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ROBERT LEE METCALF
1916–1998

A Biographical Memoir by

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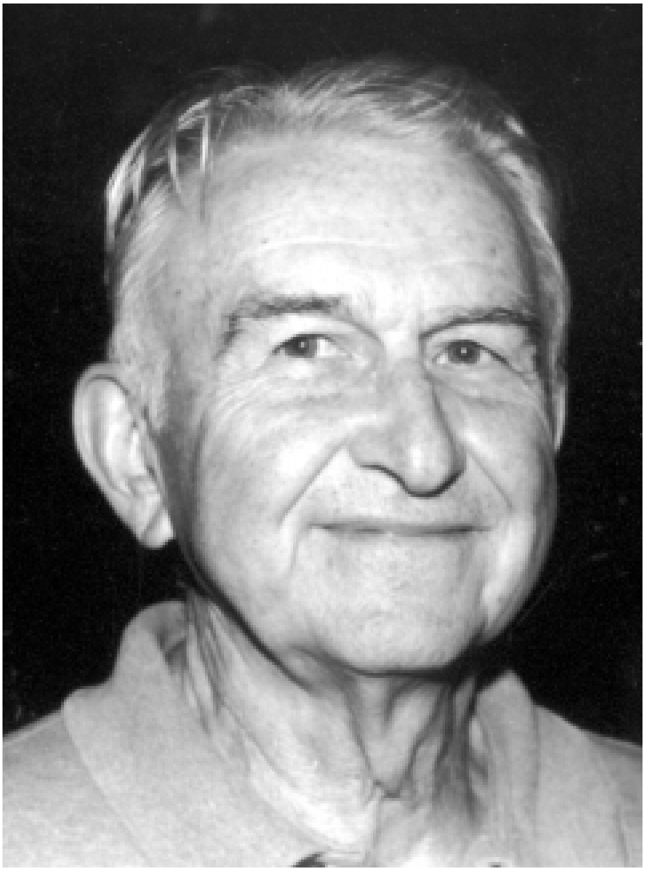

Robert L. Metcalf

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November 13, 1916–November 11, 1998

BY MAY BERENBAUM AND RICHARD LAMPMAN

ON WEDNESDAY, NOVEMBER 11, 1998, two days before what would have been his eighty-second birthday, Robert Lee Metcalf died in his home in Urbana, Illinois. Thus ended one of the most influential lives of twentieth-century entomology. More than any other single individual, Metcalf made the goal of environmentally compatible pest management achievable. Over the course of five decades, he worked tirelessly toward implementing scientifically rational and environmentally sustainable pest control, and for many of those years he was a passionate, courageous, and articulate spokesperson for a viewpoint that was distinctly unpopular among some of his peers.

Metcalf was born on November 13, 1916, at Columbus, Ohio, son of Clell Lee and Cleo Esther Fouch Metcalf. At the time, his father was an assistant professor of entomology at Ohio State University. Metcalf's entomological heritage was deep, indeed; Clell's brother, Zeno P. Metcalf, also became a well-known entomologist. When Robert was five, he moved with his family to Urbana, Illinois, where his father had been appointed as head of the Department of Entomology; Clell would serve in this capacity for 26 years. Robert attended the University of Illinois and received his bachelor's degree in 1939; a year later, in his father's department and under the tutelage of Clyde Kearns, he received his master's degree, based on a study of the toxicity and repellency of derivatives of toluanesulfonyl chloride and picramic acid (1944). He left home to pursue his doctoral studies at Cornell University, obtaining a Ph.D. degree in 1942. Although his thesis focused on fluorescence-microscopic studies of the physiology and biochemistry of the Malpighian system of *Periplaneta americana* (L.), his far-ranging work extended the use of fluorescence techniques in entomology in a number of other contexts, including fluorescence-based detection of malarial parasites in vertebrate hosts (1943). While he was at Cornell, on June 22, 1940, Metcalf married Esther Jemima Rutherford, a biochemist by training. Esther would be both marriage partner and intellectual partner for her husband for over 50 years; together they had two sons, Robert Alan and Michael Rutherford, and a daughter, Esther Lee.

Although Metcalf eventually won acclaim for alerting the scientific community and the public to the environmental consequences of pesticide abuse, he began his career as a traditional chemical toxicologist. In 1943 he obtained his first job, as an assistant entomologist for the Tennessee Valley Authority. There he spent six years developing methods for improving chemical control of mosquitoes in impounded waters. In 1949 he left TVA to become a member of the faculty at the University of California, Riverside. He rose rapidly through the ranks, advancing to full professorship in 1953 and serving as department chair from 1953 to 1965 and as vice-chancellor for research from 1965 to 1968. It was during this period that Metcalf began to recognize some of the environmental and toxicological limitations of insect chemical control, this despite the fact that he entered his professional career at the same time that synthetic organic insecticides were being heralded as the ultimate insect control agents.

In retrospect, the level of enthusiasm that permeated the entomological community and society at large is mind-boggling in its naivety. *Reader's Digest* stories trumpeted the ability of "entire towns" to "abolish flies" and *Time* magazine proclaimed in 1947 that "the flies in Iowa can now be counted on the fingers of one hand" as a result of using the new pesticides (1952, 1980). Metcalf was among a handful of prescient entomologists who recognized the dangers of excessive zeal. He observed first-hand the now familiar problems with synthetic organic insecticides, including insecticide resistance, secondary pests, bioaccumulation in non-target organisms (including humans), and accidental poisonings. Metcalf realized that the overuse of insecticides selected efficiently and rapidly for resistance, thus rendering them useless. He and his Riverside colleagues were among the first to document carefully and incontrovertibly the acquisition of DDT and lindane resistance in houseflies in southern California (1949). Moreover, he described one of the first known examples of cross-resistance; these flies, which had never before been exposed to dieldrin, a new cyclodiene insecticide, displayed resistance upon their first encounter with the toxin.

Because quantitative approaches to measuring resistance were sorely needed, Metcalf developed a laboratory bioassay using a microliter applicator to estimate precisely the LD_{50}, or dose lethal to 50 percent of a sample population; this technique rapidly became the standard in the field. Less than a decade after the first recorded example of resistance to synthetic organic insecticides was described in the scientific literature, Metcalf wrote an article in the popular journal *Scientific American* explaining to the general public the phenomenon of resistance and its implications for human and environmental health (1952). The phenomenon of cross-resistance led to widespread recognition of the importance of characterizing mode of action; chemicals with a shared mode of action were particularly prone to the development of cross-resistance. Soon, Metcalf became one of the world's authorities on mode of action of chemical insecticides (1955). In addition to developing quantitative measures of resistance, Metcalf also used his finely honed chemical skills to develop sensitive quantitative methods for determining both metabolic and environmental fates of pesticides.

Beginning in the 1950s and continuing through the 1960s, Metcalf pioneered the use of insecticide synergists, compounds that lack inherent toxicity but that by various means potentiate the toxicity of co-occurring toxins as a means of reducing insecticide inputs into the environment. He investigated the biological properties of synergists, such as their effects on non-target arthropods and biocontrol agents, as well as their chemical properties, thereby insuring that these compounds provided people with a safe alternative to applying increasingly larger amounts of insecticides to counteract resistant strains (1963, 1967). Metcalf was thus an early advocate and successful practitioner of the approach of reducing pesticide inputs without compromising efficacy—an approach that is environmentally more compatible yet acceptable to users. Metcalf and coworkers developed synthetic insecticides, such as the carbamates, that were biodegradable and more toxic to target organisms than to mammals.

Metcalf left Riverside in 1968 to return to his childhood home, Urbana, Illinois, recruited to the faculty of the Department of Entomology by the head at the time, Clyde Kearns, his former mentor and lifelong friend. A year later Metcalf began a three-year stint as head of the Department of Zoology; in 1971 he was designated a Distinguished Professor of Biology. During this period, Metcalf extended his interest in environmental fates of pesticide to the ecosystem level and in doing so developed what may well have been the most effective tool for demonstrating the impact of pesticides on the environment in a quantitative and repeatable fashion. Up to that point, information about the environmental behavior of pesticides was gleaned from decades of widespread use, which often resulted in massive environmental catastrophes. In Metcalf's view this was unacceptable. Thus, he developed a realistic laboratory model for determining the environmental fate of proposed new pesticides. Metcalf's brilliant solution was to create a miniature model ecosystem—a microcosm—in the laboratory. Metcalf designed self-contained functioning ecosystems in a series of tanks, "an Illinois farm pond in a box," as he described them (1971). Over the years Metcalf and his coworkers evaluated more than 200 chemicals, generating invaluable information on the environmental compatibility not only of insecticides and herbicides but also of animal supplements and industrial chemicals, such as polychlorinated biphenyls. Model ecosystem analyses provided data consistent with information garnered laboriously from decades of field studies, validating the method as an inexpensive, rapid, and reliable index of environmental fate. In large part because of these studies and others inspired by Metcalf's pioneering efforts, biodegradability is a prerequisite for approval of any new pesticide (1971).

In pursuit of alternative approaches to pest management Metcalf eventually turned his attention to chemical modification of insect behavior, a move perhaps facilitated by collaborations with his son Robert A. Metcalf, who had also become an insect biologist (e.g., 1970). In 1975 he highlighted a promising new approach to reduce the amount of synthetic organic insecticide applied in the environment: the use of chemicals, particularly naturally occurring plant compounds, to manipulate insect behavior rather than destroy metabolic function (1975). With his wife, Esther, and colleague Wally Mitchell in Hawaii, he commenced a long-standing collaboration to elucidate the attractants facilitating host finding and mate finding in tephritid fruit flies, economic scourges of fruit crops worldwide (1975, 1979). His work with fruit fly attractants allowed him to take his experience with the chemistry of insecticides and their mode of action and apply it to insect behavior. He felt that structure-activity studies had a dual function: the discovery of new attractants and the elucidation of the mode of action (harking back to his studies of the anticholinesterase "biochemical lesion"). He was involved in one of the first tests of the efficacy of kairomones (or attractants), a term he helped to popularize, as control agents; a single gram of methyl eugenol resulted in the mass trapping of over 7000 male Oriental fruit flies in a single day. Metcalf and Esther traveled almost annually to Hawaii to work with Wally Mitchell and his wife on *Dacus* attractants. For Metcalf, this was the perfect concept of a vacation.

Subsequent work on kairomones focused on developing attractant baits for corn rootworms, the most important pests of corn in the United States. His work had both practical significance for rootworm management and theoretical importance for understanding the evolution of host-plant specialization in insects. Metcalf and his students and colleagues documented compulsive feeding behavior by corn rootworms and cucumber beetles in response to cucurbitacins, tetracyclic triterpenoid compounds characteristic of the cucurbit host plants. In the early 1970s, Metcalf and A. M. ("Dusty") Rhodes cut open a bitter cucurbit fruit and dusted it with carbaryl. The next day, the fruits were covered with thousands of dead beetles. To say this result impressed him would be an understatement.

He immediately saw the utility of cucurbitacins for controlling one of the most important crop pests in the Midwest. From 1978 to 1990 numerous field tests were conducted with collaborators in several states to show the efficacy of cucurbitacin baits to reduce the pounds per acre of insecticide to grams per acre without loss of efficacy. Metcalf often said that the early breakthrough with *Diabrotica* was the development of beetle prints, a technique that allows the beetles to analyze the complex chemistry of the triterpenoids for the investigator. The beetles were sensitive to nanogram quantities of cucurbitacins and would eat the silica off the thin-layer chromatography plates wherever they were present. Metcalf's group produced an abundance of research articles on the cucurbitacin chemistry of the Cucurbitaceae, sensitivity of beetle species to different cucurbitacins, sequestration of cucurbitacins by beetles, and the allomonal properties of cucurbitacins (e.g., 1985; 1986). Metcalf poured his energy into elucidating the basic chemical ecology of plant and insect co-evolution, a subject of intense interest to him and one on which he lectured enthusiastically and elegantly in the chemical ecology course he started in 1983 with one of us (M.B.) in the Department of Entomology and colleague David Seigler from the Department of Plant Biology. This work led to what may be the best example in entomology of an Old World-New World co-adaptation of insects and plants (Aulacophorites and Diabroticites with the Cucurbitaceae) (1986).

In the 1980s Metcalf and his students conducted a range of studies that provided even greater insight into the chemical basis of host-plant utilization by Diabroticites. It soon became evident that corn rootworms exhibited a compulsive flight response to volatile attractants. Once again Metcalf used his biochemical lesion experience with insecticides to study the chemistry of olfaction. By 1988 structure-activity studies resulted in attractants for all of the native Diabroticites in

Illinois, both pest and non-pest species (five species in two genera). This investigation generated over 20 papers and added a new chapter to the chemical ecology of corn rootworms and cucumber beetles (1991). It is inspiring to note that the majority of these papers came after his mandatory retirement at the age of 70 in 1987.

The early 1990s also marked a period in Metcalf's life when all of his scientific prowess could not help him; he discovered he had prostate cancer, and on May 13, 1991, his wife and best friend, Esther, died, a loss that left him rudderless. He concentrated all of his efforts on writing "Plant Kairomones in Insect Ecology and Control" (1992) as a tribute to his wife, with whom he had collaborated for so many years. To his friends and colleagues he hinted he was giving up his research after the completion of the book, but he had underestimated his own resiliency. With his marriage to Elaine Reynolds, the widow of his late friend Hal Reynolds, on January 1, 1992, Metcalf displayed a sudden revitalization. He re-focused his research on the attractants of corn rootworms and continued to make cutting-edge advances in both chemical ecology and insect pest management. Metcalf split his time for the next six years about equally between Paradise, California (his second wife's home) and Urbana, Illinois. In Paradise he was known as the outstanding clarinetist with an interest in insects, and every summer he returned to Urbana to continue working with corn rootworms. From 1992 to 1998 his publication record burgeoned with descriptions of the role of indole as a synergist in corn and cucurbit blossoms, the chemical basis for attraction of *Diabrotica* to native thistle blossoms, and with reviews on trends in entomology and insecticide research.

In the summer 1998 Metcalf concentrated on a new approach for manipulating corn rootworm behavior. In collaboration with Hans Hummel from the University of Giessen and Robert Novak from the Center of Economic Entomology at the Illinois Natural History Survey, once again he discovered an unexpected phenomenon: the inhibition of pheromone responses in beetles exposed to sources of kairomones. This novel concept reminded him of the mating disruption technology used for several important insect pests. In addition, he found that large numbers of gravid western and northern corn rootworm adults were attracted to baited traps in alfalfa and soybean fields, presaging the subsequent discovery of rotation-resistant rootworms in the Midwest. Metcalf seemed so revitalized that Hans Hummel returned to Germany and told colleagues of Metcalf's good health and stamina. In retrospect it is remarkable how he willed himself to go out to the field almost every day, analyze data, complete two publications, and leave manuscripts for at least three additional papers while coping with terminal metastatic cancer. In the last conversation one of us (R.L.) had with him he talked about the summer research, the exhilarating joy of discovery of the attractants, and the fun of walking the prairie, cornfields, and soybean fields of Illinois.

Metcalf was dramatically affected by Rachel Carson's *Silent Spring*. He was aware of the controversy about the accuracy of some of the examples she used in her book, but he was nonetheless deeply moved by her spirit. It was one of the few books he always had out in his living room and was fond of picking up and repeatedly reading. After his funeral, friends and colleagues paying their respects to his family could have spotted a well-worn copy of *Silent Spring* sitting on a table by a lamp. Although scientifically rewarded and praised for his research, Metcalf was often criticized as being anti-insecticide. It perplexed him that anyone would hold that opinion considering the fact that his publications stressed the importance of selective insecticides and the need to preserve them by taking an ecological approach to insect management. His integrated pest management text, edited with his friend and collaborator William Luckmann, brought together all of the developing concepts of environmental toxicology, insecticide resistance, and chemical ecology for the integrated management of insect pests.

More than most of his peers, he was deeply committed to public service; he never shirked his responsibility to serve as an advocate of responsible pest control, within and beyond academic circles. At Riverside his laboratory functioned as the International Insecticide Reference Center for the World Health Organization. He served on the Environmental Protection Agency's Pesticide Advisory Panel from 1976 to 1982 (a crucial period in the creation of that agency). During his service on the panel he played a critical role in the banning of at least 10 highly toxic pesticides in wide use. As a member of the National Academy of Sciences, elected in 1967, he served on committees considering the impact of polychlorinated biphenyls on the environment (1977-79), the role of pesticides in urban pest management (1978-80), pesticides and water quality (1976-78), and cotton insect control (1980-81). With respect to control of insects in cotton, he testified before Congress in a charged atmosphere about the ill-advised nature of ongoing insect control efforts aimed at eradication (such as those that eventually led to $55 million failure to stop the spread of fire ants). Years later, his view—that eradication is neither a desirable nor achievable goal for all insect introductions—is the prevailing one; his testimony may well have spared the southeastern United States from massive pesticide contamination. In 1976 Metcalf traveled to China in one of the first scientific exchanges with that nation with an aim of learning more about alternative low-impact control methods (1977).

Metcalf was proud of his accomplishments. He used to say that he had an affinity for using simple tools (topical application, colorimetric assay, model ecosystem, beetle prints, sticky traps, and the like) for answering complex questions. Although he was undeniably brilliant, by his own admission, the well from which he drew most deeply was the intellectual interaction he had with his students and collaborators; many of his discoveries were either because of the challenges he presented to his students or challenges his students presented to him. Robert Metcalf was entomology's Thomas Edison. Both believed in the practical application of scientific principles and both believed that a research laboratory should consist of a team of workers systematically investigating a topic. To put it simply, Metcalf was driven to excel, whether at science (he authored or coauthored over 450 scientific papers and advised over 80 students and postdoctoral associates), sports (he played professional-level golf, tennis, and ping-pong), or music (he owned every type of clarinet known). Among the many honors he received were election as a member of the National Academy of Sciences, a fellow of the American Academy of Arts and Sciences, and a fellow of the American Association for the Advancement of Science. He was also honored with the Order of Cherubini, Pisa, Italy. Past president of the Entomological Society of America, he received its Founder's Award in 1978. In 1991 he received an honorary doctorate from Ohio State University, and in 1997 the University of Illinois, his intellectual home for over 30 years, recognized him with an honorary degree of doctor of science. Metcalf's contributions, although limited by the untimely death of a still productive scientist to the twentieth century, will continue to have impact throughout the twenty-first century in the form of a cleaner environment and a more rational approach to pest management.

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