ECOLOGICAL STRATEGIES FOR THE PREVENTION AND CONTROL OF HEALTH PROBLEMS[1]

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Health-related ecological strategies, which use knowledge of certain organisms' behavioral patterns and their ecologies to attain specific health-related goals, are likely to become increasingly important. This article describes many such strategies that are being used now, as well as a number that may be employed in the future.

Introduction

Today, "ecological" strategies tend to be defined as strategies that utilize knowledge of organisms' ecology and behavior to attain goals more efficiently and effectively than they could be attained with more traditional methods. It is also accepted that the costs involved in pursuing such strategies should be moderate and within the means of countries having modest resources.

Because ecology is such a broad discipline, encompassing many specialties, it is perhaps useful to point out that ecological strategies do not include direct actions against diseases—such as vaccination to prevent outbreaks or massive application of insecticides to eliminate mosquito vectors. Nor should ecological strategies be confused with biological control methods. The latter simply employ living organisms to control vectors or hosts of disease agents, and thus are most nearly analogous to chemical agents employed for the same purpose *(1)*. Biological control methods frequently introduce new organisms into the environment (such as the Myxoma virus employed to control rabbits in Australia), whereas ecological strategies tend to manipulate indigenous organisms. It is also true, however, that ecological strategies do sometimes employ biological control methods to achieve their goals.

Ecological strategies may be applied for one or more of three distinct purposes: (1) to detect or predict potential health problems before they begin having an impact on humans, (2) to prevent the occurrence of potential health problems, and (3) to control or combat an already existing health problem. This article describes current ecological strategies in each of these categories, as well as a number of potential strategies that appear to offer interesting future prospects.

Ecological Strategies to Detect or Predict Potential Health Problems

The Use of Free-living (Wild) Animals as Sentinels

There is clearly a distinct advantage in possessing an early-warning detection system for diseases that may occur sporadically, especially if the control measures are costly or have undesirable side-effects. Moreover, some vector-borne diseases occur only in certain seasons, and may not occur at all in certain years. In such circumstances the constant

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chemical control of mosquitoes is costly and causes unwanted side-effects—such as contamination of the environment with toxic substances having attendent effects on man and other species.

St. Louis encephalitis (SLE) surveillance. The SLE virus produces potentially serious disease epidemics in many parts of the United States. Nevertheless, these occur only in mid to late summer and almost never strike the same community on successive years *(2)*. In the past some communities tried to control outbreaks by maintaining continuous mosquito control throughout the summer, but such activities proved costly. Furthermore, it appeared better to save money during interepidemic years, and then to apply some really intensive crash mosquito control programs just before an impending epidemic struck. However, this tactic required an early-warning detection system.

Fortunately, the nature of St. Louis encephalitis outbreaks permits this strategy. The SLE virus is a natural parasite of wild birds; humans are only incidentally infected when mosquitoes happen to transmit the virus to them after first biting infected birds. While any infected mosquito could theoretically transmit the disease to a person, epidemics in fact follow the laws of probability; therefore, a certain proportion of birds must generally become infected before enough mosquitoes are infected to involve the human population. Consequently, monitoring the bird population for virus activity can provide early information—at a time when the bird infection rates are still too low to pose an immediate threat to people *(3)*. When significant levels of virus activity are detected, the mosquito control teams can then act, knowing that their work will save lives without wasting time and effort.

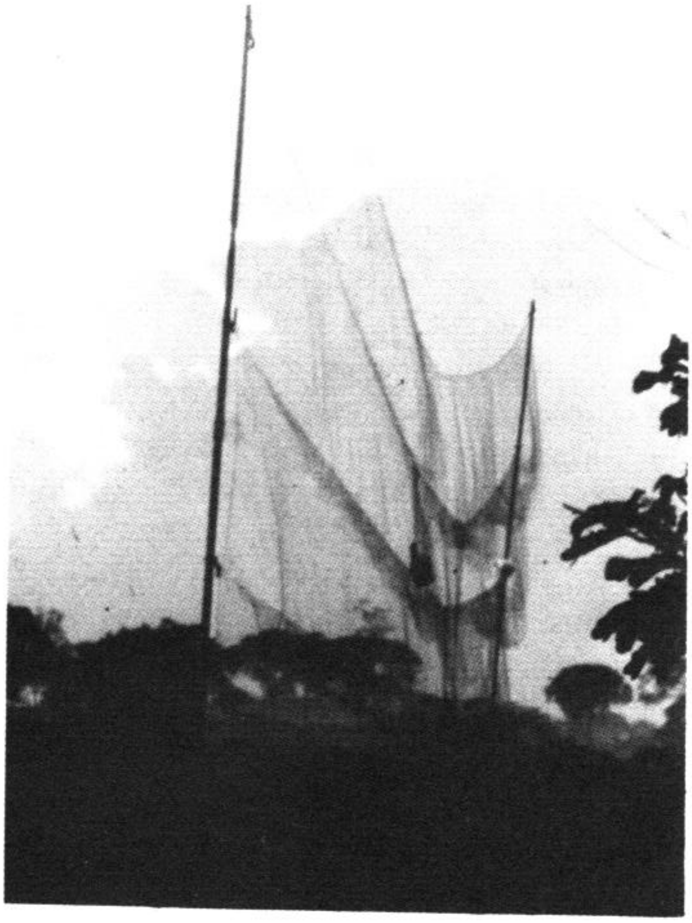
SLE viremia lasts only a few days in birds. Consequently, birds are monitored for SLE by serological examinations employing the hemagglutination inhibition (HI) test, neutralization (N) test, or both. Because adult birds could show antibody from previous years, only juvenile birds are tested. This juvenile population includes both nestlings and adult-sized juveniles, the latter being distinguished from adults by determining the degree of ossification of the skull. Such a determination can be made without sacrificing the bird, since its thin skin is transparent enough to permit direct viewing of the skull after parting the feathers.

Previous attempts at SLE surveillance were based either on collecting mosquitoes or testing flocks of sentinel chickens. Mosquitoes can be collected relatively easily in automatic light traps. However, Nature exposes them to a great variety of mortal dangers, and as a consequence their longevity is measured in terms of days. Thus, the relative probability of detecting virus activity favors surveillance systems monitoring antibody in birds.

However, monitoring antibody in sentinel flocks of chickens also has a number of drawbacks. First, it is necessary to place chickens free of the antibody in cages located where they are likely to be exposed to mosquitoes that have been feeding on wild birds. Thus, forests and the edges of swamps are preferred locations. In such places, however, feeding and caring for the chickens is a problem. And, because the method seeks to detect serum conversions, it is necessary to bleed the chickens repeatedly.

The system of bleeding young wild birds, besides avoiding both of these problems, has an additional advantage. That is because wild birds circulate over a wide area, often sleeping in different localities; and so they are exposed to mosquitoes from many localities. Compared to the sentinel chickens, which sample only the relatively small areas where they are located, the wild birds sample a very large area.

Since it was first applied in Corpus Christi, Texas, in 1966 *(3)*, this ecological strategy of monitoring SLE virus activity by testing wild birds has been adopted successfully by many cities of the southeastern United States *(2)*. The technique is equally applicable to sur-



A mist net, deployed to catch wild birds as part of an eastern equine encephalitis surveillance program in Venezuela, holds a ruddy ground dove.

veillance for eastern and western equine encephalitis viruses, and as such is providing the basis of a new surveillance system monitoring those disease agents in the Dominican Republic. Other Latin American countries might well consider this technique's potential.

Unusual Mortality or the Absence of Certain Species

Since the advent of mass insecticide applications to control agricultural pests, it has become increasingly apparent that these and other toxic substances pose an insidious threat to human health. Detection of such substances and their toxic breakdown products is a matter of straightforward chemical analysis in the laboratory.

However, it has become abundantly clear that we cannot be constantly testing soil and

A health worker examines a caged sentinel hamster used for surveillance of Venezuelan equine encephalitis in the state of Zulia, Venezuela.

water samples from everywhere. Consequently, whenever unusual die-offs of creatures such as wild birds occur, it is appropriate to conduct investigations for the purpose of determining whether the cause of the unusual mortality may not also present a threat to man.

Similarly, it saves both time and money to use bioassay techniques as a primary screening procedure for detecting dangerously contaminated sites or regions. For example, surface water samples may be brought into the laboratory where living organisms, such as fish or tadpoles, are exposed. When such exposure causes death, traditional chemical analyses can then be used to determine the nature of the toxic substance or substances involved.

Trained personnel may also be alerted to possibly hazardous environmental contamination by the absence of organisms from an environment where by all rights they ought to be. This "silent spring"[3] phenomenon can thus be used as an ecological strategy to detect the presence of toxic materials, and may even be coupled with bioassay techniques to provide a rapid and inexpensive early warning system.

Of course, final confirmation of any hazardous contamination will always depend on laboratory analysis of samples taken from the suspect environment; but the size of the regions that can be effectively monitored is considerably enlarged by these strategies—a fact that justifies their use in monitoring the environment for toxic materials.

Use of Caged or Domestic Sentinel Animals

Venezuelan equine encephalitis (VEE). As noted in passing during the discussion of SLE virus, certain disease agents can be detected through the use of sentinel animals. For example, sentinel hamsters provide one of the most sensitive tools for detecting Venezuelan equine encephalitis (VEE) virus in its enzootic state. These sentinels are utilized in several Latin American countries.

Hamsters are not native to the New World tropics and subtropics where this virus is found; and, possibly for this reason, they are unusually susceptible, generally dying within a few days of infection. Thus, workers searching for foci of this important disease (which has caused countless human deaths over the years) can monitor environments suspected of harboring the virus (frequently tropical swamps or forests) by placing caged young hamsters at appropriate sites. The cages are designed to provide easy access for mosquitoes, and the hamsters are checked once or twice a day. When dead or moribund hamsters are discovered, they are immediately frozen (on dry ice or in liquid nitrogen carried to the field) and transported to the laboratory, where routine virus isolation procedures are carried out.

Jungle yellow fever. This disease can afflict people living in or near tropical forests, and it sometimes tends to travel through the forest in waves, remaining undetected until human victims reveal its presence. In regions where this sylvatic form of yellow fever has occurred previously, and thus might recur repeatedly, it is possible to place sentinel monkeys in the forest, at sites where mosquitoes (infected by biting wild monkeys) are likely to bite the sentinels before biting humans in the vicinity. As in the case of the hamsters, sick or dead monkeys are taken to the laboratory to be examined for the presence of yellow fever virus.

Whenever early-detection techniques indicate the presence of mosquito-borne yellow fever virus, mosquito control and vaccination measures are taken to prevent the potential outbreak, thus avoiding suffering and saving lives. Recent increases in the number of Latin American yellow fever cases argue for increased use of sentinel monkeys.

Cancer. It has been suggested that pet dogs could be used as sentinels to detect carcino-

[3]The absence of singing birds in the spring season as a result of environmental contamination, as postulated by Rachel Carson in *Silent Spring* (Houghton Mifflin, Boston, 1962).

genic hazards in the general environment. A significant positive correlation has been found between the incidence of canine bladder cancer and prevailing levels of industrial activity, and the latter have also been correlated with human mortality due to bladder cancer. It has been suggested that both these correlations arose from industry-related carcinogenic substances that had escaped into the environment. The latent period for bladder cancer in man is estimated to be at least 20 years, compared to no more than 10 years in the dog, a fact suggesting that the dog could prove a useful sentinel *(4)*.

Ecological Strategies to Prevent Health Problems

There is a clear advantage in knowing ecological principles and being aware of the details of the interrelationships of as many animals and plants as possible in devising ecological strategies. Nevertheless, it is also true that people without formal training in ecology, but with natural talents and broad perspectives, have contributed more along these lines than formally trained ecologists.

Spraying with Residual Insecticides

Straightforward spraying to kill disease-vector mosquitoes directly is not considered an ecological strategy. However, certain modifications of insecticide spraying to control vectors should most certainly be considered ecological strategies. One such modification is the spraying of residence walls with a residual insecticide to kill resting anopheline mosquitoes for malaria control. In this case the mosquito control official has laid a trap, knowing full well the habits of the principal malaria vector. In the past this technique was spectacularly successful, eradicating malaria from enormous areas and curtailing its role as the dread menace of the tropics. The recent widespread recurrence of malaria suggests the possibility that new strategies involving knowledge of anopheline breeding habits should be sought to combat this health problem—especially if a straightforward solution is not found following investigation into the reasons for the malaria resurgence.

Habitat Management for Rodent Control

Rodents serve as reservoirs and vectors of a very large number of important diseases, including many in which their role as the principal host is not recognized. Since rodents are also found frequently in close proximity to man, they create a serious hazard that must be dealt with.

Nonecologists naturally tend to think of rodent control in terms of killing rodents—generally either with cats, traps, or poisons. However, ecologists are all too well aware of the ineffectiveness of this approach. The reason is simple: rodents have a very high reproductive potential. They have evolved this fecundity in compensation for high mortality; and, in ways that are only partially understood, they can modify their rates of reproduction in response to variations in mortality.

This means that when a rodent population suffers significant losses, it may raise its reproductive rate through a combination of responses. Such responses include raising the average litter size, increasing the proportion of females pregnant at any given moment, augmenting the number of litters per year, and lowering the age at which young females become sexually mature. The combined responses can produce a spectacular recovery in the population, quickly nullifying rodent control efforts. Thus, while rodenticides certainly have their place in removing rodents when rodent numbers have become intolerable, and in aborting epidemics in progress, the continued use of poisons constitutes an inefficient control method and leads to an accumulation of toxic materials in the environment.

Ecological strategies based on a sound knowledge of rodent needs, habits, and ecology have been devised. Basically, these techniques manipulate the rodents' habitat so as to remove available food and nesting sites *(5)*. Such manipulation reduces the carrying capacity of the environment to a level (usually near zero) that is more nearly acceptable to man. Thus, proper rodent control in urban environments comes to mean the implementation of a sensible and practical system of garbage disposal—including the sometimes difficult step of obtaining the collaboration of individuals in keeping private garbage containers rat-proof.

Removal of nesting sites is equally effective and achieves equally spectacular results. Most rats and mice nest in or under piles of refuse or stored construction materials. Refuse, of course, can be removed; and construction materials can either be raised above the ground or placed on a solid cement foundation. Possibly because of the rather simplistic nature of these control measures, it is difficult to obtain collaboration; therefore, effective urban rat control must rely on strict law enforcement, which is sometimes unpopular but necessary.

Rural rodent control is different. When rodents infest a rice or sugarcane field, removal of the available food supply is impossible—partly because the food is the very crop being raised. Also, nesting sites are generally inaccessible, often being under the crop's roots. Therefore, ecological strategies are directed at preventing early invasion of the crop by rodents. This tends to reduce the size of the population arising during the growing season, thereby minimizing crop losses and reducing the rate of invasion of human residences at harvest time.

The appropriate period for rodent control in agricultural fields is between the times of harvest and replanting. During this period it is essential to remove available food, nesting sites, and refuges from enemies. Usually the fields themselves are virtually uninhabitable after harvest, so surviving rodents generally retreat to available habitats on the fields' borders. Making these border areas uninhabitable for rodents is the best way of preventing future rodent problems in the following year's crops, for it is from these areas that the fields are reinvaded annually. Burning or mowing the ground vegetation on the field's borders makes these sites unable to support many rodents, because much of the natural food supply is removed and the rodents are exposed to natural predators such as owls, hawks, and foxes.

Use of Chemosterilants

A really spectacular ecological strategy for controlling certain insect vectors—including *Anopheles albimanus*, an important vector of malaria *(6)*—was first demonstrated through control of the screw-worm fly *(Cachliomyia hominivorax)*. The strategy consists of releasing sterilized males into the environment, where they mate with wild fertile females and cause them to produce sterile eggs. The strategy has been enormously successful, usually resulting in complete elimination of the fly from the treated area.

In this particular case, the high degree of success was initially attributed to the female's habit of mating only once. The reasoning was that if the female's one mating was with a sterile male, her fertile egg production would be zero; and so the release of enough sterile males would reduce the probability of a mating between a fertile male and female below some crucial threshold.

In fact, however, whether a female mates only once is not of major importance, the main consideration being the probability of matings likely to result in fertile eggs. In this vein, the main underlying reason for the strategy's success is that most insects, like rodents, compensate for high mortality through stepped-up reproduction. The sterile male technique, in the process of reducing the population, interferes with this compensation mechanism. Of course, as the population falls the mortality-causing factors that depend on population density become relatively less important; but all those independent of population density continue to operate and continue to reduce the population.

This technique has yielded an important veterinary benefit by controlling the screw-worm fly, whose larvae infest the wounds of livestock. However, our immediate concern here is with its application to vectors of human disease agents.

In some cases males are sterilized by gamma radiation; but the manner of sterilization is unimportant, and chemosterilants may be just as effective and more practical to apply. Chemosterilants such as bisazir are used to sterilize the males of *Anopheles albimanus,* an important vector of malaria in Central America. At present, as many as a million *A. albimanus* males can be sterilized daily and packaged for field release *(7).*

The effectiveness of this strategy against mosquitoes has also been demonstrated on an isolated island located off the Gulf Coast of Florida, where investigators succeeded in virtually eradicating a population of *Culex pipiens quinquefasciatus (8).*

Besides being effective, the sterile male technique has the advantage of adding no toxic substances to the environment.

Water Management

Water management has proven an effective ecological strategy as well as an economic alternative to chemical control of malaria vectors (anopheline mosquitoes) and schistosomiasis vectors (freshwater snails) *(9,10).*

The larvae of anopheline mosquitoes require the shelter of emergent or floating plants (such as bullrushes or water hyacinths) that are left high and dry when water levels are changed drastically. Such a change results in death by dessication for many larvae and leaves surviving larvae vulnerable to predation.

Snails are also adversely affected by a major change in the water level, because they become exposed to certain predators such as marsh birds, and their reproductive cycle is interrupted. Consequently, routine management of many reservoirs includes "drawdowns" to expose shore-line habitats for the purpose of controlling mosquitoes and snails. A dam has even been designed with a siphon that produces automatic changes in the water level.

Introduction of Competitive Species

One of the most interesting ecological strategies that can be employed is utilization of an organism that competes with a disease vector and displaces it, thus ending the disease problem.

One example of such a technique is replacement of the intermediate schistosomiasis host snail *Biomphalaria glabrata* with another more competitive snail, *Marisa cornuarietis,* that does not serve as a host for the parasite. Procedures have been devised for rearing *M. cornuarietis,* which are then released into streams and ponds where the intermediate host is present. In a matter of a few months the dominant snail is *Marisa,* and *Biomphalaria* has virtually disappeared.

In the past, snail control was typically attempted with molluscicides at a cost of some US$8 per hundred cubic meters of water. In contrast, the cost of control through replacement with *Marisa* is a small fraction of that amount—on the order of US$.05 per hundred cubic meters of water, and runs no risk of polluting the water with chemical agents that may have unwanted side-effects *(11).*

Ecological Strategies to Control Health Problems

Vampire Bat Control

One of the most spectacularly effective ecological strategies to deal with a health problem is the combination of techniques used to control bovine rabies, a disease transmitted by

Vampire bat control measures. Health workers starting to deploy a mist net to capture vampires (above), removing a captured bat from the net (right), and coating a captured bat with a vaseline-anticoagulant mixture prior to its release (below).

vampire bats. This disease is very important to the cattle industry in Latin America, where it kills half a million to a million cattle annually *(12)*. Traditionally, control of the disease was based on vaccination of vulnerable cattle. Attempts at controlling the vampire bats by dynamiting or burning roosts tended to yield unsatisfactory results and to kill fewer vampires than bats belonging to beneficial species.

However, some years ago a team of researchers in Mexico devised a control technique that was both specific for vampire bats and quite effective *(13)*. The technique was based on observations of vampires in their roosts that revealed much individual and social grooming. This suggested that if one bat were treated with a poison, many of its colony mates could be poisoned as well through social grooming.

Since the whereabouts of vampire roosts is rarely known, the practical procedure is to trap vampires by placing special nylon "mist" nets around a corral containing cattle. The captured vampires are then smeared with a mixture of vaseline and some slow-acting anticoagulant, such as warfarin or chlorophacinone, and released. They subsequently fly back to their roosts, where members of the colony join in licking off the vaseline smeared on their fur. In this way, treatment of one vampire bat can result in the death of 20 to 40 colony mates *(14)*.

As effective as this technique is, the area occupied by vampire bats, stretching from Mexico to Argentina, is enormous; and in fact no single country in the Region has found the resources to combat vampires systematically throughout its territory. As a result, there is every reason to pursue a control strategy capable of stopping bovine rabies without eradicating vampire bats.

The disease is apparent only through the death of cattle and sometimes other animals (horses and pigs are frequently affected); but these victims play no role in spreading or maintaining the outbreak, which is accomplished by transmission of the rabies virus from one vampire bat to another. Such transmission is efficient, and is enhanced by the fact that most vampire colonies are in communication with other nearby colonies, with a few members making "exchange" visits each night *(15)*. The resulting pattern of rabies outbreaks in vampire bat colonies is one in which the disease typically migrates through the network of intercommunicating colonies at a rate of anywhere from 10 to 40 kilometers per year *(14)*.

There is a tendency for these migratory epizootics to follow paths corresponding to natural topographic features such as rivers and foothills. The reason is that vampire populations are limited by available roosts, and suitable roosts are limited to particular types of local geology, topography, and habitat. Thus it is possible, by questioning cattle owners suffering losses, to determine the course of the epizootic. This permits an area to be established a few kilometers in advance of the outbreak where vampires are systematically eliminated, utilizing the anticoagulant technique described. Then, when the outbreak reaches that area it simply dies out for lack of available hosts. This strategy has been successfully applied in many countries—including Argentina, Brazil, and Venezuela—and has successfully terminated many outbreaks.

Biological Control Measures

By definition, controlling vectors or reservoir hosts by means of predators or disease agents is not an ecological strategy; instead it falls into the category of biological control. Nevertheless, biological control agents, like chemical agents, may be utilized in ecological strategies; and considerable ecological knowledge is usually required for proper application of biological control agents *(1)*.

Control with chemical agents does not usually depend on the density of the target organism. That is, proper application of the agent will result in elimination of nearly all the organisms or a significant proportion of them regardless of their density. In contrast, biological agents are subject to the principles of density-dependence, and their effectiveness declines as the target organism's density decreases. This does not detract from the value of biological agents, but it does mean that they cannot be expected to completely eliminate the target organism in most cases.

On the other hand, control with biological agents has the distinct advantage of establishing a self-regulating system. That is, when the target organism is abundant, the control method operates at its greatest efficacy; and when the target organism becomes scarce, the biological agent maintains itself at a low level until the target organism again becomes abundant. For example, the "top minnow" *(Gambusia affinis),* a small surface-feeding fish that preys on mosquito larvae *(16),* has sufficient reproductive capacity to keep pace with an expanding mosquito-larvae population and to control it. When the prey become scarce, such as in winter, the fish population declines as well, nevertheless maintaining itself at low levels until warm weather returns, bringing with it a replenished supply of prey.

Floating Plants for Wastewater Treatment

While the majority of ecological strategies to control health problems are directed at particular disease agents, vectors, or reservoir hosts, some strategies may be less specific. In this regard the treatment of wastewater, particularly domestic sewage, seeks to break the natural transmission cycles of several human diseases that rely on fecal contamination of food and water.

The physical treatment of wastewater has been very well studied, and excellent treatment facilities are in operation around the world. Unfortunately, such treatment facilities are as expensive to construct as they are to develop, and many parts of the globe very much in need cannot afford them.

Recently, a solution to this problem has been devised that utilizes the filtration capacities of floating plants such as the water hyacinth *(Eichornia crassipes).* Stabilization ponds of several designs (some a series of separate ponds, others a long zig-zag pond), all with a continuous flow of wastewater and a dense population of water hyacinth growing on the water's surface, have been shown to adequately remove organic and inorganic waste products and to significantly reduce coliform bacteria counts to acceptable levels *(17,18).* Water from such biological stabilization ponds may be rediverted to streams after treatment, resulting in an enormous improvement over what are the present conditions in much of Latin America. The cost of constructing and maintaining such ponds lies well within the capacity of most communities—because manual labor can be used and no expensive or sophisticated technology is required.

Possible Future Ecological Strategies Applicable to Latin America

Control of Venezuelan Encephalitis Virus through Its Replacement with Nonpathogenic Virus Strains

Most of the aforementioned strategies, with the possible exception of those for surveillance of St. Louis encephalitis virus and control of bovine rabies, are not particularly complex. However, health-oriented ecological strategies of the future are likely to involve increasingly complex methods.

One such possible future strategy is directed at the control or even the elimination of Venezuelan equine encephalitis (VEE). This disease, which kills many people in the course of its sporadic outbreaks, uses wild mammals such as spiny rats *(Proechimys* spp.) as its reservoir hosts. Equine animals then serve as amplifier hosts during epizootic-epidemics.

At present, the vaccine most used against VEE is derived from a pathogenic strain (Trinidad Donkey strain I-B) which was attenuated by 83 serial passages in tissue culture. Because at times this attenuation appears to be insufficient, many laboratories inactivate the vaccine virus before applying it.

Many other strains of VE virus occur in nature, and several of these are nonpathogenic for either man or equine animals *(19)*. Yet infection with these nonpathogenic strains confers immunity against the pathogenic strains. Thus, it appears feasible to utilize one or another of these nonpathogenic strains as a vaccine for immunizing equine animals in regions where the disease traditionally recurs (such as the Guajira Peninsula shared by Venezuela and Colombia—*20)*, using wild mosquitoes instead of hypodermic syringes to spread the immunizing agent.

Rains are seasonal in the regions involved, and their arrival is followed shortly by a sharp rise in mosquito populations. With proper timing it should be possible to infect a relatively few strategically placed equine animals with a nonpathogenic VEE virus strain that would produce about four days of viremia. Since literally thousands of mosquitoes feed on equine animals when they are at their seasonal population peak, many of these infected insects could be expected to serve as vectors of the nonpathogenic strain, producing an artificial outbreak in the area and immunizing a sufficient proportion of the equine population to form a barrier against any possible introduction and amplification of some pathogenic strain.

The concept is rational, and its feasibility has probably already been demonstrated naturally *(21)*. In 1969 an outbreak of VEE began on the border between El Salvador and Guatemala. By 1970 this outbreak had spread to Mexico, moving northward along both the Pacific and Gulf coasts. Nevertheless, the outbreak never entered certain low swampy areas in the region of the Bay of Campeche where other strains of VEE virus had previously been isolated *(21)*.

Similarly, in 1973 a panzootic of western equine encephalitis (WEE) occurred in southern South America, affecting parts of Argentina, Uruguay, Brazil, and Bolivia; but in a swampy region of northern Argentina, Esteros de Iberá, no horse deaths occurred, even though serologic tests demonstrated that WEE virus had been present in the region.

This evidence suggests that in some wet regions where mosquito vectors are continuously abundant, certain mosquito-borne virus diseases may be endemic, causing continuous sporadic infections in susceptible hosts—resulting in death of the host animals or their survival with immunity against future infection.

It is even conceivable that the pathogenic strains of VEE virus could be eradicated. It is reasonable to assume that these pathogenic strains are maintaining themselves in nature in certain enzootic foci. Although to date such foci have been found only for nonpathogenic strains (e.g. in Florida, Mexico, Guatemala, Panama, Venezuela, and Brazil) *(19)*, it may be that foci for some of the pathogenic strains occur somewhere in northwestern South America, since that region has repeatedly experienced periodic outbreaks of VEE *(20)*.

Providing these foci could be discovered, it appears feasible to introduce a nonpathogenic strain into such foci to replace the pathogenic strain. This could be achieved by placing equine animals strategically throughout the focal area immediately after inoculating them with the nonpathogenic strain. These animals are many times larger than the usual rodent reservoir hosts, and many thousands of mosquitoes would presumably become vectors of the nonpathogenic strain—later infecting the rodent reservoirs in an overwhelming manner and conceivably resulting in the desired replacement of the pathogenic strain with the nonpathogenic virus.

Carnivorous Water Plants to Control Schistosomiasis

Another interesting ecological strategy would be to exploit the possibility of using an aquatic carnivorous plant to eliminate schistosomiasis. Plants of the genus *Utricularia*, commonly known as bladder-worts, have small bladders that are triggered by moving objects and suck them in. Studies have shown that *Utricularia* can ingest cercaria and miracidia, the intermediate stages of the schistosomiasis agent *Schistosoma mansoni (22).*

It thus appears reasonable to consider trials using *Utricularia* as a control for schistosomiasis in currently affected regions. Indeed, a natural analog of this strategy may already be in action. Cuba has 17 species of *Utricularia,* and Hispaniola and Jamaica have four and two, respectively, while Puerto Rico has none. This could conceivably have something to do with the fact that there is no schistosomiasis on Cuba or Jamaica and only a small focus in the Dominican Republic, while the disease is widespread on Puerto Rico *(22).*

Rabies Control through Chemosterilant Control of the Stray Dog Population

In Latin America there is a persistent problem of canine rabies. While the disease may be found almost anywhere, the severity of the problem is clearly correlated with human populations and is based on the stray dog population. Dog pounds, rabies control districts, and so forth have never been popular because of man's traditional love of dogs and the strong public opposition to dog-killing.

Perhaps, however, a strategy is available that could satisfy the need for reducing the stray dog population to reasonable levels without destroying the dogs. This strategy has been suggested by a number of canine population studies done in the Americas and a considerable body of available information about canine population dynamics.

In general, the canine reproductive rate is high, resulting in a high annual turnover averaging something on the order of 68 per cent. This means that the natural mortality of stray dogs is also high, and so it is only high fecundity that is maintaining the dense stray dog populations. (The causes of this high mortality—distemper, hepatitis, etcetera—are not of immediate concern here.)

There are chemosterilants, such as triethyleneaminemelamine (TEM) and diethylstilbesterol, that can be offered to stray dogs in the same manner as strichnine baits—resulting in sterility instead of death and thereby avoiding adverse public reaction. Then, without the high reproductive rate compensating for natural mortality, the population should quickly subside to levels which would hopefully be below the threshold required to maintain rabies. To enhance the effectiveness of this procedure, the recently developed oral rabies vaccine could also be included in the chemosterilant baits.

Control of Argentine Hemorrhagic Fever

In the mid 1950s a new disease was discovered in the Province of Buenos Aires that was subsequently given the name Argentine hemorrhagic fever, or more popularly *mal de los rastrojos* (corn-field sickness). Subsequent investigations indicated that the reservoir host of the responsible virus, named Junín virus after a local town, were wild rodents. Unfortunately, the popular name of the disease led to a belief that the rodent reservoirs of this disease were distributed evenly throughout the extensive corn-fields of the region, thus making control of the disease through rodent control a nearly impossible task.

It was subsequently noted, however, that the rodent reservoirs were concentrated on the edges of the fields, usually along roadsides, railroads, or fence rows *(23).* This observation was later confirmed through standardized censuses of rodent populations that produced statistically analyzable results *(24).*

Since the affected region lies in a temperate zone, there is a considerable seasonal fluctuation in rodent abundance, with peak populations occurring in late summer when most human cases of the disease also occur. By late winter, just before the beginning of the breeding season, rodent numbers are at their lowest.

Rodent control efforts are generally most effective when directed at populations that have already been reduced by natural causes; and, as previously mentioned, rodent control is best achieved through habitat management that destroys shelters and food supplies. In this regard, it is relevant that in mid-winter the affected region lacks available food and cover for rodents in the agricultural fields, forcing the rodents into the available habitable strips of land on the fields' borders until spring brings a resurgence of plant growth. However, the rodent-infested roadsides, railroad right of ways, and fence lines usually support heavy turf or a great tangle of dried weeds. Some sporadic efforts have been made to burn or plow these strips; but since these local efforts are not coordinated, their effectiveness is limited.

Kudzu *(Pueraria lobata)* is a leguminous vine proposed for use as cattle fodder, but one that grows so vigorously as to have become a serious weed in the southeastern United States. Kudzu has certain specific requirements that restrict its distribution. For example, it must be planted along with a culture of symbiotic nitrogen-fixing bacteria found in its root nodes. Kudzu's large leaves shade out other plants; and where it grows it dominates other vegetation, usually to complete exclusion; but in winter it loses its leaves, making the ground bare and exposed except for the vines. Were kudzu planted on the roadsides and railroad right of ways where Argentine hemorrhagic fever is found, over the course of several years a reduction in the rodent populations might occur—since grass and weeds would be replaced by this dominant plant, which in winter offers neither food nor cover for the rodents. The possibility that kudzu might become a serious weed in this area is remote, since the plant is a favored food of livestock and thus could not successfully invade pastures; nor does it tolerate plowing, curtailing its ability to invade lands planted with corn or other crops. It would probably cover wire fences, a small problem that is readily controlled with herbicide.

Plant and Animal Indicators of Environmental Contamination

The possibility of using pet dogs as sentinels for carcinogenic substances that have escaped from industrial sites into the environment has been mentioned earlier. In this vein, many other animals and some plants are useful sentinels of air contamination and water pollution. Living organisms are also used as sensitive indicators of toxic substances. The practice of employing canaries to detect the presence of gas in mines is well-known, and today many other creatures are used to screen for toxic substances before specific identification is carried out in an analytical laboratory. While water samples to be tested are usually taken to a laboratory where fish or amphibians or their eggs are exposed to determine possible toxicity, it is likewise feasible to place test organisms in the suspect environment (for example, by placing lichens in areas with possible air contamination). Such strategies can reduce the cost of laboratory analyses by eliminating negative sampling, and the extent of sampling may also be increased, so that a larger area is tested over a relatively long period of time.

Concluding Remarks

There is a justifiable tendency to think of environmental health problems in terms of chemical contamination of water, air, and food. Nevertheless, a continuing build-up of reservoir host and vector populations of important human diseases may pose a potentially greater environmental threat. This increase in certain hosts and vectors is a result of man's continuing modification and simplification of the environment, activity that leads to an intentionally reduced number of species.

For example, most agriculture is designed to reduce the number of plant species to those producing the desired crop; the rest are weeds. Likewise, the conversion of a forest to agricultural land eliminates the forest-dwelling animal species, while favoring other species better adapted to the new conditions. Thus, throughout Latin America there are increasing problems with huge numbers of certain species. The irrigated regions along the Rio Negro in Argentina are plagued with the burrowing parrot *(Cyanoliseus patagonus)*, which continues increasing in numbers despite costly and largely ineffective control programs. In southeastern Bolivia the black-hooded parakeet *(Nandayus nenday)* and throughout a wide area of southern South America the monk parakeet *(Myiopsitta monachus)* are especially abundant in irrigated regions and are becoming more abundant every year. The rice fields south of Corrientes, Argentina, which are infested with rats *(Holochilus brasiliensis)* support plague-like population levels of certain birds, particularly the bobolink *(Dolichonyx orzivorus)* and the shiny cowbird *(Molothrus bonariensis)*, the latter also being a problem in Bolivian and Venezuelan grain-fields.

In all of the regions mentioned there have been repeated outbreaks of eastern or western equine encephalitis, including significant numbers of human cases. These diseases depend on wild birds as reservoir hosts. Furthermore, a previously unknown arbovirus disease, described as being second in importance only to jungle yellow fever, recently appeared on the coast of São Paulo, Brazil *(25)*. The area is extensively irrigated and supports large bird populations, which serve as the reservoir hosts of this disease. The responsible agent (rocio virus) is related to the St. Louis encephalitis (SLE) virus mentioned previously. SLE is also found throughout South America, where increasing urban populations of sparrows and pigeons pose a serious threat as potential hosts of epidemics such as occur in the southeastern United States.

As with birds, certain mammals (especially certain rodents) are favored by man's development activities. Plagues of rodents often infest irrigated fields of rice or sugar cane. Dense populations of this kind have been observed over wide areas, including the previously mentioned rice fields south of Corrientes, Argentina, and rice fields near Calabozo, Venezuela, where extensive fences of metal sheeting are placed around the fields to protect them from invasion by rats *(Holochilus brasiliensis)*. Sugarcane fields near Tucumán, Argentina, and throughout the Caribbean are also infested with rodents, usually *Rattus norvegicus*. This latter species, so abundant in the cities, also regularly invades the rural highlands of Mexico, where its numbers require extensive control efforts.

The ability of rodents to serve as reservoirs of important diseases such as plague poses an ongoing threat that needs to be taken seriously. Attempting to control rodent populations with massive applications of rodenticides is as useless as trying to control insect disease vectors with massive applications of insecticides, and for the same reasons. Like insects, the rodents are developing resistance to pesticides, and a switch to new and slightly different agents is merely postponing the inevitable need to resort to other control measures. Hence, greater efforts must be made to improve our understanding of the target species' ecology and behavior, so that we can obtain the information needed to apply ecological strategies that will keep their numbers at acceptable levels.

SUMMARY

Ecological strategies have been characterized as strategies that use knowledge of an organism's ecology and behavior to achieve goals with greater efficiency and effectiveness than might be achieved through more direct traditional methods. Such strategies, whether or not of a health-related nature, should entail costs that are within the means of the country or countries involved.

In general, health-related ecological strategies may be applied to (1) detect or predict potential problems before they affect human health, (2) prevent potential health problems, and (3) combat existing health problems. This article briefly describes examples of all three types of strategies. Those mentioned in the "detection or prediction" category include use of wild birds to monitor St. Louis encephalitis virus; use of hamsters, monkeys, and dogs as disease sentinels; and use of absent or reduced populations of common species as evidence of possible environmental contamination. Those in the category of preventive strategies include employment of residual insecticides to prevent transmission of disease agents, management of habitats to control rodent populations, release of sterile male insects to reduce vector insect populations, variation of water levels to combat vector snails and mosquito larvae, and replacement of schistosomiasis snail vectors with competitive nonvector snail species. And, finally, cited ecological strategies to combat existing problems include use of a "fire-break" technique to stop rabies epizootics in vampire bat populations, automatically regulated control of mosquito larvae with *Gambusia affinis,* and treatment of contaminated water with floating plants.

Possible future strategies are also noted. Among these are dissemination of nonpathogenic encephalitis viruses to replace pathogenic types, introduction of carnivorous water plants to control certain stages of the schistosome life-cycle, chemosterilization to reduce stray dog populations capable of maintaining urban rabies, introduction of kudzu to reduce the food and shelter afforded by rodent habitats, and placement of indicator organisms in areas of suspected or potential contamination in order to detect such contamination. In general, it is suggested that such ecological strategies will become increasingly complex and increasingly important as target organisms become increasingly resistant to other types of control measures.

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TUBERCULOSIS IN THE UNITED STATES

During 1981, a total of 27,373 cases of tuberculosis were reported to the United States Centers for Disease Control (CDC). The corresponding case rate was 11.9 per 100,000 population. Overall, there was an apparent 1.4 per cent decline in the number of cases reported, as compared to 1980.

Case rates for the 50 states ranged from 20.1 per 100,000 in Alaska to 1.1 per 100,000 in Idaho. Case rates were higher in the southern half of the country and in the major cities. In 56 cities with populations exceeding 250,000, the rate was 23.3 per 100,000 population—twice the national rate. Miami, Florida, had a rate of 87.0 cases per 100,000 in 1981, the highest rate observed for any major city since 1977.

Note: During the past three years, no substantial decline has occurred in the number of tuberculosis cases in the United States. From 1968 through 1978, the number of reported cases decreased by an average of 5.6 per cent per year; but during the past three years (1978-1981) the average decline has been only 1.4 per cent per year.

Surveys show that cases among newly arrived Indochinese refugees largely accounted for the leveling off of the decline during 1979 and 1980. A similar survey has not been done for 1981, but based on data from 14 states and two large cities, it is estimated that Indochinese refugees accounted for fewer cases in 1981 than in 1980. This is consistent with the fact that fewer refugees arrived in 1981 (121,959) than in 1980 (155,158). The number of cases among other persons in the United States apparently increased slightly, from 25,569 to 25,841. There is no evidence that this slight increase has been caused by transmission from the Indochinese refugees.

Sources: World Health Organization, *WHO Epidemiological Record* 57(45):351, 1982; and US Centers for Disease Control, *Morbidity and Mortality* 31(32), 1982.