the last years include the following major steps: **1.** Mapping of all breeding sites in the project area and recording data in a geographical information system (GIS/relational database). All districts, streets and houses are numbered for quick reference during the operation; **2.** Studying mosquito vector bionomics, migration and vectorial capacity in the project area, before, during and after the routine *Bti* treatments; **3.** Assessment of the optimum for effective larvicide insecticide dosages at major breeding sites against the different target mosquito species; **4.** Implementation of the microbial control agents in the integrated routine program. Adaptation of the application equipment to the local situation, training of the field staff, and routine treatments; **5.** Conducting surveillance of vector-disease (e. g., malariometric) parameters in the control and experimental area before, during, and after the application of biocontrol agents.

Key words: Integrated Vector Management, biocontrol, Benin, Poland

Introduction

In terms of morbidity and mortality caused by vector-borne diseases such as malaria, dengue fever, and lymphatic filariasis mosquitoes are the most dangerous insects confronting mankind [1]. Only malaria transmitting by *Anopheles* sp. threatens more than two billion people in tropical and subtropical regions. It substantially influenced their development, not only socio-economically but also politi-

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cally. Through the use of insecticides the annual death rate malaria has been reduced from 6 million in 1939 to 2.5 million in 1965 and to less than 2 million today [1].

In temperate latitudes, the most nuisance species of mosquitoes e. g., *Aedes vexans* (Meig.), *Ochlerotatus caspius* (Pall.) and *Ae. detritus* (Hal.) commonly breed in ecologically sensitive areas where broad-spectrum of insecticides may not be used because of their side effects [2]. The contemporary strategy for successful implementation of pest and vector management programs is to carefully select from among of variety techniques, the combination of control options which is best suited to achieve the objectives, at the same time to preserve the ecological balance. This approach which has to maintain a high flexibility has gained much support not only among scientists but also among the general public during last 20 years, and is referred as the Integrated Pest Management (IPM). It comprises a comprehensive and environmentally friendly strategy in „the war" against target pests and vectors. It incorporates all available control means with special emphasis of biological control agents, alteration and reduction of breeding habitats as well as augmentation of natural enemies. This approach utilizes all available environmentally friendly control measures, including implementation of biological control agents, mostly microbial insecticides based on bacilli *Bacillus thuringiensis israelensis* (*Bti*) and *Bacillus sphaericus* (*Bs*) in an integrated control program. Excellent results are noted in Europe, Australia and the Americas without harming the environment by chemicals [1,3,4]. Microbial control agents which are solely used against larval stages have been established as a commercially viable and promising alternative to conventional pesticides used against adult insects [1]. In appropriate formulations they may be useful supplements to, or even replacements for broad--spectrum chemicals. They are especially suited for use in the integrated control strategies when mosquito breeding sites are well defined and accessible. Mosquito control projects cannot be transferred from one area to another without modification.

According to Becker et al. [1] the successful use of microbial agents to control mosquitoes includes usually certain prior studies, i. e.:

1. Mapping of all breeding sites in the project area and recording data into a geographical information system (GIS/relational database). A spatially referenced database containing all features of interest will be the basis for all further data collection and analysis. This spatial element enables thematically related features (e. g., population densities of certain species, flooding areas, plant associations and vegetation type, and zones of human nuisance or disease) to be organised in separate layers of information, which can then be analysed and displayed in a user defined context;

2. Entomological studies of the biology and ecology of the native nuisance mosquito species (e. g., species composition, abundance and phenology in relation to the climatic conditions, variety of breeding sites, spatial and temporal distribution related to migration, age structure of adult mosquito vectors, vectorial capacity of adult mosquitoes, landing rates, correlation between larval and adult estimates and transmission competence and vectorial potential is undertaken as a fundamental study in the project area, before, during and after the routine treatments);

3. Assessment of the minimum effective dosage in laboratory bioassays with field collected larvae (LC_{99}=minimum effective dosage as well as assessment of the optimum effective dosage in small field tests conducted in dominating breeding types under various abiotic and biotic conditions);

4. Implementation of the biocontrol agents into the integrated routine program with the adaptation of the application technique to the requirements in the field;

5. Training of field staff and the governmental application formalities for the use of microbial control agents.

Mosquito control in African countries

In many African countries current approach to vector-mosquito populations is based on the strategy developed in Germany by *The German Mosquito Control Association/Kommunale Aktionsgemeinschaft zur Bekämpfung der Stechmückenplage* (*KABS/GFS*)[2]. The implementation of integrated control of mosquito populations using promising microbial insecticides *Bti* and *Bs* appear to be an effective and environmentally safe tool to combat malaria and will be cost-effective for malaria control programs in addition to bed-nets, residual indoor spraying, appropriate diagnosis and treatment of malaria parasites which are the major tools in the WHO Roll Back Malaria Program [5]. Within one decade, work on insecticide-treated bed nets (ITNs) and curtains has grown from small scale test to the operational use of more than 10 million treated nets [6]. However, it has also been recognized that in many parts of the world, nets will not give sufficient protection to control malaria, because of poor community, inappropriate use of the nets and the exophily of some *Anopheles* vectors. Therefore larval control has the potential to radically reduce malaria transmission in even the most challenging African settings and is now being reconsidered as a complementary intervention to current priorities such as ITNs and access to early diagnosis and prompt treatment [7]. Control of immature aquatic stages of *Anopheles* mosquitoes may have particular promise in urban settings where large numbers of people can be protected in a relatively small area and rural settings with focal, seasonal breeding sites.

Mosquito control in Cotonou (the Republic of Benin, West Africa)

The Republic of Benin, formerly known as Dahomey (until 1974) is located at the Bight of Benin or Slave-coast [8]. The great part of the country is under the influence of transitional tropical conditions. The city of Cotonou is under the influence of a Northern transitional equatorial climate characterized by a long dry season from November to the end of March, a first rainy season from April to July, a small dry period in August and a second rainy season in September and October.

According to the Ministry of Health Annual Report [8,9], principal reasons for health facility visits in Benin are in general: malaria (37%), respiratory infections (16%) gastro-intestinal problems (8%) diarrhoea (6%), and trauma (6%). For children under five principal reasons for health facility visits are: malaria (40%), respiratory infections (21%), diarrhoea (8%), gastro-intestinal problems (7%), anaemia (7%) and other (17%). The most common malaria species in Benin is *Plasmodium falciparum* with 97.1%; the rest is *P. malariae* with 2.9% [8,10]. In the costal area as well as in the whole country, the two most important vectors for malaria parasites *An. gambiae s. s.* and *An. melas* are abundantly present. Both species are members of the Anopheles Gambiae Complex, the similar look-alike species are distinguishable from each other by their behaviour [8,11].

The public health system is divided administratively into three levels: central, regional and peripheral (where the Health Zone is located) community. Services are provided at four levels: regional referral hospitals (CHD); communal health centres and urban health centres (CSC); arrondissement health centres (CSA); and village health units (UVS).

National plan for malaria control in Benin

The malaria control program in Benin aims at the reduction of human – vector contact by controlling adults and larvae of mosquitoes [8,12]. The main tool is the wide spread use of insecticides. In 1983, 1985, and 1994 DDT was widely used by wall spraying inside the houses therefore one of the main objectives of this project is to develop substitutes for the chemical pesticides (DDT). In 2000 until 2002 a campaign was started by the health department called „houses free of mosquito larvae”. The campaign aimed at community participation by educational programs to train the public in reduction of the breeding sites. Unfortunately the campaign was not successful at the periphery of Cotonou because of the swampy conditions. Since 2000 the major effort to control malaria is by distribution of ITNs.

Since 2006 large-scale field applications take place in all detectable mosquito breeding sites in Cotonou, Benin. Precise mapping and individual numbering of each significant breeding site enables rapid effective communication between field staff, and so provides a solid basis for a successful operation. All houses were numbered (right site of the streets=1,3,5, etc; left site of the streets even numbers =2,4,6, etc according to European system. Precise mapping and individual numbering of each significant breeding site enables rapid effective communication between field staff, and so provides a solid basis for a successful operation. In ongoing program large-scale field applications takes place in all detectable mosquito breeding sites. Treatment is carried out at dosage rates which are calculated on the basis of water surface area. Microbial larvicides likeVectoBac WDG and Vectolex WDG were used at a rate of 0.25–0.5 kg per ha, with specific rate selection depending upon water quality, species susceptibility and habitat conditions. For granular applications, 5–20 kg/ha of VectoBac/VectoLex G, with specific rate selection depending upon water quality, species susceptibility and habitat conditions density of vegetation). VectoLex WDG is also used at rates up to 10 grams/m^2 (sewage tanks) in defined breeding sites to achieve a long term effect from several weeks up to several months [8]. Small plastic bags containing e. g., 125 or 250 grams of VectoBac WDG or VectoLex WDG are prepared for quick use in the field. The new formulation of *Bti* (Water Dispersible Granules – WDGs) can be stored for years without loss of activity, easily be dissolved in water and applied. A plastic bag is dissolved in 5 litres of water and filled into the knap sack sprayer by using a net to avoid clogging of the nozzle. The size of the nozzle will be 0.8 mm. The content of one sprayer is calibrated that it will be enough for half a hectare. According to the experience a spray team needs for about 100 houses 3–4 hours. For 100 houses much less than 5 liters of the spray dilution will be enough because of the small but very productive breeding sites. All breeding sites which were mapped will be treated. Reduction of the population of vector mosquitoes (*Anopheles gambiae* s. l.) has major advantages over adult control. The phenomenon of this issue can be explained by that in contrast to adults, larvae are concentrated in predictable sites that can be easily accessed, treated or manipulated with no chance of the larvae escaping [1]. High density of vector populations can be killed when they are condensed in a very limited area. In the preliminary studies it could be shown that usually the anophelines bite inside the houses and lay their eggs close to the houses in defined small swamps and puddles usually in the yards of the houses. Because larvae are more concentrated than adults, it is possible to achieve successful control with less input into the environment. Besides biological control agents are easy to handle, safe for the environment and the user. This proposal is also cost-effective. In preliminary tests it could be shown that in a district of Cotonou with 1000 houses, less than 1 hectare of breeding sites had to be controlled to eliminate the anopheline larvae (less than 500 grams of the products are needed=amounts to less than 15 US Dollars/district/per treatment/control phase).

Larval density is assessed in selected breeding sites also prior to treatment, and at 24 or 48 hours post-treatment by standard dipping. In all reference breeding sites at least 10 dips are taken and number of developmental stages are recorded. Other breeding sites are checked randomly to control results of the application. Per average four treatments are done with VectoLex WDG and the next two treatments by VectoBac WDG to avoid the risk of resistance against *Bs*.

The swamp area ULV (ultralow volume application systems) technique is used for aqueous suspension formulation of VectoBac 12AS which is sprayed to the swamps with difficult access because of dense vegetation. The active material drifts with the wind into the swampy areas. Very low amount of active material is enough to kill all larvae. Spraying and granule distribution systems are individually calibrated and application system configurations are characterized to assure proper lane separation and uniform swath.

Because of environmental aspects it is important that the predators are not killed. Mainly bugs, dragon flies and fish can be found in the swamps in Cotonou therefore we can utilize the power of the nature by conserving the predators which will feed upon newly hatching mosquito larvae after the treatment.

Breeding places are eliminated also by physical alteration of temporary pools by drainage. Environmental management approaches to vector control aim at modifying the environment to deprive the target vector population of its requirements for survival (mainly for breeding, resting and feeding). This reduces human-vector contact and renders the conditions less conducive to disease transmission. The environmental control of breeding habitats can have an impact on the vector population, and therefore on disease transmission, only if control measures cover a relatively high proportion of the breeding sites within vector flight range of the communities to be protected.

Mosquito control in Poland

From the historical point of view mosquito control in Poland was strongly connected with the need to reduce the numbers of anophelines, because of their role as malaria vectors [13]. Malaria was endemic in several areas in Poland during the years after World War I [1,14]. In 1921, 52 965 malaria cases were recorded, mostly in the eastern and south-eastern parts of the country. In 1921–1925 anti-malarial actions were organized in eastern and south eastern parts of Poland using Paris Green. After World War II malaria was present on the Baltic coast, Mazury region (north-eastern of Poland) and near Warsaw. The serious outbreak of the disease in the northern part of the country in the 1940s and 1950s resulted in anti-malaria campaign. In 1952 in Podgrodzie resort (near Szczecin) the first large-scale action was undertaken because of the presence of anophelines (mostly *Anopheles messeae*) and *Culex pipiens pipiens*. Buildings (outdoors and indoors), forests areas near the resort, marshes ponds, and part of the Szczecinski Bay were treated with DDT. In 1956–1958 on the Karsiborz Island control measures against *Oc. communis* and *Oc. annulipes* were also provided using DDT.

In the 1960s, however, malaria was eradicated in Poland and the measures were then undertaken to reduce mosquito numbers and nuisance [1]. In the 1970s and 1980s according to the fragmentary data, control of mosquitoes in Poland was focused on adult mosquitoes only and was carried out in selected places as necessary, with residual insecticides [1]. The preparations used are mostly pyrethroid insecticides: permethrin, deltamethrin, cypermethrin, also etofenprox. Being relatively inexpensive products containing the organophosphate (DDVP) were also applied.

The flood, which took place in Central Europe in summer 1997 resulted in mass breeding of mosquitoes all over the flooded areas, including Poland, where mosquito control was carried out on a large scale in 6 of the 26 provinces affected by floods, situated mainly along the Odra river [15]. A total 10 000 ha were treated, partially by aerial spraying from helicopters, partially by spraying from the ground. Mostly adulticides were used: AquaReslin Super (permethrin); Trebon 10 S. C. (etofenprox); K--Othrine flow (deltamethrin); Alfasep Super Kill (cypermethrin). It must be pointed out, that the '97 catastrophic flood and the following huge mosquito problems, increased the public's interest in mosquito control. As a result, large-scale control activities have been re-initiated in several regions.

Since 1998 the city of Wrocław (Lower Silesia) has conducted a mosquito control program based on studies of the mosquito fauna, including mapping and monitoring of the mosquito breeding sites and the dynamics of the developmental stages and adult populations of mosquitoes, in order to introduce a biorational control program [16]. Control strategy includes the use of microbial insecticides and environmental management. According to Rydzanicz et al. [17] the control measures have been directed against larvae and adult insects: larvicides used are Simulin (cont. *Bti*) and Dimilin 25 GR (diflubenzuron); adulticides – Aqua Reslin Super and Trebon Mega S. C. (etofenprox). Since 2007 the special mosquito control program is carried on in irrigation fields which were constructed in 1890 to provide natural sewage purification as an alternative sewage purification system [18]. More than 100 km of channels serve for the distribution of sewage water into meadows for water purification. The organically polluted water provides *Cx. p. pipiens*, *Ae. vexans*, *Oc. cantans*, *Oc. caspius*, *Oc. leucomelas, Oc. sticticus* and *Culiseta annulata* with ideal breeding conditions. In July 2007 the assessment of the optimum effective dosages of different formulations based on *Bti* and *Bs* (e. g., liquid, granules) for routine control of i. a. *Cx. p. pipiens* larvae occurring in the sewage condition confirmed that the minimum dosages were highly effective for initial larval control [19]. The recommendation to use the minimum effective dosage, may allow a more cost-effective use of microbial control agents due to lower costs of the material and support the cost-effective and successful campaign.

A similar mosquito abatement program based on *Bti*, was started in 2000, among Krynica Morska, a tourist resort, located on Vistula Delta, in an area of protected landscape. Mosquito breeding sites in temporary and stable water pools were identified and mapped. Qualitative and quantitative studies on the mosquito fauna showed that *Oc. cantans* was the predominant species (84.7%), followed by *Oc. communis* [20]. The assessment of the efficacy of *Bti* larvicides (Vectobac TP and Vectobac 12 AS) resulted in the mortality rate from 97% to 99% respectively.

In the town of Gorzow Wielkopolski, situated in the Western part of Poland, mosquito and the black fly control program was started in 2001 [21]. The treated area included 1 250 ha of the city area, suburbs and marshy grounds on river banks. Adult mosquitoes were controlled with Trebon Mega S. C., while larval breeding places were treated with *Bti* agent (Simulin). The preparations were applied by helicopters, and from the ground with knapsack sprayers. Local authorities recognised the program to be effective.

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References

[1] Becker N., Petric D., Zgomba M., Boase C., Dahl C.,

Lane J. Kaiser A. 2003. Mosquitoes and their control. Kluwer Academic Publishers, New York, London.
[2] Becker N. 1997. Microbial control of mosquitoes: management of the Upper Rhine mosquito population as a model programme. *Parasitology Today* 13: 485-487.
[3] Lacey L. 2007. *Bacillus thuringiensis* serovariety *israelensis* and *Bacillus sphaericus* for mosquito control. *Journal of the American Mosquito Control Association* 23: 133-163.
[4] Glare T. R., O'Callaghan M. 2000. *Bacillus thuringiensis*: Biology, ecology and safety. John Wiley and Sons.
[5] Nabarro D. N., Tayler E. M. 1998. The Roll Back Malaria campaign. *Science* 280: 2067–2068.
[6] WHO 1996. Operational manual on the application of insecticides for control of the mosquito vectors of malaria and other diseases.
[7] Mukabana W.R., Kannady K., Kiama G.M., Ijumba J.M., Mathenge E.M., Kiche I., Nkwengulila G., Mboera L., Mtasiwa D., Yamagata Y., Schayk I., Knols B.G.J., Lindsay S.W., Castro M.C., Mshinda H., Tanner M., Fillinger U., Killeen G.F. 2006. Ecologists can enable communities to implement malaria vector control in Africa. *Malaria Journal* 5: 9-22.
[8] Lingenfelser A., Rydzanicz K., Kaiser A., Becker N. 2010. Mosquito fauna and perspectives for integrated control of urban vector-mosquito populations in south Benin (West Africa). *Annals of Agricultural and Environmental Medicine* 17 (1), *in press* (accepted in 2009).
[9] Ministry of Health, Benin, SNIGS, Annual Report 2003.
[10] Kinde-Gazard D., Gbenou D., Tohon S., da Silva C., Nahum A., Quenum A., Houndigande E., Houndekon R., Ekoue S., Massougbodji A. 2004. Monitoring and assessment indicators in 2001 of „Roll Back Malaria" initiative in Benin. *Bulletin de la Société de Pathologie Exotique* 97: 349-352.
[11] Akogbeto M., Chippaux J. P., Coluzzi M. 1992. Le paludisme urbain cˆotier'a Cotonou (R´epublique du B´enin): ´etude entomologique. *Rev. Epidemiol. Sante Publique* 40: 233-239.
[12] Roberts D. R, Manguin S., Mouchet J. 2000. DDT house spraying and re-emerging malaria. *Lancet* 356: 330-332.
[13] Szata W. 1997. Zimnica w Polsce. *Przegląd Epidemiologiczny* 51: 177-183.
[14] Więckowska E. 2002. Wpływ na stan zdrowia ludności epidemii ostrych chorób zakaźnych występujących na ziemiach polskich w latach 1916-1923. W: *Społeczno-ideowe aspekty medycyny i nauk przyrodniczych XVIII-XX wieku.* (Red. B. Płonka-Syroka). Wydawnictwo Arboretum, Wrocław: 383-411.
[15] Gliniewicz A., Krzemińska A., Sawicka B. 1998. Mosquito control in Poland in the areas affected by floyd in July/August 1997. *Acta Parasitologica Portuguese* 5: 39.
[16] Rydzanicz K., Lonc. E. 2003. Species composition and seasonal dynamics of mosquito larvae in the Wrocław, Poland area. *Journal of Vector Ecology* 28: 255-266.
[17] Rydzanicz K., Lonc E., Puzio A., Markiewicz M. 2000. Próby integrowanej kontroli komarów na terenie miasta i okolic Wrocławia. *Biuletyn Polskiego Stowarzyszenia Pracowników Dezynfekcji, Dezynsekcji i Deratyzacji* 1: 8-10.
[18] Rydzanicz K., Lonc E., Kiewra D. 2008. Organizacja integrowanego programu zwalczania komarów na terenie wrocławskich Pól Irygowanych. W: *Stawonogi. Oddziaływanie na żywiciela* (Red. A. Buczek, C. Błaszak). Wydawnictwo Koliber, Lublin: 281-288.
[19] Rydzanicz K., Lonc E., Kiewra D., DeChant P., Krause S., Becker N. 2009.. Evaluation of three microbial formulations against *Culex pipiens pipiens* larvae in irrigation fields in Wroclaw, Poland. *Journal of the American Mosquito Control Association* 25: 140-148.
[20] Kubica-Biernat B., Gliniewicz A., Kowalska B., Stańczak J. 2000. Development of the mosquito integrated biological control (IBC) program in the Vistula-Spit (Mierzeja Wislana) region, northern Poland. In: Abstracts of 13th European SOVE Meeting, 24-29 September, Belek, Turkey: 217.
[21] Piekarska A., Rydzanicz K. 2007. Mass appearance of mosquitoes and black flies and their biological control in Gorzów Wielkopolski in the years 2001-2006. In: Abstracts of the 4th European Mosquito Control Association Workshop, Czech Republic: 88.

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