ARTICLES

MOSQUITO ABATEMENT IN A CHANGING WORLD[1, 2]

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This lecture honors T.J. Headlee who did so much to introduce the principles of abatement of mosquitoes to his changing world. He inherited a good start from J.B. Smith and coworkers in New Jersey (1913). Soon he had accumulated enough material to compile a bulletin (No. 306) for the New Jersey Experiment Station, and by 1930 he was the foremost authority on floodwater mosquitoes. He showed the need and way for assessing adult mosquito populations when he with coworker T.D. Mulhern, produced the widely-used New Jersey light trap. Along with its development, they wrote classical papers on responses of mosquitoes to radiant energy of various spectral ranges. Among his other accomplishments Headlee published on the need to consider the impact of abatement on other aspects of the environment. Appropriately we honor T.J. Headlee at this, the 50th anniversary of AMCA in New Jersey at the site of the founding of the Society.

New Jersey was the scene of most early work on floodwater mosquitoes at a time when expansion of urbanization along the coast was paramount. Business needed space and needed it proximal to established ports. Any suitable commercial site carried with it a requirement for residential areas nearby. This state was blessed with space aplenty, but mosquitoes had dibs on most of it. Additionally the stretches of magnificent beaches called for development for urban vacationers, but here again mosquitoes had staked their claims. Smith and coworkers recognized the marshes as the sources of the mosquitoes; they also knew their extensive nature called for development of wholly new equipment and practices for adequate control. Headlee came on the scene when the need for organization on a wide-scale was recognized as the key to such development. In time he, together with an outstanding corps of people with practical skills in surface water management, began to tackle abatement in this formidable environment. The whole state was organized and gave rise to the New Jersey Mosquito Extermination Association which expanded nationally to become AMCA. While extermination as an objective was a bit ambitious, it appealed to the fighting spirit of the time. This term came to be supplanted by a more applicable one called abatement that has been incorporated in names of organized agencies across the nation.

From the beginning, this state set the pattern of attacking mosquitoes before they become air-borne while at their sources when they are most CONCENTRATED, most IMMOBILE and most ACCESSIBLE (referred to in my heydey as a teacher as CIA factors). Away from sources at any other place and time in the lives of mosquitoes, these criteria are seldom met dependably. Broods do become airborne in spite of our best efforts because of occasional adverse weather or faulty operational procedures. Strategy then dictates some form of *defense-in-depth* in order to provide partial relief to people on the receiving end of a ravenous horde. Any strategy based on defense-in-depth must have its first line at the source before, during and after development and prior to departure. The second defensive position is a tenuous one based on intercepting mosquitoes in transit or in staging areas (aggregation sites) within a few days after departure. The last defensive line is at sites of attack around homes and/or bodies of persons or livestock and involves some barrier such as clothing, and domestic or chemical screens.

Mosquitoes when away from their sources become erratically dispersed and are a kind of "will-o-the-wisp" much as guerrillas are in a military sense. While their origins may be readily determined, their dispersal patterns, strengths and times of invasion are imperfectly known. Indications are that some species, when leaving sources, travel certain pathways especially during the early evening, thereby making interception feasible. Their hideaways after dispersal may permit some concentration but are likely to be less accessible than at larval sites. Extensive documentation of habits is required for any kind of reliable abatement because no two species and no two situations or seasons call for the same tactical approaches. (Our national

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journal, *Mosquito News*, over the years has provided a widely used means for disseminating research findings and novel operational information.) As in the case with guerrilla forces, we must try to neutralize mosquitoes at the source and keep those on the wing from attacking. The analogy to a military situation involving guerrillas where tactical flexibility is demanded gives us cause to consider the pitfalls inherent in a structured defense. We shall return to aspects of tactics later. First, though, let us look at areas in North America where mosquitoes may occur in great numbers.

Floodwater mosquitoes invade as blanket hordes at times from vast flatlands or marshes around the fringes of the continent wherever high tides alternately flood and recede. Other sites are on the prairies and plains of the mid-continent at times of spring thaw, summer deluges or flooding incident to agricultural activities. Still others border rivers and streams where floodplains are crisscrossed by former channels that retain water after a river has first left, then returns to its normal channel. Wetlands span much of northern USA-48, Canada and Alaska during spring thaws. All of these areas have shallow depressions which are sequentially flooded then dried. Eggs are deposited on drying soil following inundation, and they remain until they hatch during some subsequent submersion.

Other areas that produce seasonal broods of mosquitoes are covered by sheets of shallow water in margins of lakes, streams and ponds. Such places are particularly productive where surfaces of shallow water are broken by emergent plants or their floating remains. Mosquitoes opting for these sites deposit eggs on water surfaces protected from wind and wave where they tend to hatch in a day or two. Broods are continuous because generations overlap each other throughout the growing season.

Now we come to the effect of urbanization on populations of mosquitoes. Possibly our worst record for encouraging mosquito nuisances by the populace has come with urbanization. Our cities and towns often allow surface accumulations of foul water sometimes far in excess of our ability to manage them at sources. Sewage that is inadequately processed is sometimes spewed into impoundments or streams where unbelievable populations of *Culex* spp. develop. Possibly more insidious are the thousands of street-side, peridomestic catch basins where water may collect to produce mosquitoes right at their sources of blood. While individually these sites are small, their number and distribution in a community make them threats.

Urban centers on prairies of the mid-continent often have evolved by erecting buildings over the flat, well-drained farmland. In their haste to build, developers often failed to provide adequate replacement drainage means for disposal of summer deluges. The former absorbent agricultural soil is replaced by roofs, sidewalks, streets and parking lots that have hastened movement of runoff water to natural drainage thereby causing more frequent inundation of floodplains. Where formerly one or two broods of mosquitoes may have come from a floodplain we now have situations where five or more broods may take wing.

Metropolitan areas have created immense lighted zones that influence movement and places of congregation of invading mosquitoes. Mosquitoes outbound from peripheral developmental sites are attracted to a lighted horizon especially if a low cloud layer or urban smog hovers overhead. They fall out in the residential areas bordering the cities and become a plague to suburbia. The blue street lights so common in cities along streets no doubt increase attractiveness. Lighted tall buildings are veritable beacons to mosquitoes far removed. The orange-yellow street lights now being used to some extent instead of blue ones may act to diminish attractiveness. On this point we need more study.

On an ever-increasing scale, discarded tires, often in vast dumps have become prolific sources. In tropical and wet temperate regions, domestic containers, cisterns, wells, garden pools and cemetery urns engender mosquitoes. These dispersed and hidden sites produce mosquitoes immediately adjacent to human dwellings. We have neither the luxury of space between their sources and sites of attack nor the degree of accessibility needed to apply opposition tactics.

Even our interstate system of highways has done its part in providing developmental sites for mosquitoes by inadequate grading and drainage especially at ramps where grass and detritus clog the flow lines. Runoff from the deposits left by passing vehicles collects in the complexes of ramps creating sites for larvae of several species. Now let us review situations where changing times have aided mosquito management.

Drainage necessary for dry-land agriculture over the last century has coincidentally brought about mosquito abatement affecting vast areas of USA-48 from coast to coast. Deep, surface ditches lead from streams and rivers across nearby flat alluvial and loessial lands of the mid-continent. Networks of tile run under fields to drainage ditches across thousands and thousands of square miles that have changed wet lands to farm land. Surface water percolates through the soil into the tiles thence into the surface drainage where it is more concentrated and accessible for abatement procedures. Flat, coastal lands, where the rise and fall of tides is of the order of several feet, have been ditched to allow movement of water to and from hatching sites of marsh mosquitoes and then to provide avenues for flushing the larvae into the sea.

Several water-management plans along major rivers have gone far to abate mosquitoes and associated diseases. The great rivers of the midcontinent have been restricted to their channels by extensive levees thereby preventing normal seasonal floods from inundating enormous areas. Other rivers all over the US have been dammed to create impoundments over wide parts of their floodplains so that the soil is no longer attractive to floodwater mosquitoes. In a few instances, notably the Tennessee and Cumberland rivers, the valleys have sequential impoundments that provide effective means for holding and releasing water under management plans that minimize production of marginal and floodwater species.

Another example of water-management prevents tidal waters from encroaching into marsh areas where tides are minimal by diking the seaward sides and using tide gates to allow runoff water to escape beyond the marshes when the tide is out.

Additionally the last line of defense by screening is widely disregarded by current fads for wearing scanty clothing and by expanding outdoor activities where and when mosquitoes are present. The latter includes attendance as spectators at lighted outdoor arenas and backyard cookouts, et al. Besides many people are hitting trails to out-of-the-way places where protection requires personal screening as the sole line of defense. These practices mean more annoyance even though actual mosquito abatement is done properly.

Elimination of sources and limiting of productivity at sources which are basic to abatement may not be feasible, therefore we must employ expedient measures in any strategic plan involving defense-in-depth. Chemicals come to mind as suitable. Because chemicals are many and varied in impact, choices must be carefully weighed. If one looks on an environment producing mosquitoes as the ecological equivalent of the medical situation where a human is sick in a medical sense, the abatement practitioner must consider the patient as a whole and apply chemical cures accordingly. Medicine that acts on the cause of a disease of a patient often produces unfavorable secondary responses. The practitioner must choose carefully the dosage, timing and duration of a treatment to provide the best end result. Mosquito abatement by chemical means similarly requires the maximum action on the mosquito targets, while exerting a minimum adverse effect on other life. For the most part, this desired end is accomplished by using chemicals that are (1) themselves specifically active against mosquitoes, (2) specifically placed where mosquitoes are most concentrated, and (3) transient so that they restrict action largely to the intended target. While these criteria apply to all situations, compromises are necessary in individual cases after due consideration in the manner of the analogous medical practice. Let us examine instances of tactical use of chemicals that meet the criteria most of the time.

Aquatic stages of mosquitoes live in or just below the surface. Where the surface film is intact, that is, not interrupted by emergent vegetation or flotage, the simplest and most direct attack calls for use of a toxic deposit that covers the water. Some petroleum fractions serve well on unobstructed water surfaces. When the water surface is penetrated by dense herbaceous vegetation or flotage, oil has limited value at acceptable dosages. We then turn to any of several chemicals, that (1) is adherent to the dry particulate carrier permitting it to fall through the vegetation, (2) floats on the surface, and (3) yields its toxicant at the surface. Whatever the choice of chemical, its concentration should be at the surface where aquatic stages of mosquitoes concentrate.

Even with most conscientious attempts to minimize emergence of mosquitoes from extensive sources, efforts to attack adults enroute to feeding sites may call for use of chemicals as well. Under these conditions far more care in choice and use is required if the maximum effect is exerted on the mosquito and minimal adverse environmental impact results. The mosquitoes must be attacked either in transit or at times and places where they aggregate. The chemical of choice must be dispersed as minute particles in air through which mosquitoes are passing or must be drifted through staging areas (aggregation sites) where and when mosquitoes are quiescent. Timing is of the essence and habits of the species involved requires constant monitoring.

All is not lost, however, should mosquitoes arrive in residential areas. We are able to fend them off by peridomestic chemical screens, domestic window and door screens and personal screens of clothing or lotions. We may even repel invaders of limited areas by judicious use of smokes and volatile chemicals. These are useful in yards and in areas occupied by crowds at night.

Persons who react severely to mosquito bites should be advised to take added personal measures such as wearing moquito-proof clothing over the torso, arms and legs. Children might well be kept in properly screened houses when mosquitoes are about. Hands and neck may be made less accessible to mosquitoes by coating them with salves or lotions containing chemicals repellent to them.

A word of caution in any use of chemicals: avoid those that persist especially in outside environments where adverse effects on the many other forms of life are likely to occur. This note is particularly applicable where air-borne toxicants are released so as to minimize contamination of vegetation, soil and other surfaces. Any acceptable toxicant should perform its service and become inactive within a short time. Whatever the approach to abatement, we must analyze the total problem and employ tactics that are derived from the "CIA" factors.

In spite of great advances in abatement, our changing world insists that we keep up the good work and maintain a vigorous program of research by all agencies responsible for abatement practices. Such efforts are in progress at small-scale local areas, and even metropolitan interstate ones. A notable current research effort involves the rice-growing states of the lower Mississippi Valley and Gulf Coast and California where a consortium of researchers is active and productive. Efforts of this consortium encompass studies of a whole gamut of tactical weapons applied as defenses-in-depth with due regard for adverse environmental impact. Agencies in the northern plains are embarking on a vast program to abate the plains species of floodwater mosquitoes and safeguard health of livestock and man by considering the total aspects. Both efforts may well become the modern approach to abatement for our changing times. All of the old programs elsewhere are intact and prospering. The future is bright.

I think that were Dr. Headlee to assess abatement over the years he would be pleased with the great advances made, and we hope that he is figuratively looking over our shoulders and approving our efforts as we go forward.