be as effective as possible, it is still desirable that there be a marked improvement in the organization and equipment of the local governing bodies.

Engineering Supervision Essential

Particularly is it desirable that all local road work be carried on under engineering supervision. There may still linger in the minds of some people a feeling that roads can be built without technical direction. There was a time not so long ago when that opinion was entertained by many people. But the demonstration of the effectiveness of technical control which has been made in the improvement of the Federal-aid and State highway systems should have convinced most of the doubters.

However that may be, building roads for modern traffic can not be efficiently carried on without the highest type of technical direction obtainable; and that kind of direction the counties must endeavor to provide for the success of their local road programs—that and the necessary equipment and plant which such direction will suggest.

It is probable that efficient technical supervision and adequate equipment will be obtainable in many cases only by the consolidation of several counties into larger administrative districts. This, for the reason that the overhead cost of the necessary supervision and plant would constitute too large a proportion of the total cost unless it were spread over a greater volume of work than many of the existing counties have to do.

By such consolidation of administrative control, and the employment of the efficient supervision and equipment which will thus be made possible; by following the orderly process of improving the roads in the order of their importance, after the example set by the National and State Governments; by these means will the work that must always remain under local control be brought to a high standard of efficiency. And such are the means by which the local farm-to-market roads will ultimately be raised to a state of improvement comparable with the present state of the primary roads.

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RODENT-CONTROL Studies Develop Specific Methods for the Different Species

The need for the control of rodents has grown as agriculture has developed. The most important factor limiting rodent abundance—that of seasonally scant food supply—has been removed in many areas for such species as have proved capable of accommodating themselves to changed conditions, and many of them early developed into first-class agricultural pests. Not only is their control necessary for economic reasons, but in some places because of consideration for human health. Examples of this are found in the bubonic-plague infestation over wide areas among the California ground squirrels as well as spotted fever among other ground squirrels in the Rocky Mountain region. Fortunately, an increasing knowledge of the animals' habits and of their physiological responses has made it possible for the Bureau of Biological Survery to develop methods of control that are constantly becoming more specific. Educational methods also are employed by the bureau to win the agricultural population to adopt newer methods in rodent control, in preference to the crude formulas and methods of application formerly in universal use.

Some years ago W. C. Jacobsen, of the California Department of Agriculture, made a study of the rodent problems in California and of efforts for their solution. The earliest community rodent-control project of which he found record was one conducted about the Santa Barbara Mission in 1808. Since that day settlers in California and in other Western States have found it necessary to resort to intensive campaigns, using every sort of device and agency to protect their crops against the swarming hordes of rodents.

Poisons of various kinds were early used by farmers, some of the baits, in the light of present-day knowledge and practice, being of astonishing strength. Mixtures of 1 ounce of phosphorus to 6 pounds of wheat, and strychnine and cyanide combinations of almost the same proportionate strength, were rather widely used. Poisoned water also was used in some localities with deadly effect, not only on ground squirrels but also on other forms of mammals as well as on birds. One astonishing formula printed in California in 1873 recommended 24 ounces of strychnine to 2 quarts of wheat. This is in startling contrast with the present-day proportions of 1 ounce of strychnine to 20 or more pounds of grain. Phosphorus was a favorite with many farmers because of its cheapness, despite the fact that occasional grain fires were almost certainly traced to its use.

About 1909, S. E. Piper, of the Biological Survey, began investigations of rodent damage, methods of reducing the losses, and the possibility of reducing the proportion of poison in the baits. His tests and those of many subsequent Biological Survey investigators have gradually established four important facts that have aided greatly in making poison formulas more specific against such rodents as become pests:

(1) Animals, including birds, show a great variation in their resistance to any poison; long before it was demonstrated in laboratory tests, control workers knew in a general way that it was much more difficult to poison birds than mammals. (2) Mammals, even races of the same species, show a constant variation in resistance, which can be utilized to advantage in selective control. (3) Sufficent variation exists in choice of food and in manner of feeding among various species to make utilization of these factors feasible in control work, including seasonal and territorial change of baits. (4) In some localities poisons that are effective at one season are ineffective at others, possibly because of food interference with the lethal action.

Some Birds Practically Immune to Strychnine

An example of the first point is found in gallinaceous birds, whose tolerance to strychnine is so high as to amount to practical immunity from its effects. This fact has been demonstrated time and again by feeding tests on quail, domestic chickens, pheasants, and others, and the results made available in a mimeographed leaflet (Bi–1028) of the Bureau of Biological Survey. Pigeons and doves also show the same resistance to strychnine, though in a lesser degree. The lethal dose of strychnine for these birds is approximately four times as great per unit of body weight as in the case of ground squirrels. Other birds also show higher resistance to other poisons than do the mammals commonly classed as pests. Obviously weakening the formula by spreading the poison over greater quantities of bait material would operate to the advantage of the resistant groups. For example, the old phosphorus formula required only two or three kernels of wheat to kill the average

pigeon; in the strong strychnine mixtures of the early days 20 to 40 kernels would be sufficient; while in formulas recommended at present a lethal dose requires about 100 kernels. Where poison is distributed in small baits intended for the less-resistant forms, as ground mammals, it is apparent that the chances of an individual bird picking up 100 kernels of grain are much less than of its getting 2 or 20 or 40.

The difference in resistance to poison by closely related forms of animals, even of races of one species, is exemplified in Douglas's ground squirrel (*Citellus douglasi*) of northern California and western Oregon. This rodent is easily susceptible to strychnine, while in California south of the San Francisco Bay region the nearly related California ground squirrel (*C. beecheyi*) is one of the most resistant.

In Montana, northern Idaho, and eastern Washington the Columbia ground squirrel (*Citellus columbianus*) is one of the most difficult to handle. Strychnine is much less effective against this rodent in this territory than in northeastern Oregon, and for many years this was not understood. In 1928, when the species was divided into two races, the line of demarcation followed closely the boundary that had been noted in the differences in reactions to poison.

Curiously enough, the Columbia ground squirrel and the Oregon ground squirrel (*Citellus oregonus*), which are found more or less closely associated in northeastern Oregon, have such a marked difference in susceptibility to strychnine that it is possible to prepare a grain mixture to kill the latter without harming more than a very small percentage of the Columbia squirrels, even though these may feed freely on the bait. This fact complicates control of the Columbia squirrel with bait intended for use against the Oregon species.

Food Preferences Utilized

An example of the third point is found in the fact that small birds have been found in a majority of tests to prefer wheat to barley or oats, while ground squirrels of several species prefer the coarser grains to the wheat. Advantage has been taken of this, and as a result wheat has been gradually eliminated as a bait material, despite the fact that at the time organized study of the control problem began, it was the bait most widely recommended and used for rodent control. Many tests repeated at various seasons over wide territory have demonstrated this habit of discrimination to be general, even though occasionally the squirrels will eat one grain as readily as another, and less frequently small birds will not display any selectivity even though given a choice.

The development of pouch poisons for ground squirrels as opposed to stomach poisons is another and outstanding example of increasing efficiency in control through taking advantage of the rodents' manner of handling foods. Baits can be prepared in such manner as to release poisons in the mouth and thus kill ground squirrels that pick up quantities of the grain in their cheek pouches, rather than await the much slower absorption through the stomach. Consequently smaller proportions of poisons than previously were thought necessary are now used in the baits.

Neither pouch nor stomach poisons, however, are particularly effective against the Columbia ground squirrel because this species does not often pouch or eat sufficient grain without hulling it to carry a killing dose. Successful control of this species has been obtained by preparing a coated bait with flour paste, which is brittle and easily flakes off in the mouth as the grain is hulled.

The California ground squirrel furnishes the outstanding example of seasonal variation in response to poison. During the summer and fall months pouch poisons carrying strychnine as the lethal agent are quite generally successful. Spring operations are markedly less so, yet other poisons substituted for strychnine at this season are satisfactory. Variations in feeding habits and character of foods taken, and perhaps food interference with the action of poisons, play a part in producing this state of affairs.

Much educational work on the part of the Biological Survey has been necessary to teach the desirability of undertaking control not only at the proper season but also on a community and crew basis. Organizing control work on a community-wide basis accomplishes two things: It reduces the possibility of reinfestation from one farm to another; and it greatly reduces the length of the poisoning season. Where the practice of covering a considerable territory at one time does not prevail, poison is commonly exposed by farmers at one point or another over a period of months. Formerly they would place handfuls here and there, on stumps, in logs, and at other places where the rodents might find it, sometimes many days later. For these sporadic practices there has been largely substituted the community method of scattering over a given area sufficient baits of grain directly at the entrances of the burrows of the rodent it is desired to kill, and doing this at a season when that animal is feeding on grain. This method normally results in a good rodent clean-up over the entire area treated and consequently in lessened necessity for further exposure of poisons during that season.

Poisoning has thus far proved to be the most effective method of dealing with rodent pests. Bounties have resulted either in fraud or in unprofitable expenditure of large sums of money. Guns, traps, and other mechanical devices are hopeless means of control in the face of the endless hordes of rodents always present. So-called viruses, such as those widely advertised for controlling rats, have never been satisfactory and, furthermore, are looked upon with disfavor by many health authorities as a possible source of spread of diseases to human beings. They have not been used in control campaigns conducted by the Biological Survey.

Of fumigants for burrowing species, carbon bisulphide is the most satisfactory thus far employed. It has been widely used against California ground squirrels, in some places with great success. Though too expensive for practical use in heavy infestations, carbon bisulphide is valuable chiefly as a follow-up agent, where the rodent population has already been greatly reduced by poison. Calcium cyanide is useful as a fumigant to a certain degree, but it has not completely fulfilled the high hopes early held for it by control workers. Fumes of sulphur, gasoline, petroleum distillate, and kerosene also have been tried with varying success, but none of these substances has yet come into general use.

Poisoning and fumigating are the only known methods offering any possibility of satisfactory solution of the rodent-control problem, and of these, poisoning is the more practicable. Contrary to the opinion commonly held, it is possible, with our present knowledge of the characteristics of poisons and of the habits of animals, so to select, prepare, and expose baits as not seriously to endanger animals other than the rodents for which the poisons are intended. Ordinary precautions, of course, are always to be taken in handling any poison, so as not to endanger human beings, domestic stock, or valuable wild life.

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