WILDLIFE MANAGEMENT CONCEPTS COMPATIBLE WITH MOSQUITO SUPPRESSION[1]

PAUL F. SPRINGER[2]

Leader, South Dakota Cooperative Wildlife Research Unit, South Dakota State College, Brookings, South Dakota

The problem discussed in this paper is the finding of ways to satisfy the environmental needs of desired wildlife species and at the same time to encourage conditions unfavorable for mosquitoes. Study and experience have shown that means often can be developed for providing water for wildlife without creating a mosquito breeding habitat. The procedures vary, depending upon the type of environment and whether the principal interest is in wildlife management or in mosquito control.

Physical Principles

Impounding. *Permanent Flooding.* Many marshes do not attain their full wildlife potential because their ponds are choked with vegetation. By providing for a greater amount of permanent, open water, either through diking and impounding or through deepening existing low areas, the wildlife carrying capacity of these wetlands can be increased. If the water is clear and if fertility is satisfactory, submerged aquatic plants of the type desired by waterfowl, such as pondweeds (*Potamogeton*), horned pondweed (*Zannichellia palustris*), naiads (*Najas*), and wild celery (*Vallisneria americana*) are fostered (Addy and MacNamara, 1948; Steenis *et al.*, 1954).

Provision for permanent ponds also can accomplish a high degree of control of pasture or floodwater mosquitoes (*Aedes* and *Psorophora*), which lay their eggs in dewatered situations. When flooded by rain, by a rise in stream or pond level, or, along the coast, by high tides, the eggs hatch, and under favorable conditions produce adults within as little as a week's time.

The usual physical approach for control of mosquitoes in these alternately dry and flooded sites is to construct open ditches in order to prevent water from remaining long enough for a brood to be produced. But keeping the area flooded constantly to a depth of about half a foot or more during the mosquito breeding season can, by preventing egg deposition, provide mosquito control that is just as effective as ditching and which at the same time enhances the value of the area for wildlife (Darsie and Springer, 1957; Chapman and Ferrigno, 1956).

The wildlife species benefited include waterfowl and many other kinds of water birds, fish, turtles, frogs, and aquatic mammals such as muskrats and mink. Not only do these animals have esthetic and recreational values, but some, including furbearers, fish, and shellfish such as shrimp and crabs, are important commercially.

Breeding of permanent-water mosquitoes (*Anopheles* and *Culex*) may be controlled by flooding to a greater height, which reduces the amount of interspersed vegetation and increases wave action, thereby affording less protection to mosquitoes. If marginal breeding is the principal problem, the shoreline may be steepened to reduce the extent of the shallow water zone inhabited by emergent vegetation. A good method is construction of the borrow pit on the inside of the dike. Another method is erection of contour levees close enough together so that water abuts against each back levee instead of grading off into a feather edge.

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[1] Paper presented with slight modification at Conference for Co-ordinated Program on Wildlife Management and Mosquito Suppression, Yosemite National Park, October 15–18, 1962.

[2] Formerly Chief, Section of Wetland Ecology, Patuxent Wildlife Research Center, Laurel, Maryland.

Although decreases in the stands of shore-frequenting plants usually reduce the value of the area for some waterfowl and marsh birds, the ponds still will be satisfactory for many kinds of fish. Deepening the pond margins also has the important additional advantage of decreasing the likelihood of botulism outbreaks (Kalmbach and Gunderson, 1934).

Temporary Flooding. In many places it is often impossible to keep ponds fully flooded throughout the mosquito breeding season. Also, in many places waters are turbid or dark and do not allow enough light transmission for submerged plants to grow. Under these conditions, water management for wildlife is based on keeping the area partially or completely de-watered during the growing season, to encourage germination and growth of native species of desirable moist-soil plants (Addy and MacNamara, 1948; Steenis *et al.*, 1954). These include annuals, such as wild millets or watergrasses (*Echinochloa*) (Miller and Arend, 1960) and other grasses, certain smartweeds (*Polygonum*), cyperuses (*Cyperus*), and certain spikerushes (*Eleocharis*), which bear seed sought by waterfowl and other wildlife, and perennials such as bulrushes (*Scirpus*), certain species of smartweeds and spikerushes, and cattails (*Typha*), which produce seeds and/or root structures utilized by waterfowl, muskrats, or other animals. In addition, cultivated plants, including sorghums, barley, and other small grains may be grown. Dewatering during the summer also provides good control of mosquitoes by eliminating habitat necessary for larval development (Wiebe and Hess, 1944). Toward the end of the principal mosquito breeding season the food plants can be flooded and thus made available to ducks.

In some years the manager of a refuge may have to bring in water sooner than he wishes in order to divert early migrating ducks that otherwise would feed in nearby private fields still containing unharvested crops. Thus, he may reflood before the principal mosquito production season is over and cause a hatch of floodwater species. The problem is compounded if he floods over an extended period or intermittently, thereby producing a succession of broods.

These difficulties can be partly alleviated by certain management practices (Darsie and Springer, 1957). For example, the water drawdown may be delayed as long as possible and restricted in duration in order to reduce mosquito egg deposition and to minimize the establishment of excessive growths of perennial plants, such as phragmites (*Phragmites communis*) and cattails. These plants have little or no food value for most ducks and may provide conditions favorable for mosquito breeding. Also, the area may be reflooded quickly so as to reduce the length of time during which the floodwater mosquitoes hatch (Sacramento County-Yolo County Mosquito Abatement District, 1961). Reflooding can be facilitated by restricting the size of the ponds to the available water supply and by providing reservoirs in which water can be stored prior to flooding the ponds. Dikes should be impervious to water movement and broad enough to prevent water loss from muskrats and crayfish burrowing. If seepage occurs, it may be corrected by plugging with a layer of clay. If this is unsuccessful, the seepage area can be deepened to form a permanent water body, or a ditch can be constructed to drain off the standing water.

When "tame" rice is grown for waterfowl, the land should be leveled and checks established according to standard agricultural practice. Provisions for adequate water supply and drainage facility are essential to production of maximum crop yields and prevention of mosquito breeding. As in permanently flooded ponds, sides of rice fields may be steepened to prevent marginal breeding and fish may be introduced after flooding to aid in mosquito control.

Ditching. *Controlled Ditching.* Ditching that is useful in wildlife management perhaps can also be adapted to mosquito control needs. The kind I refer to is not open ditching, which may or may not drain a marsh and cause it to become drier, depending upon its effect on the water table (Stearns *et al.*, 1940; Bourn and Cottam, 1950), but controlled ditching in which the lower level of drainage is regulated by adjustable gates or by sills or plugs (Steenis *et al.*, 1954). Usually these ditches are fairly large and may more properly be called canals. Ditching of this type improves a marsh for waterfowl, muskrats, fish, and other animals by providing a better interspersion of water. This procedure follows the wellknown principle of diversification of habitat to improve its animal carrying capacity (Leopold, 1933).

If these ditches and canals can be constructed in the low, intermittently dry and wet areas where floodwater mosquitoes breed, they may provide good mosquito control (Bradbury, 1938). To prevent mosquito breeding it usually is necessary to remove only the surface water. It may be that modifications of this kind of ditching will be required to achieve adequate mosquito control. Testing and development of types of ditching compatible with both mosquito control and wildlife management are greatly needed.

Sump drainage. Sump drainage also appears to have a place in coordinated wildlife management-mosquito control programs. Radiating ditches drain shallow mosquito breeding waters into a deeper reservoir or sump. These sumps attract wildlife and, if they can maintain fish during periods of low water, they provide foci from which the fish may spread, multiply, and prey on mosquitoes when the marsh is flooded (Clark, 1938). If the area has a uniform gradient, special ditches may not be needed, because drainage and reflooding will occur evenly.

BIOLOGICAL PRINCIPLES

ANIMAL RELATIONSHIPS. One biological principle to be considered is the use of fish. The objective of fishery management is to maintain or increase balanced numbers of species desired for their sporting or commercial value. Fish can be stocked or can be encouraged by making the environment favorable through provision for a year-round supply of water of the proper quality, and insurance of satisfactory feeding and breeding conditions (King, 1960). Mosquitofish (*Gambusia*) and killifish (*Fundulus*), which serve as forage for larger fish, also are noted for their predation on mosquito larvae and pupae (Gerberich, 1946). Some other species of fish, principally the young, have similar habits. Aquatic insects also are desirable in that they provide food for fish, and some of these same insects are important predators of mosquitoes (Hinman, 1934).

PLANT RELATIONSHIPS. Plants of many kinds have been introduced or managed as food and cover for wildlife, and some of them also discourage mosquito production. Squarestem spikerush (*Eleocharis quadrangulata*) is an important waterfowl food (Martin and Uhler, 1951). Dense stands of it and other naked, emergent plants provide poor breeding conditions for malaria mosquitoes (*Anopheles quadrimaculatus*) (Rozeboom and Hess, 1944). Hardstem bulrush (*Scirpus acutus*) is a similar species that is a poor producer of all mosquitoes (Communicable Disease Center Technology Branch, 1959). It is a good to excellent waterfowl food and provides valuable nesting cover for some waterfowl species. Watershield (*Brasenia schreberi*), another good food plant, discourages production of malaria mosquitoes (Hess and Hall, 1945). Olney's three-square (*Scirpus olneyi*), wildrice (*Zizania aquatica*), dense stands of duckweeds (Lemnaceae), certain species of muskgrasses (*Chara*), and pondweeds (Zosteraceae) in open water are fair to excellent waterfowl food plants that generally have low breeding indices for all kinds of mosquitoes (Ferrigno, 1961; Matheson, 1930; Communicable Disease Center Technology Branch, 1959). Darsie and Springer (1957) and Chapman and Ferrigno (1956) have measured the mosquito production associated with other plant species.

Some plants, such as alligatorweed (*Alternanthera philoxeroides*), water-hyacinth (*Eichornia crassipes*), waterchestnut (*Trapa natans*), water primroses (*Jussiaea*), watermilfoils (*Myriophyllum*), cattails and algae, ordinarily have little or no value to most waterfowl and take up space that might better be occupied by more desirable species (Martin and Uhler, 1951). These same plants also are considered pests by mosquito control workers because of their high mosquito production potential (Hess and Hall, 1945; Barber and Hayne, 1925; Smith, 1962).

Thus, programs designed to control these plants and encourage desirable replacements benefit wildlife and also discourage mosquitoes. Compatible weed control methods include flooding, dewatering, cutting, disking, burning, grazing, and diversion of highly fertile water inflow, or combinations of these methods. Chemical herbicides also have a place, especially for plants that are difficult to control by other means (Martin *et al.*, 1957). Available evidence indicates that many of these materials are of low toxicity to fish and wildlife, but that some are highly poisonous (Springer, 1957; George, 1960). The effects of even some of the most common compounds need more study.

Compatible Control

Physical and Biological Control. The majority of compatible methods of wildlife management and mosquito control described in this paper are physical or biological in nature. They rely on manipulation of the environment by processes found in nature in order to create conditions favorable to wildlife and unfavorable to mosquitoes. Management by these methods is the soundest approach because it is based on a knowledge of the biology of the species and of primary ecological factors that cause populations to increase or decrease. As Rees (1961) has pointed out, "The problem of mosquito abatement is basically one of proper water management directed at preventing the creation of suitable water habitats in which mosquitoes can be produced." Essential to successful use of physical and biological controls is provision for (1) proper design and application, and (2) adequate maintenance. These needs cannot be emphasized too strongly.

Coordinated Control. Physical and biological methods also have two definite advantages over a third method of mosquito control, the chemical method, in that they avoid the problems of (1) toxicity to beneficial animals, including those that exert natural control of mosquitoes, and (2) development of resistant strains of mosquitoes. Rees (1961) states that "Chemical control of mosquito larvae and adults is at best a curative measure in mosquito abatement and should only be used when mosquito prevention by proper water management has not been applied." Because of our present inability always to achieve adequate control of mosquitoes by non-chemical means, it can be reasoned that the use of chemicals has a place in mosquito abatement programs. However, if a chemical method is used, it should be safe (Springer, 1956) and should be coordinated with existing physical and biological programs so as to supplement them rather than work against them (Lewallen, 1960; Michelbacher, 1954). Such programs should not rely on one method but rather on a combination of methods, in which chemical control is a well integrated part and not a sole, matter-of-course approach.

There is another cogent reason for developing coordinated programs of mosquito control and wildlife management. This is simply one of good public relations. People will naturally give more support to a program that has dual benefits than to one that is oriented only toward mosquito control or wildlife management and that may create wildlife loss or mosquito breeding problems.

In the future it would seem that both mosquito control and wildlife agencies could benefit by seeking ways of sharing costs in developing coordinated programs. A mosquito control agency is responsible for reducing the numbers of pest mosquitoes in an effective, yet safe and economical manner. Benefits, if any, to wildlife usually are incidental. If modifications and additions to increase the value of the program to wildlife are desirable and feasible, they should be borne by the fish and wildlife agency. Similarly, a wildlife agency's responsibilities seem fulfilled if it participates with other landowners in compatible, area wide programs designed to reduce mosquitoes to a reasonable level and if its wildlife programs do not increase the mosquito problem to an unacceptable level. Any modification to reduce mosquitoes below this point should be at the expense of the mosquito control agency.

The development of coordinated mosquito control-wildlife management programs may not be easy, but such programs are in the best interest of the public.

Summary

Application of physical and biological principles offers the most acceptable means of developing compatible programs for wildlife management and mosquito control. When chemical control is used, it should supplement rather than work against physical and biological methods. Programs coordinated in this manner are in the broad public interest.

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A COST ANALYSIS FOR OPERATION OF LIGHT TRUCKS

A. W. BUZICKY AND C. L. LANGER[1]

In most mosquito control districts, vehicular costs are a substantial portion of the total budget. In order to maintain accurate records, a cost accounting system was set up in 1958 in this district and has been in operation to the present time. The basic document from which costs flow is a weekly vehicle report kept by each driver on each vehicle. All costs are entered on the form as they are incurred, and submitted at the end of each week to a clerk for entry into a ledger. Keeping up the vehicle report by each driver has become perfunctory and takes a negligible amount of time. The account clerk then prepares whatever statistical or cost summaries are required by management. In addition, the vehicle reports permit a check to see that specified maintenance is being carried out. If mileage for any particular vehicle is substantially below the average, repair or tuneup can be performed promptly.

A trend has developed in industry and government in recent years for leasing items of equipment rather than purchasing such equipment. There are some advantages and restrictions to leasing which must be considered before a decision to lease vehicles is made. The vehicles must not be special purpose models but common, readily resalable types. If possible they should be returned to the lessor in the early fall before new models appear. The vehicles should be returned in excellent condition less normal wear and tear.

One advantage of leasing is that new vehicles can be specified each year. Maintenance costs are very low since most re-

[1] Director and Business Administrator, respectively of the Metropolitan Mosquito Control District, 797 Raymond Avenue, St. Paul, Minnesota.