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ABSTRACT: Capitalizing on research directed toward oral contraceptives for humans, a wide variety of compounds are now under study for their practical value in inhibiting rodent reproduction to suppress detrimental populations. This paper discusses the specifications of ideal rodent chemosterilants and the advantages of chemosterilants over other methods of control, and compares the potential values of chemosterilants acting on females, males, and both sexes. Specific situations are detailed where chemosterilants will be most valuable in rodent control, together with proposed methods of application. Chemosterilants are not expected to become a panacea for control, but since they are based on sound biological principles they should be a safe and effective approach to regulation of rodent populations.

Recent years have seen considerable enthusiasm over the possible use of chemosterilants for suppressing population levels of troublesome rodents. Interest in this approach has existed for a long time, but a major surge of interest has developed in the United States during the last few years. This interest has been stimulated in part by chemical and pharmaceutical companies, which have recently expanded their research on potential chemosterilants.

Since a variety of specific descriptive terms are sometimes used — such as antifertility agents, spermatocides, embryocides, and gametocides — confusion might be avoided if we adopt the all-inclusive term "chemosterilant." A chemosterilant can be defined as a chemical that can cause permanent or temporary sterility in either or both sexes or, through some other physiological aspect, reduce the number of offspring or alter the fecundity of the offspring produced. This definition, thus, does not define the mechanism or the specific phase in which the compound operates; it simply classifies the compound on the basis of its biological effect.

Researchers in the United States and elsewhere are currently evaluating chemosterilants in both laboratory and field. There is little indication, however, that chemosterilants are currently being used in normal or routine rodent control practices. There is a multitude of information on compounds that affect various aspects of mammalian reproduction, and in many of these studies the test animals were laboratory rodents. The purposes of most of these studies range from contributing to basic knowledge of physiological mechanisms to studying the effects of drugs destined for human contraceptives; but, even though they are not oriented toward regulating naturally occurring rodent populations, they do provide information of enormous value in the selection of candidate chemosterilants for rodent control purposes. In this respect, vertebrate pest control has and will benefit immensely from the intensive search now under way for contraceptives for humans.

Credit for the concept of sterilization of insects goes to Dr. E. F. Knipling, who proposed it in 1938 (Smith, 1966). About two decades later, after many years of research, the concept was applied to eradication of the screwworm, Cochliomyia hominivorax (Cqrl.), a serious pest of livestock in southeastern United States. We would hope that rodent chemosterilants will become a practicality much more quickly, although, realistically, they will not be found and proven effective without considerable effort and expense.

The concept of regulating reproduction in rodents and other wild mammals has been discussed by Knipling (1959) and Davis (1961). In the United States, Davis conducted one of the earliest studies of this approach to rodent control-- in 1957-58 on a rat population in the city of Baltimore. The results, though promising, were inconclusive, and the studies were terminated for other reasons (Davis, 1961). This approach to rodent control has received greater attention more recently (Balser, 1964b; Brooks and Bowerman, 1969; Howard, 1967a, 1967b, 1968; Howard and Marsh, 1969; Marsh and Howard, 1969; Pingale et al., 1967; Skinner, 1968; Srivastava, I966; Wetherbee, 1964).

Research on chemosterilants is further along for the suppression of pest birds than for rodent control. This approach to regulating pest species of birds has been reported on by Davis (1959), Elder (1964), Vandenbergh and Davis (1962), Wetherbee (1964, I967), and others. Balser (1964a, 1964b), Linhart (1963, 1964), Linhart et al., (I968), and Linhart and Enders (1964) studied the possibilities of chemosterilants for several predator species, but the technique is not yet in general use.

Much more is known about the physiological capabilities of prospective chemosterilants than the ecological aspects of their use in rodent control, and, of course, their efficacy must ultimately be ascertained in the ecological niches occupied by the target species. The wide ecological tolerances and adaptive characteristics of most species of rodent pests makes any thorough study of a chemosterilant complex. The efficacy of chemosterilants will depend more on our knowledge about the biology and ecology of a rodent species than is presently necessary for effective use of lethal rodenticides.

There are many ways in which chemical agents can interfere with the physiological events of reproduction. "Interference with reproduction may take the form of direct or indirect damage to the developing or mature gametes prior to copulation, or after this event but before fertilization. The union of sperm and ovum may be prevented or the fertilized ovum may be hindered during the process of implantation into the uterus. Finally, the implanted embryo may be the focus of chemical attack in various ways at different stages of its development" (Jackson, 1959). Neonatal interference with sexual development in the offspring, causing irreversible sterility, or other chemically-induced factors that cause mortality by reduced lactation or abnormalities in the young, would all suppress populations. Compounds that might produce mutagenic effects decreasing fertility or increasing early mortality or subsequent offspring should also be studied as potential chemosterilants. Compounds should be sought that will inhibit the production of sexual pheromones, for an animal lacking this basic means of communication might not elicit typical sexual responses from the opposite sex. Significant reproductive inhibition could be expected from what is known about rodent pheromones, produced by some animals to induce one or more specific responses within members of the same species (Whitten, 1965).

Ideally, chemosterilants should possess some degree of specificity, be effective orally, and affect both sexes, or at least the females. Least desirable are those which affect only males. Compounds producing permanent sterility in a single feeding are more desirable than those which cause temporary sterility or affect only some post-copulatory phase. Compounds that must be consumed over several days before they are effective create application problems, although not always insurmountable ones. Likewise, compounds that fail to produce permanent sterility necessitate repeated exposures.

Prospective chemosterilants should not cause satiation or an immediate loss of appetite. As a general rule, there needs to be a wide margin between effective and lethal doses of chemosterilants. They should not produce a discomfort or ill feeling that might disrupt their feeding or influence bait acceptance later. The chemosterilant should not unfavorably alter libido or aggressive and territorial behavior. The action of chemosterilants should not be influenced by diet or previous nutritional deficiencies of the subject nor by environmental extremes in temperature or humidity.

Prospective chemosterilants should be easy to formulate into baits and, when in use, should remain biologically active for the required exposure period. Prepared bait must have a shelf life adequate for marketing channels. If the compound is not species-specific, it should break down in the body of the target animal into inactive components, avoiding secondary sterility or toxicity hazards. The target species must not be able to develop genetic tolerance and acquired resistance to the chemosterilant. Last of all, chemosterilants must be economical to use.

Obviously, no compound will meet all the suggested specifications, and ways of compensating for certain undesirable characteristics will have to be developed.

In the search for effective chemosterilants it seems advantageous to place emphasis on the female rather than the male. There is no evidence that the sterile-male approach, so successful in the control of certain insects, can be achieved in rodents. The idea of releasing large numbers of sterile individuals into an already troublesome or health-menacing population of vertebrate pests is not readily acceptable to people and, of course, is economically impractical even if the species would eventually respond to this approach. Although Knipling (1959) postulated the use of sterile males with vertebrate pests, to our knowledge the idea was never tested in natural conditions. He did point out that his theoretical models would not be valid for polygamous species. Unlike the sterile-male approach to insect control, reproduction in polygamous rodents, which also breed several times in a year, creates the mathematical probability that a relatively few nonsterile males can compete successfully for females against an overwhelming number of sterile males. Sterile male rats can have a greater influence in reducing the biotic potential of a population than elimination of the same number of males by poison, because female rats go through pseudopregnancy if mated with sterile males. The occurrence of pseudopregnancies and competition by sterile males for mates lends some (although weak) support to the sterile-male approach, but a given percentage of sterile male rats will not have anywhere near the same inhibiting effect on the number of offspring produced that would occur with a similar percentage of sterile females. If both sexes are sterilized, however, the results will be compounded, with reproductive rate decreased below that achievable when just the males or females are sterilized.

Monro (1963) suggested that harmful animals might be controlled by overloading a population with enough sterile individuals to cause a population crash. Calhoun (1948) conducted tests on the creation of an artificially supersaturated population of Norway rats (Rattus norvegicus). The mortality of the introduced rats was extremely high, though, which would reduce the feasibility of such an approach.

One similar, though more practical, approach which has not been adequately considered is that of increasing the fertility of rodents by chemical means (fertility compounds), thus overloading a population and causing it to crash, as occurs naturally in species like meadow mice (Microtus spp.). This approach might be practical with certain species under specific conditions, but not for most situations. From present knowledge of rodent behavior, animals born into the population have a greater competitive effect on the existing population than the same number of animals released into an already established rodent population. Thus, a chemically induced increase in fertility as a means of overloading a population is biologically more sound than overloading a population artificially by introducing animals trapped from other areas.

The possibility has been suggested of introducing into wild populations rodents that will transmit lethal genes or genetically produce sterile offspring. The theories involved have not to our knowledge been put into practice. Considerable research will be needed to determine the validity of such approaches.

These approaches are much more complex than is the use of chemosterilants. It is impossible to speculate with any certainty as to which specific compounds will eventually be utilized as rodent chemosterilants; therefore, it seems irrelevant at this time to detail the physiological action of the many candidate chemosterilants. We will, therefore, mention a few that are undergoing study and discuss the general categories of potential compounds to provide some basis for understanding their possible use and methods of application.

Several nonsteroid compounds, such as clomiphene and transclomiphene, are presently being evaluated, although steroid hormones have been explored to a greater extent. Both estrogens and androgens can be used as reproductive inhibitors. Several potent synthetic steroids, e.g., mestranol, quinestrol, and diethylstilbestrol, possess some desirable qualities as potential chemosterilants. Of particular concern with the hormonal compounds is that their efficacy in the rodent community might well be influenced by unfavorable behavioral changes induced by the treatment, e.g., increasing social tolerances or creating a high percentage of nomad individuals might prove self-defeating. An effective sterilant should not unfavorably alter libido nor upset social hierarchies, territoriality, or other behavioral traits. A chemosterilant that creates submissive or subdued individuals in the population might permit the population to increase to an abnormal density if only part of the population received the treatment.

Since the gestation period in rodents is short and offspring are born relatively undeveloped, treatment with sex steroids just before or soon after birth can create irreversible sterility. Mestranol, for example, when obtained via the mother's milk within the first few days of life, will produce sterility in both sexes (Howard and Marsh, 1969). It seems doubtful that this aspect by itself can be capitalized upon as a means of creating a high number of sterile individuals in a population. Some steroidal compounds, while orally effective on rodents, may be far too expensive for control purposes (Skinner, 1968). From the economic point, nonsteroidal compounds may be more rewarding.

A number of steroidal or nonsteroidal compounds are capable of interrupting postcopulatory events, i.e., inhibit implantation or act as abortifacients and in other ways. Most generally these compounds must be available to the rodents immediately after insemination or early during gestation, which requires precise timing of application, unless application methods can be utilized whereby the compound is continuously available to the rodent population throughout the breeding period. In light of existing knowledge of endocrine control and duration of spermatogenesis (Jackson, 1959), the hormonal approach of creating male steri11ty-does not seem very promising in the adult male.

The alkylating agents seem to offer great possibilities for sterilizing male rats, although the biological activity of alkylating agents is by no means restricted to males alone. The nitrogen mustard compounds may be rewarding for vertebrate pest control, although their toxicity makes them of little value as human contraceptives. The most interesting antispermatogenic compounds are the alkylating agents, represented by the ethyleneimine and methanesulfonate derivatives. They are being studied extensively (Skinner, 1968).

Familiar ethyleneinine derivatives are triethylenemelamine (TEM) and triethylenethiophosphoramide (thio-TEPA). Myleran, one of the methanesulfonate group, well known in cancer chemotherapy, which produces an inhibition of spermatogonial development in the male rat, does not affect the fertility of female rats at the same oral dose (10 mg/kg). If it is given to pregnant rats 5 to 6 days before term, however, sterile offspring of both sexes result (Skinner, 1968). Brooks and Bowerman (1969) speculated (though this has not been confirmed) that the alkylating agent TEM might be the active ingredient of Glyzophrol, a commercial rodenticide presently marketed in Europe, that has both lethal and sterilizing capabilities. To what extent this product is being used in routine rodent control is presently unknown. Because of its lethal qualities, Glyzophrol must be considered more of a toxicant than a chemosterilant.

Nitrofuranes, e.g., Furacin, Furadantin, and related compounds, have been reported to interfere with spermatogenesis. Srivastava (1966) studied Furadantin with bandicoot rats (Bandicota bengalensls) and recommended its use along with colchicine for field rodent control. Alkylating agents are reported to be quite diverse in their biological activities (Skinner, 1968), which also increased the likelihood of finding a compound with considerable specificity.

Colchicine, a rather toxic alkaloid substance found in a number of the Liliaceae family, is frequently used in plant genetics and for medicinal purposes. According to Srivastava (1966), it is a valuable female chemosterilant for bandicoot rats. Certainly more study is needed on both Furadantin and colchicine. Other compounds of botanical origin or synthesized counterparts are known to inhibit reproduction, and some may have potential value as rodent chemosterilants. Naturally occurring compounds from plants may prove to be far less expensive than some of the synthesized ones, though their efficacy must be proven first.

A highly effective male sterilant, U-5897 (3-chloro-l,2-propanediol), is currently being developed by the Upjohn Company. Research on their compound is being conducted in several parts of the country. In mature Norway rats (Rattus norvegicus) this chlorohydrin compound causes epididymal lesions, creating permanent sterility in a single feeding (Ericsson [in press], Ericsson and Connor, 1969). It appears that the lesion producing action of this compound is limited to certain rodent species, while temporary sterility may be produced in a greater variety of mammals. Of the male chemosterilants known to us, this compound shows the greatest promise for rats.

Dose levels, the number of consecutive dosages, and the reproductive state of the animal may determine the biological activity of candidate compounds to produce either irreversible sterility or various degrees of temporary sterility. A compound may inhibit implantation at one period or dose level, and at another stage of gestation be an abortifacient or induce sterile offspring. An impressive number of compounds have reproduction-inhibiting or chemosterilant qualities. When these compounds are judged by the requirements of a desirable rodent chemosterilant, however, the list will narrow considerably.

To quote Howard (1967b), "Vertebrate pest control is applied ecology, i.e., it is the management of the behavior of individual animals and the regulation of population levels — not the destruction of individuals. All animal control must be based on a prudent translation of the ecological laws of nature into an effective management policy." A lack of adequate diversified and specific tools and methods presently prevents us from practicing programs known to be ecologically sound. Destruction of rats by artificial means such as trapping, poisoning, etc., where the habitat remains unchanged, may have only a temporary effect. Frequently, such populations quickly recover to levels equaling or exceeding the densities which existed before control. This population resurgence, sometimes referred to as Errington's (1945) inverse-density law, has been demonstrated in the field many times, as illustrated by two more recent studies (Batcheler, 1968; Rowley, I968).

Populations of rats and other prolific rodent species have a very steep growth curve, the classic sigmoid curve. Artificially destroying great numbers of individual animals, with poison or other methods, to push them off the plateau onto the precipitous slope is of little value unless there is some means of preventing or slowing recovery (Howard, 1967b). This is where chemosterilants could play a major role.

When reproduction can be suppressed economically, this procedure is far superior to attempts to regulate population densities by increasing one or more mortality factors. As Balser (196Ab) pointed out, "It may be more practical to prevent animals from being born than to reduce their numbers after they are partially or fully grown and established in a secureenvironment."

Following conventional reductional control procedures with poisons or traps, two factors tend to compensate for deaths: 1) reproduction by those that survive; and 2) immigration -- a movement of rodents into the treated area. It is recognized that small voids in the population created by removing appreciable numbers of animals through poisoning or trapping may be filled with immigrants from the surrounding untreated area. This is of greatest significance when the density of the population is high at the time the control is instigated. This density, of course, depends on the carrying capacity, competition, and species involved. That is why rat control campaigns, for example, are best conducted over large areas, delineating the area with natural barriers whenever possible.

Control programs encompassing large areas tend to reduce the importance of immigration, at least initially, since it will occur for the most part only on the periphery of the control area. Enlarging the areas under control increases the time required to repopulate them from outside sources. This same principle (treatment of large areas) should be applied with chemosterilants.

If used alone, chemosterilants would not create immediate voids, and the population would be reduced over a period as a result of natural mortality surpassing natality. Thus, the infiltration of nonsterile immigrants would be gradual, though not without significance. Most evidence suggests that immigration of adult rodents is uncommon; young adults usually fill the voids.

Chemosterilants that produce temporary sterility or are short-term in effects will necessarily be used with great regularity to avoid nullification by the compensation principle. On the other hand, individuals that are permanently sterilized will contribute nothing to reproduction but will remain in the population to compete for space, food, and shelter.

It is anticipated that some day there will be an assortment of chemosterilants to use, just as we have a variety of rodenticides today. The chemosterilant will be selected with the characteristics or biological activity most suitable for a particular situation, taking into account safeness, effectiveness, duration of action, and so forth. As our methodology advances we begin to move away from general recommendations and approach a time when preventive or corrective measures will be prescribed for each and every vertebrate pest problem.

No single chemosterilant will fit all needs, any more than one lethal rodenticide is useful in all situations. For example, antifertility agents specific to a given species may be highly desirable in some situations but not in cases where several species occupy an ecological niche and must be controlled. Likewise, a nonspecific compound causing permanent sterility when consumed once may be ideal for rat control in sewers but not appropriate for rodent control in food crops. The method of use of chemosterilants can contribute greatly to their degree of selectivity even if they are not themselves nonspecific.

Chemosterilants alone will not reduce rodent populations immediately, but without adequate reproduction the population will gradually decline through natural mortality. It is theorized that their use will permit populations to be regulated with greater precision, and populations might then be reduced to slightly below the economic damage threshold and kept there.

The physiological action of acute toxic rodenticides frequently causes an animal to cease feeding before a lethal dose has been consumed. The rodent then may reject such bait thereafter, becoming "bait-shy". Since problems relating to poison-bait shyness are not easily overcome, this phenomenon decreases the effectiveness of successive treatments. The physiological action of some chemosterilants, even if slightly distressing to the rodent, may be sufficiently delayed that bait shyness will not occur, just as they are absent in some of the chronic rodenticides, such as anticoagulants. This suggests that it may be possible to get effective doses of palatable chemosterilants into a greater percentage of a rodent population than might be possible with acute rodenticides. Chemosterilants that are poorly accepted initially or in subsequent exposures of the bait will be of little value. If taste or odor is the causative factors, however, some means of masking or overcoming these objectionable aspects may be possible, although we are not aware of any masking agent used successfully in this manner. Presently, one of the major stumbling blocks to finding suitable chemosterilants is the problem of bait acceptance, particularly where the compound must be consumed over several successive days or at intervals before it is effective.

One of the distinct advantages of many chemosterilants is that their selectivity and manner of use presents little hazard to humans, pets, domestic stock, or nontarget wildlife, compared to some rodenticides now used. In regions where illiteracy is high, any nonlethal means of reducing detrimental rodent populations will contribute greatly to the safety of the populace. There are many spots in the world today where serious efforts at control of rodent populations are hampered because of the hazards associated with acute rodenticides. Thus, it is no wonder that those responsible for rodent control are looking to chemosterilants with great anticipation.

Chemosterilants are more compatible with certain religious philosophies and philosophies of protectionists or preservationists than are many other methods of regulating rodent populations. In countries where some of the more common rodenticides have been legislated out of use for so-called "humane" reasons, the chemosterilants will increase the available materials for control. From the "humanitarian" aspect, antifertility agents rate very favorably since populations are regulated by preventing birth rather than by destroying animals. Certainly such an approach is more acceptable to everyone, especially those with strong convictions against killing animals. Opponents of pesticides in general view the use of nonlethal agents for pest control with considerably less alarm.

There has long been interest in finding and developing species-specific rodenticides or at least those specific to rodents alone. The toxicant norbormide, developed a few years ago, in some ways approached the ideal by being nearly specific to the genus Rattus. Developing chemosterilants that are specific or nearly so may be less difficult. This optimism can be attributed to the reproductive differences in the animal kingdom and to complex physiological events culminating in the production of mammalian offspring. Early experimentation supports a degree of specificity for several potential chemosterilants. For example, mestranol, a potential chemosterilant used in early studies, has shown a wide range of effective doses within the rodent family, with rats (Rattus) highly susceptible, and the house mouse (Hus musculus) very low in susceptibility. Effects on jack rabbits (Lepus californicus) were not measurable under field conditions (Howard and Marsh, unpublished). The male sterilant, U-5897, presently under study, produces permanent sterility in males of certain rodent species but apparently not in others.

Community rat-control programs, involving systematic control efforts over extensive areas, frequently lose continuity of complete coverage because, for some reason, toxic agents cannot be used safely within a portion of the area under the program. Such islands of rats, left unchecked, hasten reinfestation of surrounding rat-free areas. Chemosterilants could resolve this problem.

A frequent question asked by the layman concerning chemosterilants is that if you must bait them to achieve control then why not poison them? As was pointed out earlier, if a control program using poisons does not reduce the number of rodents to a very low level, the success of the control will be short-lived and the population will quickly recover. Since many of the values of chemosterilants are too subtle for ready demonstration, it is not always easy to convince people of their advantages. As with most new approaches to control, the public must be adequately informed through educational programs.

More easily understood and accepted than the use of chemosterilants alone are integrated programs that use poisons for initial reduction of rodent populations, followed by chemosterilants to keep the population down. The initial satisfaction of seeing dead rats is at least psychologically convincing that control is being achieved. Such conviction is not forthcoming where a chemosterilant is used alone, although, on the positive side, the absence of numerous dead rats eliminates the nuisance and odor of putrefying carcasses.

There will probably always be some merit to the statement "kill the rodents," for in some situations it will be more prudent to remove rats with a toxicant or traps than to rely on chemosterilants. Where rats are an immediate threat to public health, for example, we may not be able to tolerate a single rat in a dwelling. In these situations chemosterilants will be nearly valueless. In a food-handling or processing establishment, under threat of legal action through condemnation or forced closure for failure to maintain the premises free of rats, even sterile individuals could not be tolerated until they die of natural causes. A population of rats, even if primarily sterile individuals, will still continue to cause damage, inflict bites, transmit diseases, and contaminate foodstuffs.

We do not expect chemosterilants to be of primary value in maintaining "Rat-Free Cities", as are now being established in parts of Europe, since control with lethal agents keeps the population suppressed well below even the most optimistic level hoped for through the use of chemosterilants. Antifertility agents might be useful in the early phases of establishing a rat-free area, especially in reducing the population in adjacent areas to prevent reinvasion.

Chemosterilants may be useful in suppressing rodent populations that are implicated in endemic sylvatic plague and other diseases. For example, they would be useful in suppressing diseased populations of ground squirrels (Spermophilus spp.) living in close proximity to dense populations of humans. It is generally accepted that the reduction in density of endemic rodents, the reservoir of infection, is followed by a decrease in plague potential, and such control may in some situations eliminate the natural food of some diseases. Native and alien rodents which are implicated in transmitting disease to man can sometimes be tolerated in the wild in relatively low numbers; only when they become extremely abundant do health hazards become critical. Aside from the fact that chemosterilants can be important in regulating disease-bearing rodent populations, it is also fortunate that they permit this to be done without destroying great numbers of rodents. This means that, unlike with lethal rodenticides, there will be no sudden appearance in the environment of fleas, mites, and ticks that have abandoned poisoned rodents. Such release of ectoparasites increases the risk that the vectors will further spread the rodent-borne diseases, necessitating additional treatments for control of ectoparasites.

Chemosterilants will be a welcome measure for countering anticoagulant-resistant rodent populations. Resistance, as experienced in several countries, might theoretically be held in check in rural or farm areas by offering anticoagulants and chemosterilants on an alternate basis or in combination. Intense use of any rodenticide increases the likelihood that resistance will develop; integrated control practices incorporating a chemosterilant would reduce the likelihood.

It is visualized that chemosterilants will be most useful in controlling rodent populations on rangelands and in crop-producing and wildland areas. They will also be valuable for rodent control along waterfronts, on the banks of canals and rivers, in sewer systems, warehouses, garbage or refuse dumps, and other situations where a few rats can be tolerated or where total elimination of the population is economically unattainable by other means or, for some reason, undesirable.

Chemosterilants will be exposed to rodent populations in the same manner as lethal rodenticides, with baits the primary method. Water baits and wet or dry baits of cereals, fruits, meats, etc., will be effective; dry baits, however, lend themselves to a wider range of application methods. Compounds that require several successive feedings to be effective can be exposed at bait stations, as are anticoagulant rodenticides. In sewer systems, semi-permanent bait blocks may be the ideal method of exposure. Depending on the characteristics of the chemosterilant, prebaiting may not be necessary to achieve good acceptance. Tracking dusts, another effective means of getting a chemosterilant to rodents are particularly useful with compounds that are not readily accepted in bait form.

Certain chemosterilants, to be effective, will have to be ingested at precise times in relation to breeding; furthermore, they may necessitate repeated applications at very exacting intervals. A rat control program relying on chemosterilants alone, if poorly planned, will certainly fail, having even less impact than would a poor poisoning program. In an integrated program, with poisoning preceding antifertility agents, failure of the latter would have no bearing on the initial control through poisoning, although the synergistic effect of the two in sequence would be lost. The results of a poisoning program are relatively easy to ascertain, whereas the efficacy of an antifertility agent shortly after it has been applied is much more difficult to determine. Procedures for analyzing the results are dictated by the mode of action of the chemosterilant used. The dependence of efficacy on rodent density is presently unknown, but its significance may be major.

Theoretical mathematical models of rodent populations under the influence of chemosterilants will be helpful in determining results; however, we must have effective chemosterilants and know their complete role in reproduction before conceptual models can be developed and tested for validity.

Obtaining maximum value from any antifertility agent will require a thorough knowledge of the pest species and of the compound utilized. Adequate technical training must be provided those responsible for establishing and directing rodent control programs that use chemosterilants.

A basic handicap in the development of avian chemosterilants is the lack of suitable mechanics for dispensing treated baits to the pest population. Those involved in control of pest birds with lethal agents can attest that failures are attributed most frequently to the fact that too few birds consume the bait for it to be effective. While it may not be necessary to affect as great a percentage of the population with chemosterilants as with a toxic substance, the mechanics of application are nonetheless a major problem yet unsolved. It is felt that the development of rodent chemosterilants should be correlated with concomitant research in application methods. The necessity for adequate application techniques has been well emphasized by those attempting to utilize chemosterilants for pest birds and mammalian predators. Some problems are evident in the mechanics of offering chemosterilants to rodents, but it is anticipated that these can be resolved. Since the hazards associated with chemosterilants are minute compared with those with lethal rodenticides, it is possible that revolutionary approaches to application may be forthcoming. Mechanical bait applicators mounted on vehicles or backpack units may be utilized extensively. Aerial baiting will become increasingly valuable as selective chemosterilants are developed. This will be especially useful where rodent control is attempted over large acreages (Marsh, 1968). Techniques of application must be expedient and efficient since the effectiveness of chemosterilants, depending on their particular biological action, may rely heavily on both precise timing and thoroughness of application.

In summarizing, it should be emphasized that chemosterilants for regulating rodent populations are in the initial stages of development, and only after much intensified research will they fulfill our awaiting needs. Greater insight into rodent chemosterilants and their efficacy in the environment must be attained before we can employ them in rodent control practices. Most encouraging, however, is the current development of information on all aspects of rodent chemosterilants, especially practical application. This relatively new approach to a safer and more effective rodent control, while no panacea, will greatly broaden our present technology. Perhaps the greatest importance of chemosterilants is that they will reduce the need for lethal rodenticides, an especially worthy goal now that concern over environmental contamination is at an all-time high. Chemosterilants will change the emphasis from increased mortality to reduced natality for regulating population densities. This is supported by sound biological principles.

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