1992 Proc. Calif. Mosq. Vector Control Assoc. 60: 122-134

PARADIGMS OF THE MOSQUITO CONTROL COMMUNITY OF CALIFORNIA: PAST AND PRESENT

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Introduction.

Mosquito control agencies of California have conducted remarkably successful environmental health programs, protecting the public from vector-borne disease and pest mosquitoes for over eighty years. Today, in the midst of the "environmental era", many feel these agencies are facing their most serious challenge. The challenge, simply stated, is to bring the activities of mosquito control into balance with the natural systems. The task is our share of the larger task of bringing our whole socio-economic system into balance with natural systems.

Nowhere is the challenge to the mosquito control community of California (MCCC) greater than in meeting public demand to restore, enhance, and manage wetlands. Since in state and federal law the responsibility for the regulation and management of the environment has been fragmented into parts and distributed to a number of public agencies, all agencies are required to work effectively together to steward these complex environmental systems.

Fritjof Capra (1982) speaks to the issue of fragmentation in his book "The Turning Point" and in the 1991 movie "Mindwalk" which was based upon his book. He finds the mechanistic world view of Cartesian-Newtonian science inadequate. He feels we live in a globally interconnected world needing a new holistic perspective, a new vision of reality. Capra believes we are facing a crisis of perception.

Daniel Botkin, Professor of Biology and Environmental Studies at the University of California at Santa Barbara, offers a similar message. He believes that, more than any other factor, the major challenge in interpreting nature and dealing with the environmental issues is recognizing and confronting our deep seated assumptions about nature. Botkin (1990) believes that before we reach a point where our role in the environment is positive we will have settled upon a new set of metaphors, images, and symbols of nature.

The purpose of this paper is to explore our perceptions of reality and nature in the MCCC. This, I believe, is slippery business and I expect my efforts to be of more value as a force to stimulate reflection rather than a presentation of facts. I concur with the above authors, however, in believing that the process is an essential first step in meeting the environmental challenges facing the MCCC.

Mental Models.

Why are metaphors, images, and symbols of primary importance? First and foremost, because they influence what we see and do. They shape the development and provide a frame for a complex cognitive structure that has only in the past few decades become recognized and studied. The structure has been alluded to by various investigators as "assimilatory schemata" (Piaget 1954), "image" (Boulding 1961), "tacit infrastructure" (Bohm and Peat 1987), "theory-in-use" (Argyris et al. 1985), and "mental models" (Senge 1990). There has been a wealth of knowledge developed about these highly abstract cognitive structures which shall be referred to in this paper as mental models. Following is a compilation of some of that knowledge provided by the above cited authors:

1. Mental models begin developing at birth and continue to serve the individual throughout life by interpreting the world and influencing behavior.
2. Mental models are deeply ingrained assumptions, generalizations, even images that influence how we understand the world. They take a subliminal and unconscious form as

time passes (habitualization).

3. When a message reaches a mental model, three things may happen: the message may be ignored; the message may change in a well defined way; or it may be changed in a revolutionary way as in a religious conversion.
4. Mental models determine what see and therefore what we do. Perhaps more importantly, they also determine what we do not see.
5. There is a powerful natural tendency for individuals to resist changing their mental models. In fact, individuals develop elaborate "defensive routines" designed specifically to defend them. The resistance to change can be a severe impediment to learning that affects individuals and their organizations.
6. Mental models are not reality and therefore fall short of completely describing reality. In the vernacular: "mental models are maps not the territory". Yet, we tend to confuse the map with the territory.
7. Techniques have been developed to manage mental models by conversing in a manner which balances inquiry and advocacy, where people expose their thinking to make it open to the influence of others.

The crisis of perception can be fully appreciated in light of our knowledge of mental models. The metaphors, images, and symbols of nature that are communicated in the MCCC influence our individual mental models. They, in turn, influence what we see and do. Learning about the dynamics of mental models, and reflecting on our individual mental models, can help us to improve them as necessary to establish a solid foundation for judicious and effective environmental action by the MCCC.

The Kuhnian Paradigm.

Exploring the mental models of the mosquito control community of California could be a most slippery endeavor were it not for the historic work done by Thomas Kuhn. In his seminal work "The Structure of Scientific Revolutions", Kuhn (1962) introduced the concept of a scientific "paradigm". It is a premise of his paper that paradigms operate in a scientific community to generate and reinforce the metaphors, images, and symbols of a scientific community and that paradigms are instrumental in shaping mental models. Therefore, by identifying and examining the paradigms of the MCCC, we can learn about the quality of prevailing images of nature being communicated in our community, and can also gain insight into the structure of mental models.

A paradigm was defined in a variety of ways in Kuhn's work. In this paper it is distilled to: "... universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners" (Gutting 1980) creating "... an entire constellation of beliefs, values, and techniques that bind the community together" (Horgan 1991). Upon close examination of Kuhn's work (1970), a paradigm can be seen to have a life-cycle of five stages:

STAGE ONE (Discovery Phase): The discovery phase starts with an "archetypical experiment", or by new models of law, theory, application, or scientific achievements that become the basis for further practice (Kuhn 1970). The achievement usually focuses on critical problems (anomalies) that cannot be solved by the old paradigm.

STAGE TWO (Demonstration Phase): During this stage scientists who are privy to the archetypical experiment enlist converts by lectures, publications, or applied demonstrations. Adherents to the old paradigm tend to resist the new approach even though the new paradigm solves problems that have led the old paradigm to crisis.

STAGE THREE (Paradigm Shift): The shift has occurred when a preponderance of scientists shift professional allegiances to the new paradigm. Scientists then re-interpret and give new meaning to the same pool of data they saw prior to the paradigm shift. Some, however, remain unconverted, cling to the old paradigm, and are assigned to a form of scientific oblivion.

STAGE FOUR (Productive Phase): High productivity is attained by way of "normal science". Debate subsides, efficiency and effectiveness increase, and the vexing problems of the previous paradigm are solved. Paradigmatically-induced blindness prevails. When anomalies are detected, scientists attempt only to modify their theory or practices.

STAGE FIVE (Crisis Stage): The crisis stage occurs when anomalies have accumulated to the level that they can no longer be ignored.

"Extra-ordinary science" is now allowed to create novel solutions outside paradigmatic boundaries. Scientists, usually young and ignoring the prevailing paradigm, focus on anomalies. The result is a proliferation of competing, non-traditional, approaches and new discoveries. Incommensurability prevails as different scientists describe and interpret the same phenomena in different ways.

The Paradigms of Mosquito Control.

Search for Paradigms: The written proceedings of the California Mosquito and Vector Control Association provide a rich history of mosquito control in California. Its pages have served to communicate vital information to vector control personnel in California since 1930. Not surprisingly, the proceedings also contain the story of the rise and fall of the paradigms of the MCCC. Analysis of the proceedings revealed that two successive paradigms have emerged to dominance during the history of mosquito control in California. Both paradigms were found to have passed through the five previously defined stages. Interestingly, it appears that the MCCC is currently in a prolonged crisis stage of the second paradigm, with four incipient paradigms vying for dominance (Fig. 1).

The Permanent Mosquito Control Paradigm: The first paradigm of MCCC might be called permanent mosquito control. Its origins can be traced to the discovery made by Ross in 1898 that malaria was caused by a particular genus of mosquitoes (Jones 1931). Malcolm Watson, a British scientist, along with others in many parts of the world, developed a "species sanitation" approach where a selective attack would be aimed at the species of mosquito that was known to be transmitting malaria (Gray and Fontaine 1957). The development of a species-specific malaria control program, based upon the discovery by Ross, was the compelling "tricky idea" or first stage of the permanent control paradigm.

The second stage of the permanent control paradigm, the demonstration phase, was conducted primarily by William Herms, a medical entomologist at the University of California. He implemented a remarkably successful demonstration of permanent control measures in Penryn, California in 1910. The project effectively broke the malaria cycle, eradicating it from the area by 1912 (Gray and Fontaine 1957). The essence of permanent control approach can be summarized as: "To the greatest extent possible the places where mosquito control larvae were found should be eliminated by either

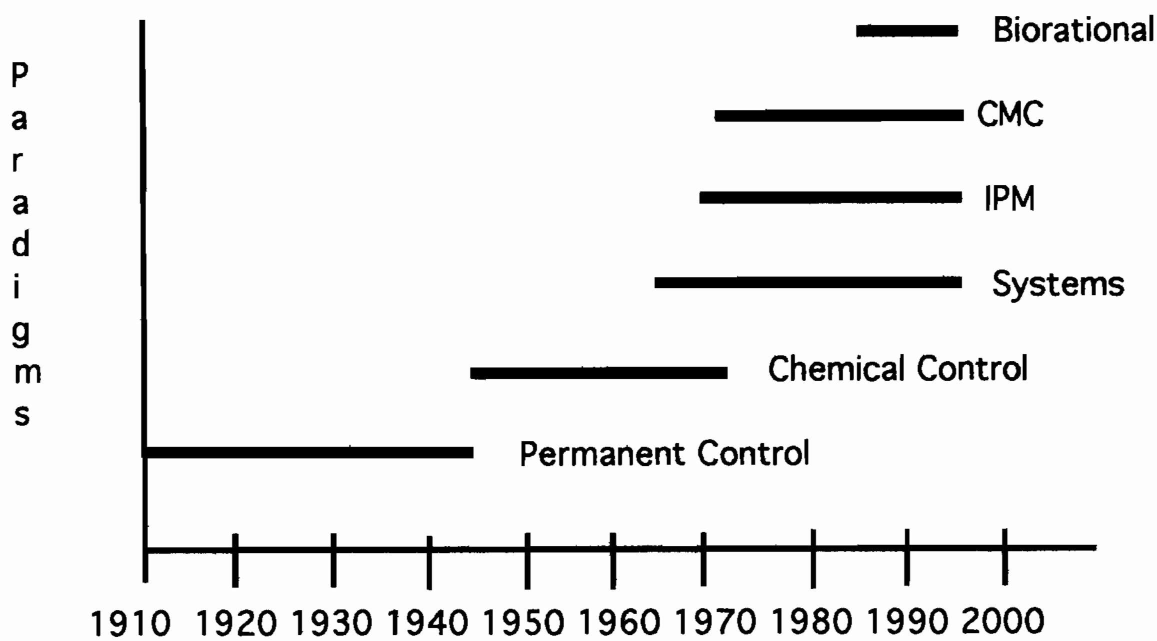

Figure 1. Prevalence of paradigms in the mosquito control community of California (MCCC) over the last 80 years. (IPM =integrated mosquito control, CMC =comprehensive mosquito control).

drainage or filling, to minimize the need for repetitive applications of oil as a larvicide" (Gray and Fontaine 1957). The demonstration phase of the paradigm continued after the Penryn Campaign when Professor Herms traveled the length of the Central Valley spreading the word on how malaria control could be accomplished (Gray and Fontaine 1957).

Perhaps the first evidence of stage three, the paradigm shift, was passage of the Mosquito Abatement Act in 1915. It institutionalized the permanent control approach by providing agencies with the authority to eliminate larval breeding sites. In order for there to have been a typical Kuhnian paradigm shift, however, there had to be a paradigm to be replaced. A scientific paradigm did not really exist at that time, although the public at large held the empirically derived idea that malaria was caused by the "bad air", or miasmas, that emerged from the swamps (Jones 1931). In the face of such tenuous theory, Ross' discovery and Herms' demonstration at Penryn, found fertile ground.

Stage Four of the permanent control paradigm, the productive phase, is very evident in the literature. After the Mosquito Abatement Act had passed, increasing numbers of agencies were formed to accomplish mosquito control. By 1945 there were 24 mosquito control agencies in California, all practicing their particular version of permanent control. Kuhn calls this period "puzzle-solving" and much of the literature from 1930-1937 demonstrated solutions to practical problems that had been encountered. During that period, there was a fairly even balance between papers presented on larviciding and those on drainage techniques.

The final, or crisis stage, of the paradigm began to appear in the later half of the 1930s as anomalies increased. In 1937, the proceedings listed "particular handicaps to work" that were experienced by the 23 mosquito control agencies in California. The agencies experienced: invasions of mosquitoes from outside the boundaries of the control agency (8 agencies), lack of funding (6 agencies) and lack of cooperation from land owners in their water management (8 agencies). Even more serious problems appeared in 1938 when there was a decided increase in malaria cases to 368, the greatest number in over twenty years (Dommes 1939). Another serious assault upon the paradigm came in 1941 when researchers found that some viral encephalitides were transmitted by mosquitoes, and that there were hundreds of previously undiagnosed human cases of mosquito-borne encephalitis in the Central Valley of California (Howitt 1941). A paradigm that had proven itself by painstaking, longterm efforts aimed at elimination of mosquito sources was now faced with the need to provide instant success.

The crisis stage of permanent control had been reached, providing fertile ground for a new paradigm. The discovery, or archetypical experiment of a new paradigm was provided by a new "miracle" insecticide that was developed and used during World War II. Its introduction was destined to have enormous benefits as well as incalculable liabilities for man and nature throughout the world. In California, it was the perfect tonic to cure the anomalies of permanent control. Ironically, it was William Herms, pioneer of the permanent control paradigm, that presented the first paper in the proceedings on the use of DDT as a mosquito larvicide. He had tested DDT against mosquito larvae with great success in 1943 and presented his findings in 1946 (Herms 1946). Stage one of a new paradigm had been launched.

<u>The Chemical Control Paradigm</u>: Shortly after Professor Herms' announcement, his colleague, Harold Gray, another pioneer of permanent control, presented a paper on the successful use of DDT (Gray 1946). In fact, the proceedings of 1946 contained an unprecedented 12 articles on DDT ranging from its use in mosquito control to potential public health and environmental hazards. The second, or demonstration stage, of the chemical control paradigm had begun, and the MCCC was poised for a paradigm shift: the permanent control paradigm was in crisis; a competing paradigm was in its early stages; and a great number of new, unindoctrinated professionals were entering the MCCC.

The increase in the unindoctrinated can be traced to state subvention funds made available to mosquito abatement districts (Dahl 1946). Spurred by subvention funding, the number of districts would climb from 24 to 44 in the space of a few years. Those agencies receiving state subvention funds were compelled to employ professionally trained and experienced men (Dahl 1946). The State's large pool of "unconverted" professionals provided fertile ground from 1946 to 1950 for the paradigm shift from permanent to chemical control.

Surprisingly, and in seeming violation of Kuhnian principles, the proponents of the shift were the aging pioneers of the previous paradigm, Herms and Gray. Where was the rigidity and resistance to paradigm change that Kuhn suggests (Kuhn 1970). Where, as Kuhn would have us believe, are the young, new, and unindoctrinated proposers of the new paradigm that are expected to stand on the shoulders of the giants of the field, bashing them over the head (Horgan 1991). The answer to the puzzle lies in the permanent control paradigm itself, which proposes draining and filling of mosquito sources to the greatest extent possible to minimize larviciding. Herms and Gray must have felt they were only adding another, more powerful, larviciding tool to their permanent control armamentarium when they proposed DDT. To the sea of unconverted, however, a different perspective was yet to be fashioned by the use of DDT in the field. The remarkable field successes in the early days of DDT became a most powerful indoctrination into the chemical control paradigm for those young, and often inexperienced, professionals. The shift to chemical control occurred quite rapidly. The proceedings in the years 1948 and 1949 were dominated by presentations on the successful use of DDT in various circumstances.

The productive phase (stage four) of the chemical control paradigm had been reached. Meanwhile, the permanent mosquito control paradigm continued to function. The fact that it did not disappear immediately is wholly consistent with the Kuhnian view which suggests that it would only completely disappear when the last hold-outs die (Kuhn 1970). The permanent control paradigm, however, had more than stubborn adherents. It had been institutionalized in law (the Mosquito Abatement Act), institutionalized in the policy of the State Health Department (Dahl 1946), prescribed in text (Herms and Gray 1940), and etched in the minds of the proponents who still held powerful positions in the State and the University. Their presence and advocacy continued to be felt throughout the life of the chemical control paradigm. This period of time, roughly from 1946 to 1960, was characterized by "incommensurability" between the adherents of the two paradigms. Gray epitomizes the resultant conflict best in his lecture of 1953:

> "I stated (in 1949)...over the past forty or more years, both experience and logic have indicated that the basic function of mosquito control is to eliminate or minimize the production of mosquitoes . . . The introduction of new insecticides of greater toxicity has not changed this basic postulate . . . Well, what happened? Nothing! You were all bemused in the phantasmagoria of DDT - wonderful stuff!"

The appearance of an anomaly in the chemical control paradigm began in 1952 with the advent of resistance to DDT in mosquitoes (Gjullin and Peters 1952, March 1952). The resistance problem spread rapidly as did the solution to the problem, the substitution of a new insecticide.

The productive phase of the chemical control paradigm was sustained by simply using a new chemical on the resistant mosquitoes. The chemical control records of the period illustrate the seductiveness of the paradigm, showing a continuing increase in chemical use until it peaked in 1958 to begin a slow and gradual decline (Eldridge 1988). By 1966, however, it had become apparent that the rate of production of new insecticides was falling behind the rate at which resistance was being developed. The crisis stage of the chemical control paradigm had been reached. Later in 1972, Dr. Charles Schaefer said it clearly:

> "No new compounds are currently under commercial development that would be effective in controlling our highly resistant strains. This means MADs cannot expect to have any new larvicides available for a minimum of several years."

Dr. Schaefer's speech marked the end of the predominance of the chemical control paradigm that, for the most part, had provided effective mosquito control in California since World War II. The crisis was not caused by pesticide resistance alone. Other anomalies included secondary pest outbreaks (Dahlsten et al. 1969), killing of non-target species (Lusk 1971), water contamination problems (Bissel 1988), and human safety considerations (West 1964). Without doubt, however, the recurring phenomena of resistance was the major factor to bring down the chemical control paradigm. In 1966, the tone of the annual meeting of the California Mosquito Control Association was one of novelty. The shift from normal science to extra-ordinary science was evident in the presentations that year as a variety of competing paradigms emerged. Permanent control measures were being discussed anew (Reginato and Meyers 1966). New ideas in genetic (McClelland 1966) and biological control (Hokama and Washino 1966) were being offered as solutions. The keynote speaker at the conference envisioned a new and promising era for the MCCC brought about by a the use of the rapidly developing "systems approach" (Stead 1966). The 1966 conference was a watershed. The seeds of new paradigms had been planted.

The Current Paradigms of Mosquito Control - Paradigm Wars.

Analysis of the proceedings of the California Mosquito and Vector Control Association revealed the absence of a dominant paradigm from the mid-1960s to the present. Instead, it suggested that at least four paradigms are currently in active competition, none having been accepted by a clear majority of the MCCC. The four competing paradigms are comprehensive mosquito control, the systems approach, integrated mosquito control, and bio-rational control (Table 1). What follows is an examination of the four paradigms with particular emphasis on identifying the metaphors, images and symbols that are evident in each paradigm to represent nature.

Comprehensive Mosquito Control: Comprehensive mosquito control (CMC) is a candidate paradigm formally presented to the MCCC in numerous presentations (Kimball 1973; Mulhern 1971, 1973, 1980). It is defined as:

> ". . . applying all of the available technology of naturalistic control, prevention or source reduction and, chemical control, each in appropriate situations. "

The roots of comprehensive mosquito control can be traced to the old permanent control paradigm. Both paradigms feature engineering-entomological approaches focusing on modifications of aquatic sources. The primary proponent of CMC, Thomas Mulhern, declared in 1973, that the "era of comprehensive control had already begun but it is only in the transition stage". In that year, Mulhern and other staff of the California State Health Department's Bureau of Vector Control created a training manual for the mosquito control agencies of California (Mulhern 1980). The manual institutionalized the paradigm and made it required reading for personnel wishing to be certified to conduct mosquito control in California. CMC had a powerful mechanism by which to gather its fold. The fact that comprehensive mosquito control has not become the dominant paradigm may be traced to the fact that the paradigm is largely a collection of rules and guidelines that have been derived from historically successful approaches to mosquito control (Mulhern 1973). The knowledge generated by the paradigm is a body of un-connected, yet practical techniques which have been collected by practitioners who may be guided by other paradigms. The bottom-up, ad hoc approach provided by CMC may be highly practical in some circumstances, but it fails to provide the practitioner any explicit theoretical framework with which to guide his activities. When facing new or novel circumstances, he is limited to searching for descriptions of successful approaches that most closely match those he faces. The paradigm is effective when the methods developed are applied to relatively simple mosquito sources. In complex systems, however, such as wetlands, there is significant ecological variation from region to region as well as different defined purposes for the wetlands. The paradigm fails here in that there is not one success model for wetlands that provides a set of specific rules for mosquito control.

The influence of engineering on CMC suggests that the machine metaphor of nature may be lurking at its core. For the most part, however, this paradigm seems devoid of powerful symbols. The strength of this paradigm has been based upon continuous updating of the body of knowledge of practical applications of mosquito control. In fact, since the State of California appears unlikely to upgrade the training manual in the near future, and since there are currently no outspoken proponents for this paradigm, it seems highly unlikely that the paradigm can be responsive to the changing needs of the MCCC.

Systems Paradigm: Frank Stead (1966) formally introduced the systems paradigm to the mosquito control community at their conference in 1966, calling it the "Systems Analysis Era". He characterized the approach as encompassing the totality of a problem by drawing boundaries which would capture:

> "All the effects of these acts, all of the costs, all of the benefits, all of the penalties and all of the rewards assigned to different people. . ."

The author felt that a systems view offered

Table 1. Paradigms in the mosquito control community of California (MCCC).

	PERMANENT MOSQUITO CONTROL
Definition:	"to the greatest extent possible the places where mosquito larvae were found should be eliminated by either drainage or filling, to minimize the need for repetitive applications of oil as a larvicide" (Gray and Fontaine 1957).
Discovery:	Ross finds in 1898 that malaria is carried by anophelines.
Demonstration:	Herms and Gray demonstrate in Penryn, California, 1910.
Evidence of Shift:	Mosquito Abatement Act of 1915.
Productive Phase:	1915-1937.
Anomalies (Crisis Stage):	Increase in malaria cases -1938. Evidence that some viral encephalitides were carried by mosquitoes demanding rapid action -1941.
Images of Nature:	Machine.
	CHEMICAL MOSQUITO CONTROL
Definition:	Apply larvicides and adulticides to suppress mosquito populations. Substitute new insecticide when resistance occurs.
Discovery:	DDT is successful as a larvicide in the lab (Herms 1946).
Demonstration:	Gray demonstrates use of DDT as larvicide (Gray 1946).
Evidence of Shift:	High percentage of papers in Proceedings in 1948-49 were describing successful use of DDT.
Productive Phase:	1948-1966.
Anomalies (Crisis Stage):	Resistance, secondary pest outbreaks, killing non-targets, ecosystem disruptions, water contamination, safety.
Images of Nature:	Nearly devoid. Target, "arms race" or co-evolution.
	SYSTEMS SCIENCE
Definition:	Encompass the totality of the problem by drawing conceptual boundaries that capture all the effects of the acts, all of the costs, all of the penalties and all of the rewards (Stead 1966).
Discovery:	Introduced to MCCC by Stead (1966).
Demonstration:	Computer modeling of wetlands (Schooley 1983).
Productive Phase:	Not attained.
Anomalies (Crisis Stage):	Too soon.
Images of Nature:	Nature as an "open system", a homeostatically self-regulating system, as "artificial life", chaos, etc.
	INTEGRATED MOSQUITO CONTROL (IPM)
Definition:	A pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury (Smith 1970).
Discovery:	Introduced by Smith 1970.
Demonstration:	Demonstrated in saltmarshes (Telford and Rucker 1973).
Productive Phase:	Probably not attained.
Anomalies (Crisis Stage):	Too soon.
Images of Nature:	Nature-in-balance, GAIA, chaos, and others.
	COMPREHENSIVE MOSQUITO CONTROL (CMC)
Definition:	Applying all of the available technology of naturalistic control, prevention or source reduction and, chemical control, each in appropriate situations (Mulhern 1971).
Discovery:	Synthesis and Introduction by Mulhern in 1971.
Demonstration:	All successful projects are subsumed. Concepts incorporated into training manual for mosquito control technicians.
Productive Phase:	Not distinguishable.
Anomalies (Crisis Stage):	Avoided by definition.
Images of Nature:	Probably nature as machine, otherwise devoid.
	BIO-RATIONAL MOSQUITO CONTROL
Definition:	Customized and bio-engineered insect-specific materials to control larval mosquitoes (Eldridge 1988).
Discovery:	Altosid and *Bti* discovered and became available in 1980s.
Demonstration:	Successful experimental and field trials of biorationals (Mulligan and Schaefer 1984).
Evidence of Shift:	Since 1970s conventional pesticides have declined while biorationals have increased. This may portend a paradigm shift or simply use as a component of one of the integrated paradigms.
Productive Phase:	If it has reached status of paradigm, it may be in the productive phase.
Anomalies (Crisis Stage):	Too soon.
Images of Nature:	"Target" or "co-evolution" or "arms race".

great hope to the field of mosquito control. He touted the record of successes that occurred in its application to space and weapons technology. In spite of Mr. Stead's enthusiasm, the systems approach only began to surface in the proceedings in the late 1970s. The approach appeared as models to predict mosquito dynamics and abundance (Gilpin et al. 1979, Milby 1984); computer modeling of mosquito sources (Collins et al. 1986, Schooley 1983, Fry and Taylor 1990); research projects aimed at supporting systems models (Cech and Linden 1985, Mead and Conner 1987, Milby and Meyer 1985, Orr and Resh 1987); and computer system development (Rusmisel et al. 1983).

The systems approach, in spite of its formal introduction in 1966 and numerous demonstrations of the approach citations, has not captured the imagination of a sufficient number of adherents in the MCCC to prevail over the other paradigms. The development of this paradigm may be hindered by the almost total absence of systems courses in curricula taken by professional biologists of the MCCC.

The systems approach appears to be the most expansive of all of the competing paradigms of the MCCC. The paradigm is based upon a premise that the world as we know it is an organizing cosmos and inherently unified, integrated, and harmonious (Reckmeyer 1982). More simply, the systems view suggests everything is connected to everything else. It leads to recognition that we deal with an extremely complex, dynamic world in which our actions are expected to have a variety of consequences, and those consequences may often be counter-intuitive. The practitioners of the systems approach in the MCCC tend to rely heavily upon ecological theory to inform their applications while excluding a vast portion of the domain of systems science. Today, system sciences offer a number of "hard" and "soft" approaches to solving problems in a range of system contexts (Flood and Jackson 1991), yet the MCCC has only barely ventured into computer modeling of mosquito populations and wetlands. As a result, the expansiveness provided by systems thinking has not been fully realized. When it has, mosquito and vector control will be viewed as an organizational system connected to and interacting with the human and natural systems. The systems paradigm, in its broadest context, is capable of generating a wide range of images of nature including: nature as an "open system" (Odum 1983), a "homeostatically self-regulating system" (Odum 1983), as "artificial life" (Langton 1989), and others. Recently a metaphor has emerged that depicts the earth as a single, interacting system, alive and self-safeguarding (Myers 1990). Simultaneously, studies of "chaotic systems" suggest that the cherished "equilibrium" or "balance-of-nature" metaphor of nature must be reconciled with new knowledge concerning the chaotic behavior of non-linear, dynamical systems (Gleick 1987). The developing metaphor seems vaguely consistent with the illusive metaphor sought by Botkin and hinted at in the title of his book "Discordant Harmonies".

Integrated Mosquito Control: Integrated mosquito control emerged primarily from the applied academic community, designed specifically to overcome the anomalies associated with chemical control. It has been named variously "pest management", "integrated pest control" and "integrated pest management" or IPM. For convenience, this paradigm is called IPM in this paper. An early proponent to integrated control concepts, Ray Smith, discussed the proposed paradigm to the MCCC in 1970. He formally defined it as:

> "A pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest population at levels below those causing economic injury . . . (integrating) all suitable management techniques with the natural regulating and limiting elements of the environment . . . (applying) the principles of population ecology toward the goals of pest population management (Smith 1970)."

In 1970, when Ray Smith introduced integrated mosquito control, he felt that the MCCC was not yet desperate enough to go into something as difficult and intellectually challenging as IPM. Since that time, however, a number of mosquito control projects can be cited that fall within the framework of the integrated mosquito control paradigm (Garcia and Des Rochers 1984; Pelsue 1984; Miura et al. 1986, 1989). IPM stresses a number of up-front rules dealing with monitoring the pest population, balancing control activities with development of insecticide resistance (spray thresholds), and minimizing impact on natural enemies of the mosquitoes as well as non-target organisms.

The IPM paradigm, once past the initial rules, is primarily informed by ecological theory and practice. Indeed, the practitioners of this paradigm have done much to advance the knowledge of ecological systems in the course of their mosquito control research and practice. In theory, this paradigm also espouses a systems approach and computer modeling, yet current adherents to this paradigm in the MCCC have not used much in the way of system approaches. The relatively limited application of the IPM paradigm by the MCCC suggests it does not clearly dominate other competing paradigms at this time.

The IPM paradigm defines a world where mosquito species and other organisms are connected and behaving dynamically in a natural environment. IPM, however, has not yet adequately illuminated the important interactions between the public, the socio-economic environment, the natural environment, and the mosquito control organization. It appears that the paradigm could overcome much of its limitations if it were to incorporate more systems methodologies into its approach.

IPM, informed by both ecological and systems theory, presents a wide range of metaphors to represent nature. This paradigm, along with the systems paradigm, is being influenced by our increased knowledge of chaos theory (Gleick 1987).

<u>Bio-Rational Paradigm</u>: In his presentation to the MCCC in 1988, Dr. Bruce Eldridge, Director of the Mosquito Research Program in California, reported a declining use of pesticides and predicted an end to uses of "conventional" pesticides for mosquito control in "our professional lifetime". He felt, however, that, in the short term, the conventional pesticides would probably be replaced by insect-specific materials such as insect growth regulators and bacterial insecticides. He lauded these materials because of their specificity to target vectors and because of low human toxicity. According to Eldridge, the advent of bio-engineering had created a "vast untapped potential for customizing present insect-specific materials, as well as the possibility of creating new materials".

Already, a number of the bio-rational products have proven effective in both experimental trials and actual usage (Mulligan and Schaefer 1984, Mulla et al. 1988, Kramer 1989). In fact, the use of both bacterial insecticides and insect growth regulators (bio-rationals) has increased markedly since the mid-1970s, while conventional pesticide use has declined (Eldridge 1988).

The use of bio-rationals hardly seems worthy of paradigm status, since it would seem to serve as just one narrow component to be integrated into one of the more expansive competing paradigms. Yet some factors suggest it could become a "paradigm-by-default" in the same manner as the chemical control paradigm. A compelling force operating for a bio-rational paradigm is its simplicity, a major factor that also operated for the chemical control paradigm. If, as some fear, the future holds an insufficiency of graduating professionals in vector control (Scudder 1988), the likelihood increases that the bio-rational approach will become a paradigm-by-default.

It is quite apparent that the bio-rational control paradigm provides a limited perspective. Knowledge accumulated in the MCCC by the bio-rational control paradigm would be generated primarily by the field experiments conducted by way of actual applications of bio-rationals. The technologies of larval detection and identification, biocide applications, larval susceptibility testing, as well as research and development of bio-rational products, would be highly developed in this paradigm. The paradigm would be largely blind, however, to the complexity of the natural and human world; a major failing.

This prospective paradigm is quite limited in its ability to generate metaphors to provide a broad view of nature. One metaphor that comes to mind is that of an "arms race". The target population is pressured with a bio-rational pesticide; it adapts genetically to survive; the bio-rational is bio-engineered and applied again; and the cycle continues. Nature at its simplest in this metaphor would simply be a target or the "enemy". A more complex interpretation of the metaphor might depict the target mosquito as an co-evolving organism, capable of ultimately producing the "Red Queen Effect," where, in spite of reciprocal escalation on both sides, neither the mosquito control agency nor target population make any relative progress (Dawkins 1987). This metaphor can provide a powerful perspective on the dynamics relationship between the mosquito control agency and the target mosquito population. It does little, however, to help us enrich our understanding of the relationship between the target and the environment, or the mosquito control agency and its environment.

It is obviously not the intention of Dr. Eldridge (1988) that bio-rationals be used excessively or to the exclusion of other appropriate physical/biological approaches. Yet the simplicity of this powerful approach may well lead to an over-dependence on bio-rationals, just as occurred with chemical pesticides after World War II. Excessive and singular use of these powerful tools could give them paradigm status in the mind of the users. The result could be a limited perspective for the MCCC and missed opportunities for sound environmental management.

Findings and Implications.

Since the decline of the chemical control paradigm in the mid-1960s, four competing paradigms have influenced the MCCC by shaping mental models and generating images of nature. Both the bio-rational and CMC paradigms generate limited perspectives of nature. The CMC paradigm, emphasizing an engineering approach, appears to have the machine metaphor lurking at its core. The bio-rational paradigm does little to generate useful images of nature. One metaphor, that of an "arms race", portrays the target population and the mosquito control agency as co-evolving organisms. The metaphor is useful in that it shows the possible development of the "Red Queen Effect" where, in spite of reciprocal escalations on both sides, neither the target population nor the mosquito control agency have made any relative progress (Dawkins 1987). The two paradigms appear limited, however, and seem to offer little hope in solving the crisis of vision in the MCCC.

The IPM and systems science paradigms are both informed by ecological theory and systems theory, promising the infusion of rich and varied images of nature. They also are capable of incorporating bio-rational approaches as a component of the paradigm. An important contribution of systems science is that it provides a framework that can encompass the socio-economic system as well as the natural system. A major shortcoming of systems science appears to be the lack of access to curriculum by the MCCC. The primary image generated by IPM is of "nature-in-balance", unfortunately a failing myth (Botkin 1990). The major advantage of the systems science paradigm is that it provides a framework which connects the socio-economic systems with ecological systems. If the MCCC is to attain the broad vision prescribed by Capra (1982) and Botkin (1990), it is vital that both of these paradigms be further developed by increased infusion of ecological and systems theory.

Managing Paradigms and Mental Models in the MCCC.

The current climate in the MCCC suggests that forces are operating to prevent any one paradigm from obtaining dominant status. The Universities are cutting back on graduates trained in vector ecology and IPM; access to systems science curriculum by students of vector ecology seems limited; the vector control programs of the state have been cutback dramatically in the last decade, reducing the ability to promulgate the concepts of comprehensive mosquito control in their certification and training programs; and finally, the bio-rational approach does not yet seem in danger of being perceived as a paradigm.

There are both negative and positive consequences associated with the continued competition of the paradigms. One positive benefit is that it is unlikely in an atmosphere of competing paradigms that an anomaly would escape detection due to paradigm blindness. When anomalies are not seen by adherents to a paradigm that produce them, they may be easily seen and emphatically identified by adherents of other paradigms. A problem associated with the continued paradigm competition would be that adherents would tend to actively suppress novelty and innovation when it is outside the boundaries of their paradigm. Yet today, the MCCC is much in need of new and novel solutions. Bohm and Peat (1987) say it most succinctly:

> "The cycle of perception and action cannot be maintained in a totally arbitrary fashion unless we collude to suppress the things we do not wish to see while, at the same time, trying to maintain, at all costs, the things we desire most in our image of the world. Clearly the cost of supporting such a vision of reality must be paid."

Perhaps the most serious problem of continuing competition between the paradigms is caused when adherents to different paradigms ascribe different meanings to the same words. For example, the word "mosquitoes" spoken to a member of the MCCC will conjure up different images depending upon his or her paradigm. If he were an adherent to bio-rational control, he would focus on knowledge of mosquitoes centering around their range of behavior as immature and susceptible larvae. An adherent to IPM would likely visualize a population of mosquitoes managed to maintain susceptibility to insecticides. Those in comprehensive mosquito control would likely focus on mosquitoes as they are inextricably tied to a particular type or types of aquatic sources. Finally, an adherent to the systems paradigm might visualize the mosquito as an information processor capable of a determinant number of states. When the word "mosquito", or any other of the paradigmatically defined terms, is communicated to a typically heterogeneous group of individuals of the MCCC, the message intended to be sent by the speaker may be very far from what is received by the listener.

In a scientific community, such miscommunication may be divisive. Flood and Carson (1988) have described the possible outcomes of transparadigm discussion:

> "First, that the opposing camps literally ignore each other and carry on maturing their own paradigms by in-house debate. Second the transparadigm debate leads to further entrenchment in a battle between paradigms. Third, and last, that an individual may change camps adopting in its entirety the whole set of philosophical beliefs and rejecting wholly the set of beliefs previously subscribed to."

In the face of today's environmental challenges, the MCCC can ill-afford the inherent inefficiencies of the above described options. A fourth option would be for individuals in the MCCC to be trained in techniques to surface test, and improve their mental models. Once the skills of managing mental models have been developed, and an ethic of openness has been established, the forces working for a paradigm shift may be blunted. In effect, the MCCC might seek to prolong the crisis stage, thereby providing the advantages of innovation and novelty associated with extra-ordinary science. The MCCC could use the images generated from any of the competing paradigms as temporary epistemological devises by which to obtain a differing view of the world. The result could be a giant step toward meeting the crisis of perspective posed by Botkin and Capra.

Conclusions.

1. There are currently two competing paradigms (systems and IPM) in the mosquito control community of California that appear capable of generating a variety of powerful and useful images of nature. Both paradigms need further development in the MCCC. The bio-rational paradigm should be subsumed within the framework of systems or IPM.
2. No single paradigm is currently predominant in the MCCC. Instead, at least four are in competition with both negative and positive consequences. The natural propensity to advocate the principles of ones paradigm, to suppress novelty, to be blind to phenomena outside paradigmatic boundaries, and to resist conversion can generate divisiveness in the MCCC. Incommensurability between adherents of different paradigms confounds communication and reinforces the divisiveness. On the other hand, the fact that the MCCC is composed of adherents of more than one paradigm offers the opportunity to generate more novel approaches and to reduce the problem of paradigmatically-induced blindness in the scientific community.
3. The MCCC now has a unique opportunity to manage the dynamics of the paradigm competition to obtain a high level of productivity of the kind associated with the operation of normal science, while allowing the innovation and resultant creativity associated with extra-ordinary science.
4. It is essential that appropriate, well-planned action be taken immediately to sustain and enhance the period of extra-ordinary science. The objective should be to learn methods to avoid cognitive traps commonly associated with a dominant paradigm while utilizing paradigms as "useful and temporary perspectives". Senge (1990) has provided a synthesis of a great deal of work aimed at that goal.

References.

Argyris, C., Putnam R., and D.M. Smith. 1985. Action Science. Josey-Bass Publishers, San Francisco.

Bissel, G.E. 1988. Pesticide disposal practice of the 60s haunts vector control district in the 80s. Proc. Calif. Mosq. Vector Control Assoc. 56:99-100.

Bohm, D. and F.D. Peat. 1987. Science, Order, and

Creativity. Bantam Books, New York.

Botkin, D.B. 1990. Discordant Harmonies: A New Ecology for the Twenty-First Century. Oxford University Press, New York.

Boulding, K.E. 1961. The Image. Univ. Michigan Press, Ann Arbor.

Capra, F. 1982. The Turning Point. Bantam Books, New York.

Cech, J.J., Jr. and A.L. Linden. 1985. Comparative larvivorous effects of mosquitofish and Sacramento blackfish in experimental rice fields. Proc. Calif. Mosq. Vector Control Assoc. 53:93-97.

Collins, J.N., S.S. Balling, and V.H. Resh. 1983. The Coyote Hills Marsh model: calibration of interactions among foating vegetation, waterfowl, invertebrate predators, alternate prey and *Anopheles* mosquitoes. Proc. Calif. Mosq. Vector Control Assoc. 51:69-73.

Dahl, A.H. 1946. State subvention in California mosquito control. Proc. Calif. Mosq. Control Assoc. 15:73-84.

Dahlsten, D.L., R. Garcia, J.E. Prine and R. Hunt. 1969. Insect problems in forest recreation areas. Calif. Agr. 23:(7)4-7.

Dawkins, R. 1987. The Blind Watchmaker. W.W. Norton and Company, New York.

Dommes, S.F. 1939. Observations of mosquito problems throughout the state. Proc. Calif. Mosq. Control. Assoc. 10:57-66.

Eldridge, B.F. 1988. Conventional chemical pesticides for mosquito control: past and present. Proc. Calif. Mosq. Vector Control Assoc. 56:207-213.

Flood, R.L. and M.C. Carson. 1988. Dealing with Complexity. Plenum Press, New York.

Flood, R.L. and M.C. Jackson. 1991. Creative Problem Solving. John Wiley and Sons, New York.

Fry, J. and C.E. Taylor. 1990. Mosquito control simulation on the connection machine. Proc. Calif. Mosq. Vector Control Assoc. 58:207-213.

Garcia, R. and B. Des Rochers. 1984. Towards an integrated mosquito control strategy for Gray Lodge Wildlife Refuge with emphasis on the floodwater species: *Aedes melanimon* and *Ae. nigromaculis*. Proc. Calif. Mosq. Vector Control Assoc. 52:173-180.

Gilpin, M.E., W.R. Thomas and G.E. McClelland. Modifications of an *Aedes aegypti* systems model for *Aedes sierrensis*. Proc. Calif. Mosq. Vector Control Assoc. 47:86-87.

Gjullin, C.M. and R.F. Peters. 1952. Abstract of recent studies of resistance to insecticides in California. Proc. Calif. Mosq. Control Assoc. 20:44-45.

Gleick, J. 1987. Chaos. Viking Press, New York.

Gray, H.F. 1946. The control of mosquito breeding in street inlets (catch basins), underground utility vaults and similar structures by DDT residual spray. Proc. Calif. Mosq. Control Assoc. 14:61-64.

Gray, H.F. 1953. Temporary control measures vs. mosquito source reduction. Proc. Calif. Mosq. Control Assoc. 21:46-47.

Gray, H.F. and R.E. Fontaine. 1957. A history of malaria control in California. Proc. Calif. Mosq. Control Assoc. 25:19-39.

Gutting, G. 1980. Introduction. *In:* C. Gutting (Ed.) Paradigms and Revolutions: Appraisals and Application of Thomas Kuhn's Philosophy of Science. Univ. Notre Dame Press, Notre Dame. pp. 1-7.

Herms, W.B. 1946. Some comparative laboratory tests with minute dosages of DDT, 666, and DDD on mosquito larvae and pupae. Proc. Calif. Mosq. Control Assoc. 14:3-6.

Herms, W.B. and H.F. Gray. 1940. Mosquito Control. The Commonwealth Fund, New York.

Hokama, Y. and R.K. Washino. 1966. Potential invertebrate predatory-prey relationships in rice field habitats. Proc. Calif. Mosq. Control Assoc. 34:59.

Horgan, J. 1991. Profile: reluctant revolutionary. Sci. Amer. 5:40-49.

Howitt, B.F. 1941. Relationship of the St. Louis and the western equine viruses of encephalitis to man and animals in California. Proc. Calif. Mosq. Control Assoc. 12:3-23.

Jones, G.P. 1931. A Short History of Malaria in California. Proc. Calif. Mosq. Control Assoc. 2:42-54.

Kimball, J.H. 1973. A changing emphasis of mosquito control in California: planning, persuasion, negotiation, cooperation and legal action. Proc. Calif. Mosq. Control Assoc. 41:83-84.

Kramer, V.L. 1989. Efficacy and persistence of *Bacillus sphaericus*, *Bacillus thuringiensis* var. *israelensis*, and methoprene against *Culiseta incidens* in tires. Proc. Calif. Mosq. Vector Control Assoc. 57:139-140.

Kuhn, T.S. 1962. The Structure of Scientific Revolutions. Univ. Chicago Press, Chicago.

Kuhn, T.S. 1970. The Structure of Scientific

Revolutions, 2nd Edition (enlarged). Univ. Chicago Press, Chicago.

Langton, C.G. (Ed.) 1989. The Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems Held September, 1987 in Los Alamos, New Mexico. Addison Wesley Publishing Co., New York.

Lusk, E.E. 1971. Environmental conflicts. Proc. Calif. Mosq. Control Assoc. 39:26-28.

March, R.R. 1952. Aspects of insecticide restistance. Proc. Calif. Mosq. Control Assoc. 39:26-28.

McClelland, G.H. 1966. Genetic control. Proc. Calif. Mosq. Control Assoc. 34:29-31.

Mead, S.E. and G.E. Conner. 1987. Temperature-related growth and mortality rates of four mosquito species. Proc. Calif. Mosq. Vector Control Assoc. 55:133-137.

Milby, M.M. 1984. Predicting *Culex tarsalis* abundance in Kern County. Proc. Calif. Mosq. Vector Control Assoc. 52:153-155.

Milby, M.M. and R.P. Meyer. 1985. The influence of constant versus fluctuating temperatures on larval *Culex tarsalis*. Proc. Calif. Mosq. Vector Control Assoc. 53:117.

Miura, T., D.E. Reed and R.M. Takahashi. 1986. Efficiency and cost analysis of chemical vs. integrated *Culex tarsalis* control in central California rice fields. Proc. Calif. Mosq. Vector Control Assoc. 54:22-25.

Miura, T. and R.M. Takahashi. 1989. A model of population dynamics of *Culex tarsalis* on rice fields in Fresno, California. Proc. Calif. Mosq. Vector Control Assoc. 57:61-66.

Mulhern, T.D. 1971. Little used technology valuable in a program of comprehensive mosquito control. Proc. Calif. Mosq. Control Assoc. 39:93.

Mulhern, T.D. 1973. The third era of mosquito control in California has just begun. Proc. Calif. Mosq. Control Assoc. 41:75-78.

Mulhern, T.D. 1980. Mosquito control: past, present and prospective future. Proc. Calif. Mosq. Vector Control Assoc. 48:20-23.

Mulla, M.S., H.A. Darwezeh and H. Axelrod. 1988. Activity of slow release formulations of IGRs fenoxycarb and altosid against mosquitoes and non-target aquatic organisms. Proc. Calif. Mosq. Vector Control Assoc. 56:184-191.

Mulligan, F.S. and C.H. Schaefer. 1984. Field trials of *Bacillus thuringiensis* H. 14 commercial formulations. Proc. Calif. Mosq. Vector Control Assoc. 52:80-84.

Myers, N. 1990. The GAIA Atlas of Future Worlds. Anchor Books, New York.

Odum, H.T. 1983. Systems Ecology. John Wiley and Sons, New York.

Orr, B.K. and V.H. Resh. 1987. Interaction between mosquitofish (*Gambusia affinis*), sago pondweed (*Potamogeton pectinatus*), and the survivorship of *Anopheles* mosquito larvae. Proc. Calif. Mosq. Vector Control Assoc. 55:94-97.

Pelsue, F.W. 1984. Integrated pest management of an urban swamp. Proc. Calif. Mosq. Vector Control Assoc. 52:60-61.

Piaget, J. 1954. The Construction of Reality in the Child. Balantine Books, New York.

Reckmeyer, W.J. 1982. The Emerging Systems Paradigm: An Historical Perspective. Unpubl. Ph.D. dissertation, The American University.

Reginato, R.J. and L.E. Myers. 1966. Recent water management research. Proc. Calif. Mosq. Control Assoc. 34:19-22.

Rusmisel, J.R., R.O. Abriam and P.S. Turney. 1983. A computerized database and simulation system to support decisions in the Alameda County Mosquito Abatement District. Proc. Calif. Mosq. Vector Control Assoc. 51:67-68.

Schaefer, C.H. 1972. Mosquito control crisis in the Central Valley. Proc. Calif. Mosq. Control Assoc. 40:76-80.

Schooley, J.J. 1983. The Coyote Hills Marsh model: calibration of the interactions among fish and floating vegetation. Proc. Calif. Mosq. Vector Control Assoc. 51:74-76.

Scudder, H.S. 1988. Medical entomology manpower: an analysis and a plan. Bull. Soc. Vector Ecol. 13(2):323-331.

Senge, P.M. 1990. The Fifth Discipline: The Art and Practice of the Learning Organization. Doubleday Currency, New York.

Smith, R.F. 1970. The application of integrated control principles to mosquito control problems. Proc. Calif. Mosq. Control Assoc. 38:28-30.

Stead, F.M. 1966. Changing program perspectives in environmental quality management. Proc. Calif. Mosq. Control Assoc. 34:9-14.

Telford, A.D. and J.D. Rucker. 1973. Successful source reduction on tidal salt marshes. Proc. Calif. Mosq. Control Assoc. 41:70.

West, I. 1964. Safety considerations in mosquito control operations. Proc. Calif. Mosq. Control Assoc. 32:64-65.