Sterile-Male Method of Population Control

Successful with some insects, the method may also be effective when applied to other noxious animals.

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Laboratory investigations (*1*) followed by the successful eradication of the screwworm (*Callitroga hominivorax*) from the island of Curaçao (*2*) have established the value of utilizing induced sexual sterility as a means of regulating insect populations. Progress in the eradication program currently under way in Florida and other southeastern states under the sponsorship of the U.S. Department of Agriculture and the Florida Livestock Board is further confirmation of the soundness of this approach for the control of this pest of livestock.

I have previously discussed the principle involved in control or elimination of an insect species through the release of a dominant population of sexually sterile males (*3*). The purpose of this article is to consider further possibilities of controlling insect and other animal populations through application of the same principle. It is hoped that such discussion will stimulate research leading to broader application of this technique for use against insects and possibly for regulating or for eliminating from problem areas undesirable populations of higher animals, such as rodents, predators, and other wild animals.

These possibilities are based on the following biological principle: The introduction of sexually sterile but otherwise sexually vigorous males, and to a lesser extent females, into the natural population of an animal species will have greater influence in reducing the biotic potential of the population than elimination of the same number of individuals from the population by destruction or removal.

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If this is a valid biological principle, then biologists concerned with the regulation of animal populations might find it profitable to devote considerable research effort to the development of practical procedures for introducing substantial numbers of sexually sterile males of a species into the population rather than to devote all efforts to the development of ways to kill the organisms. The relative effectiveness of the two procedures will depend on a number of factors, including the mating and dispersal habits of the species. Many obstacles to practical application of the sterile-male technique may limit its usefulness. However, full exploration of the method may lead to broader application than is apparent with current knowledge.

Theoretically, the maximum degree of reduction in the biotic potential of the total population of an organism is directly proportional to the ratio of sterile to fertile males. The degree of control that can actually be achieved probably will vary with the species and may fall well below the theoretical maximum because of the many factors involved. However, the potential effect, provided that normal sexual behavior is retained in the males, is much greater than when the conventional procedure of animal population control is followed. This can be shown to be the case even when the effectiveness of the sterile males is well below the theoretical maximum.

Insect Populations

To illustrate the possibilities of the sterile-male method I have established certain hypothetical conditions. On the basis of these conditions, I have calculated the theoretical maximum effect on the populations of insect and other animal species when they are treated in different ways for the introduction of the sterility factor. Research to develop effective and economical ways of achieving a high level of male sterility in natural populations would greatly extend the application of the procedure for pest control. Thus far, the rearing and release of a dominant number of irradiated insects is the only method that has been employed. If a chemical or other satisfactory method of causing high sexual sterility could be developed which could be applied to the natural populations of certain insects, it would not be necessary to rear and release insects, as is now done for screwworm eradication.

The effect of procedures that cause the desired type of sexual sterility in an insect population, in comparison with those that kill the same number of individuals, is indicated in Table 1. The following assumptions are made in this hypothetical model. (i) The female is monogamous in mating habit, and each sterile male in the population is fully competitive with normal fertile males in mating with the normal females. (ii) The sterilizing agent or procedure will induce sexual sterility in 90 percent of the males and females of each generation, and the killing agent will kill 90 percent of both sexes in each generation. (iii) The biotic rate of increase in an untreated population is fivefold in each generation, and the survivors in the two treated populations increase at the same rate. The potentially greater effect of the sterility approach is readily apparent from the figures in the table.

As shown in Table 2, inducing sexual sterility in the natural population by chemicals or other means is even more effective than rearing the insect and releasing a dominant number of gamma-irradiated males, the procedure used for screwworm eradication.

Theoretically, the effects of a treatment that induces sterility in 90 percent of the natural population is much more marked in the first generation than the effect of releasing enough sterile males

Table 1. Theoretical population trends of an insect species subjected to no treatment and to a chemical or other treatment that affects 90 percent of the population (i) by killing and (ii) by sexual sterilization.

Generation	No treatment	Treatment that kills	Treatment that induces sterility
Parent	1,000,000	1,000,000	1,000,000
F_1	5,000,000	500,000	50,000
F_2	25,000,000	250,000	2,500
F_3	125,000,000	125,000	125

Table 2. Theoretical effect on an insect population of chemical treatment that induces 90-percent sexual sterility as compared with the effect on a like population of the release of gamma-irradiated sterilized males in numbers that dominate the natural male population by a ratio of 9:1 (five times the rate of increase from one generation to the next in an untreated population).

Generation	Chemical sterilization	Constant release of gamma-sterilized males
Parent	1,000,000	1,000,000
F_1	50,000	500,000
F_2	2,500	131,578
F_3	125	9,535
F_4	5	50
F_5	<1	<1

Table 3. Theoretical population trends of a monogamous animal species subjected to destruction or removal, in each generation, of 25 percent (i) of the individuals of each sex and (ii) of the females, with return of sterilized males to the environment.

Generation	Untreated population	Destruction of both sexes	Destruction of females and return of sterile males
1	200	200	200
2	300	225	200
3	450	252	181
4	675	284	156
5	1012	320	122
6	1518	360	99
7	2277	405	76

to equal 90 percent of the combined population of fertile and sterile insects. If the initial rate of release of sterile insects remains constant, however, the final result is the same, because in the latter case the ratio of sterile to fertile insects increases as the population declines. The reason for the greater initial effect of a method that sterilizes 90 percent of the natural population is that the total effect in each generation is 99 percent, as compared with 90 percent in the first generation for the population exposed to released insects. As the population declines, the ratio of released sterile insects to the natural population of fertile insects will increase and will soon exceed 99:1. When this occurs, the effect will be greater than that produced by sterilizing a constant percentage of the natural population.

Other Animal Populations

The possibility of controlling animal populations by the sterile-male method is not necessarily limited to insects. Theoretically the method can be applied to any animal. The procedure may have practical application for the control of certain rodents, predators, or other undesirable wildlife or for limiting the rate of increase of large game species in overpopulated areas. The feasibility of using such techniques must be determined by wildlife biologists who are familiar with the life history, habits, and population dynamics of the animals. Many factors will influence the results, and practical application of the method might be limited. However, the possibilities, based on theoretical calculations, are so intriguing that the figures are presented, for consideration by specialists in this field of science.

In managing desirable wild animal species, circumstances arise that make it necessary to limit the rate of increase of the population. The application of the sterile-male method of regulating such populations may be the most effective and desirable way to achieve this objective. Table 3 shows the theoretical population trend of an animal species under circumstances where 25 percent of both males and females of each generation are trapped and removed from the environment, as compared with the trend where 25 percent are similarly trapped but where all the females are destroyed or removed and all the males are returned after treatment in a manner that will cause sexual sterility without otherwise adversely affecting sexual vigor or behavior. The normal untreated population is assumed to be increasing at the rate of 50 percent from one generation to the next.

As indicated earlier, it is assumed that the species is monogamous in breeding habit and that the sterile males released in the population are fully competitive with normal males in mating with the females. It is also assumed that environmental resistance is reasonably constant and that the parent population produces enough progeny to equal in number, at maturity, the original parent population, whereas the original parent population, owing to normal environmental resistance factors, is reduced by one-half. The population trend is projected for seven generations.

Table 3 shows that the removal of 25 percent of both males and females in each generation has a strong regulating effect on the population. However, this rate of control would not maintain a stable population, and the number of individuals would gradually increase.

The greater regulating effect resulting from the return of the sterile males to the environment, in this hypothetical situation, is readily apparent. If the maximum theoretical effect is produced, the population will gradually decline instead of increasing when the males are removed.

It is, of course, doubtful whether the procedure will produce maximum theoretical effects for most animal species, but the presence of substantial numbers of sterile males would certainly exert greater effect than their removal, even for species that are polygamous in mating habits.

The effects of the presence of sterile males in an animal population could of course be estimated in many ways. The hypothetical situation selected for the model in Table 4 clearly indicates the marked advantage of the sterility method over killing as a means of controlling animal populations. In this case it is assumed that it would be desirable to drastically reduce or even eliminate an undesirable wild animal population. The conditions are similar to those in the situation shown in Table 3. It is assumed that each breeding pair produces two young that survive to maturity, and that the original adult population declines by half before the next breeding period. The net increase would therefore be 50 percent.

The elimination of 90 percent of both sexes from an animal population that

Table 4. Theoretical population trends for an animal species that normally increases at a rate of 1.5 when subjected to an intensive control program that destroys or removes 90 percent of the population (i) of both sexes, or (ii) of females, with return of all trapped males after treatment to produce sexual sterility, or with replacement of destroyed males with sterile males from other sources.

Generation	Elimination of both sexes	Elimination of females and return of sterile males: Total population	Fertile males	Fertile females	Sterile males
1*	1000	1000	50	50	450
2	150	285	30	30	225
3	225	145	18.5	18.5	112.5
4	337	80	12	12	56
5	506	44	8	8	28
6	759	26	5.8	5.8	14
7	1138	16†	4.5	4.5	7

* Parent pretreatment. † If projected beyond the seventh generation, the population would continue to decline to a low point of 9 individuals in the tenth generation and would then begin to increase.

has reached damaging proportions would no doubt represent an effective control program. However, with a rate of increase of 50 percent in each generation, the population could be expected to rebound rather rapidly. It is interesting to note the complete reversal in the population trend achieved by returning sterile males to the environment. Theoretically, the population will continue to decline at a rapid rate. If a method of animal population control is employed that destroys both sexes, the introduction of sterile males from other sources should of course have the same effect on the population.

The theoretical population trend is projected through seven generations for both methods of control. On the basis of the original assumptions, however, the normal population theoretically would show a further rise beyond the seventh generation, or until maximum carrying capacity of the environment has been reached. In contrast, the population into which the sterile males were introduced would continue to decline beyond the seventh generation. A theoretical low of nine individuals would be reached in the tenth generation, but then the population would begin to increase. If complete elimination was desired, this could be achieved by introducing into the population from other sources a relatively few sterile males after several generations had elapsed. To achieve theoretical elimination through initial control efforts, a reduction of 92 percent of the females and replacement of a like percentage of sterile males would be necessary.

The regulating effect of the presence of the sterile males would be very great even if two sterile males were required to nullify the reproductive capacity of one fertile male. Calculations (not shown) made on this basis indicate that the population trend in successive generations would be 1000, 311, 180, 115, 88, 85, and 103, the low level being reached in the sixth generation.

In support of the possible validity of the estimates of population decline by the sterile-male method given in these hypothetical models, it may be pointed out that eradication of the screwworm on the island of Curaçao was achieved by the fourth generation. The actual population trend was in line with prior estimates, based on calculations of the type presented in this article.

Procedures

If, in fact, it can be shown that a population will respond in a manner approaching the theoretical estimates in Tables 3 and 4, research to develop practical procedures for utilizing this method of controlling or eliminating animal populations seems justified. Procedures that will induce the desired type of sterility in both males and females of the natural population would be the most practical. In the absence of a practical way of inducing sterility in the natural population, the destruction of a high percentage of both sexes by whatever means is most practical and replacement of the destroyed males with sterile males reared or obtained from other sources should be given consideration.

In considering the release of sterile males for regulating animal populations, I believe that it would usually be necessary first to reduce the natural population to a low level so that domination of the natural population can be achieved with a minimum number of sterile males. This might be necessary not only from the standpoint of the cost of providing the necessary animals but also to prevent damage that might otherwise be caused by the animals released. This procedure is believed to offer the most promise for the practical application of the sterile-male technique in insect control. Natural populations of many insects are too high, even at the low point in the abundance cycle, to make it economically feasible to rear and release enough sterile insects to dominate the male population without prior reduction to a low level.

Summary

The principle of animal population control through the use of sexually sterile males has been demonstrated for insects. Sexually sterile males that retain their sexual vigor and behavior will exert greater influence in regulating animal populations than can be achieved by destroying or removing the same number of individuals from the population. This hypothesis is supported by calculations showing theoretical population trends in assumed insect and animal populations subjected to treatments that destroy or eliminate certain percentages of the individuals as compared with a procedure that retains or replaces the same number of males in the population after sterilization. The maximum regulating effect that can be achieved is in direct proportion to the ratio of sterile to fertile males competing for mates.

The advantages of inducing sexual sterility in a natural population of an insect species by chemical or other treatment over the method of rearing and releasing a dominating population of sterile males are considered. It is suggested that the sterile-male method may have practical application for undesirable populations of certain wild animals as well as for insects.

References

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