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HIGHWAY-WILDLIFE RELATIONSHIPS

Vol. 1. A State-of-the-Art Report

D.L. Leedy

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Final Report

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16. Abstract This study assesses, primarily through an extensive literature review, what is known about highway-wildlife relationships and suggests research and management approaches to protect and enhance fish, wildlife, and environmental quality. A cooperative effort to this end among natural resource and highway agency personnel is needed on a continuing basis from the initial planning stages for new highway construction through operation and maintenance. The 20 million or more acres in highway rights-of-way have been largely neglected as wildlife habitat. Opportunities exist for creating valuable fish and wildlife impoundments during construction, yet the minimal effort needed to locate and design such impoundments has generally not been made. The Nation's four million miles of streets and highway often create "edges" conducive to wildlife. Many millions of wild vertebrates are killed annually, but apparently most wildlife populations are not seriously affected by such losses. Highway construction through limited ranges of endangered species can be a serious problem, as can erosion, wetland drainage, stream alteration, structures which block the passage of anadromous fish, and pollutants resulting from highway maintenance and use. Better measures for mitigating habitat losses, predicting effects of highways on fish and wildlife, reducing animal-vehicle accidents, and enhancing highway environment for fish, wildlife, and people are sorely needed.

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PREFACE

This two-volume work, consisting of a State-of-the-Art Report and an Annotated Bibliography on Highway-Wildlife Relationships, was prepared by the Urban Wildlife Research Center, Inc. for the Department of Transportation, Federal Highway Administration. The primary purpose of the project was to assess what is known about the effects of highways, their construction, maintenance and operation on fish, wildlife and their habitat. In addition, the effects of wildlife on highway structures, vehicular use, and rights-of-way vegetation were considered. Also, suggestions were made as to what might be done, especially with respect to research, to promote the protection and enhancement of fish and wildlife and of environmental quality in the conduct of the Department's program.

The report was written not only with highway planners, engineers, landscape architects, and others in the transportation field in mind, but, also, for fish and wildlife agency administrators, biologists, ecologists, and others concerned with natural resources and environmental quality. The project involved an extensive review of the literature in both the transportation and natural resource conservation fields. This literature review was supplemented by personal observations and by information derived from discussions and correspondence with individuals in both of these fields. This approach showed a surprising lack of understanding of each others' problems in these areas and little appreciation of what might be accomplished through research and a cooperative management effort.

In order to set the stage for such cooperation and understanding among highway and natural resource personnel, certain references concerning highway construction and maintenance operations, and some references on ecology, hydrology and wildlife were cited in the State-of-the-Art report or abstracted in the Bibliography which do not deal directly with highway-wildlife relationships. They do have relevance, however, in that they provide information on highway pollutants, for example, or deal with food and cover requirements of, or pollutant effects on, fish and wildlife.

Of the 794 references abstracted in the Annotated Bibliography, 489 are cited in the State-of-the-Art Report. Although some of the references cited in the Report utilize a considerable amount of the material included in the respective abstracts, many of them contain only a fraction of the information available in the Bibliography. Likewise, the reader will find much relevant information in the remaining 305 uncited bibliographical items.

As a convenience to the reader, the Bibliography has been arranged under headings and sub-headings which correspond, generally, with the subject matter headings in the State-of-the-

Art Report. In addition, because some articles dealt with more than one subject and required cross-referencing, a dual system of identifying the reference was used.

Each reference in the Bibliography was given a number and listed consecutively. This number was used along with the author's name and date of publication for those articles cited in the State-of-the-Art Report. Thus, the reader can locate, immediately, the reference in the Bibliography and obtain any additional information provided therein.

The authors have been impressed with the opportunities and challenges that exist for closer cooperation and more effective exchange of information among highway and natural resource agency personnel at all levels on matters concerning highways and the environment. Environmental laws, administrative directives, memoranda of understanding and some guides exist for such cooperation and coordination of effort, but much more effective implementation is needed. This is particularly true at local levels in the construction and maintenance of township and county roads. If this report leads to more scientific input from biologists and ecologists, beginning at the earliest stages of planning and selecting a route for a highway and continuing through the construction, operation and maintenance of the highway; and if some of the needs and opportunities for research which are identified, can be pursued, we shall consider our time spent on the project worthwhile.

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References and information were also provided by Richard Banks, Kenneth J. Chiavetta, Clyde Jones, Chandler Robbins, and Lucille Stickel of the U. S. Fish and Wildlife Service; John L. Buckley of the U.S. Environmental Protection Agency; Mason Hale of the Smithsonian Institution; John S. Gottschalk of the National Association of Game, Fish and Conservation Commissioners; Fred G. Evenden, Executive Director, the Wildlife Society; Kenneth Taylor of the California Native Plant Society; the

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Nancy L. Dagenhart, Retrieval Specialist for the Transportation Research Board, National Research Council, was especially helpful in providing summaries of completed research and descriptions of current research related to highways and their effects on fish and wildlife and the environment. Likewise, the Smithsonian Institution's Science Information Exchange provided computer printouts of descriptions of recent or on-going research projects relating directly or indirectly to the impacts of highways on fish and wildlife and the environment; and the Water Resources Scientific Information Center, U. S. Department of the Interior provided abstracts of pertinent published reports.

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INTRODUCTION

A U. S. Fish and Wildlife Service biologist estimates the current annual mortality of birds on United States roads at 57,179,366; less than 40 years ago, a writer estimated a loss of 6,000,000 total vertebrates per year on the highway. A state fish and game employee is concerned because interstate highways do not provide access for hunters to adequately harvest big game herds, while his counterpart in another state points out that the interstate highways open up areas for more recreationists. Another investigator states that highway ditches are a factor in the drainage of valuable wetlands, while others are enthusiastic about the opportunities to create impoundments in connection with highway construction. Some wildlife biologists recommend development of nesting cover for birds and other wildlife along highways, but others suggest that cover attractive to deer and other wildlife species should be discouraged.

"The Plight of the Rightofway-Victim of Vandalism" is the subject of a recent book by Frank E. Egler and Stan R. Foote. Egler, who has studied and worked with rights-of-way vegetation problems and management for over a quarter of a century, is dissatisfied with the way vegetation is being managed and the fact that available information and techniques are not more widely used.

Highways serve many purposes. They are vital for industry and defense; we could not exist without them in today's world; and driving for pleasure--yes, even when the nation is faced with severe energy problems--is a favorite form of recreation for many of us. Wildlife observed from the highway, except for the animals left crushed or mangled on or along the road surface, adds to the enjoyment of motoring; and, of course, the availability of highways is a major means of gaining access to, and utilizing, the wildlife resource.

Obviously, the construction of highways, bridges and related facilities and the maintenance and use of highway systems have an impact on fish and wildlife and their habitat. Yet, relatively little attention has been given to this impact, or to the role of highway rights-of-way in wildlife production.

Highway-wildlife relationships are complex and there are many gray areas which can be clarified only by well designed and scientifically conducted research. Highways are neither all bad nor all good in their impacts on fish and wildlife habitat. There are, it would seem, many opportunities to improve highway-wildlife relations.

EXTENT OF HIGHWAYS AND STREETS

Precise information on the amount of land occupied by surfaced roads and streets and the amount of land in rights-of-way that may be at least partially vegetated is not available; the land area involved, however, is substantial. Miller and Powell (1942-4), reporting on a 1936-37 nation-wide investigation of game and wild-fur animal production on agricultural land, estimated that public highways occupied 17,787,000 acres or .7 percent of the total land area of the United States, excluding Alaska and Hawaii. They concluded that 75 percent of the highway area was providing food and cover for wildlife and that on an estimated 75 percent of these highway lands, it was economically feasible to improve food and cover for wildlife. Looking back some 40 years later, it would appear that little deliberate effort has been made to improve such lands for wildlife.

About 7 years after the Miller and Powell survey of wildlife lands, Van Dersal (1943-6) calculated that of the total land area of the United States (1,903 million acres), 20,000,000 acres were in highways and roads and 4,000,000 acres were in railroad rights-of-way.

Wooten and Anderson (1958-8) reported that during the period 1945 to 54, the acreage of land in urban areas, highways, airports and reservoirs increased an average of about 831,000 acres a year, with the area occupied by highways increasing about 78,000 acres per year.

In 1956 the Congress authorized a program of interregional highways which, as pointed out by Mayer (1958-3) provided for 41,000 miles of modern highways, a substantial part of which would be in metropolitan areas with rights-of-way 250-300 feet wide. Mayer indicated, also, that at the interchange between expressways and other arteries, vast areas of land would be made available for other development. In discussing this same program, Robert Paul Jordan (1968-2) stated, "...the super-roads are gobbling up 1.6 million acres for right-of-way--an area larger than the State of Delaware. Enough material is being excavated to bury Connecticut knee-deep. The sand, gravel, and stone going into the roads would build a wall 9 feet thick and 50 feet high around the world."

As a further indication of land required for highways, the Council on Environmental Quality (1974-1) reported that each mile of interstate highway consumes up to 48 acres; over two-thirds of the land area in some cities is consumed by streets, roads and parking; and 26 million acres of America's rural land is consumed by the transportation system.

Frank E. Egler, a long-time student of right-of-way vegetation management, stated in the introduction to his recent book (Egler and Foote, 1975-384) that "the total area in this Rightofway Domain is prodigious and is growing prodigiously." He indicated that about 15 years earlier he had estimated that the soil-and-vegetation covered lands in rights-of-way for highways, railroads and utility lines embraced 50 million acres for the contiguous United States.

Except for Alaska, however, where a road is being built in connection with the construction of the Alaska Pipeline, the rate of construction of new highways may have reached a peak; discussions at a September, 1975 research conference sponsored by the Federal Highway Administration in Minneapolis, Minnesota, would indicate that this is true. Rather than building new highways, apparently the emphasis, henceforth, will be in widening and improving existing highways which will result in decreasing the amount of vegetated right-of-way along these highways.

According to the 1973 edition of Highway Statistics (U. S. Department of Transportation (1973-5) the total rural and municipal mileage of highways and streets as of December 31, 1973, based upon reports of state authorities, was 3,806,883 of which 3,175,654 miles were classified as rural roads and 631,229 as municipal mileage. Presumably logging roads in timber areas and many back-country roads and navigable trails are not included in these totals. The acreage of rights-of-way is not given. These statistics should suffice to point out, however, that a substantial amount of land is in highway rights-of-way--enough, on the basis of our literature review, to warrant much more attention than it is currently receiving with respect to fish and wildlife values.

HIGHWAYS AND HIGHWAY RIGHTS-OF-WAY AND THEIR USE BY WILDLIFE

Highways usually consist of a graded strip of ground surfaced by one of various materials; a berm or shoulder often of gravel, crushed rock, or sandy materials at each side; a ditch or slope away from the surfaced highway; and the land area encompassed in a right-of-way of varying widths and degrees of slopes. Divided highways have a median strip of varying width and cover types--often closely cut grass--but, somet mes, with landscape plantings of shrubs and, sometimes, with native trees. A narrow strip of vegetation next to the highway surface almost always is kept mowed, while that at the outer part of the right-of-way may be allowed to remain in, or grow up in, native vegetation, with due consideration being given to highway safety factors. Some states have standard guides for mowing or otherwise controlling highway right-of-way vegetation. Often, highway construction will have resulted in cuts through hills thus providing new cliff habitat, or fills which alter drainage patterns and provide impoundments or water in road ditches. Highway construction, also will have altered soil characteristics which have an effect on vegetation and, indirectly, an effect on wildlife populations.

Wildlife research in the past 40 years or more has indicated, repeatedly, the value of "edges" for wildlife. Highways create edges. In forested areas, the more or less uniform forested habitat is broken up and diversified by bulldozing and cutting activities during highway construction, or in maintenance of the right-of-way following construction. In prairie areas, now largely agricultural, highways often result in strips of vegetation, including remnants of native prairie grasses or other prairie vegetation, some in danger of extinction, or in exotic vegetation provided by landscape plantings in median strips or along the highways. In desert, or near-desert areas, the hard-surfaced highways may result in sufficient runoff and increase in soil moisture in the highway berms to provide conditions suitable for the extension of the range of mammals such as the pocket gopher (Huey, 1941-30).

Highways and highway rights-of-way, per se, have been studied relatively little by wildlife biologists as to their use by wildlife; yet Dambach (1951-20) pointed out that Ohio's roadsides, then totaling some 250,000 acres--an area greater than the State forest in Ohio--have a part in conservation, and he indicated that mile for mile and acre for acre, Ohio's roadsides, next to fence rows, probably are the most productive of wildlife lands in the State.

Use By Upland Game Birds

Aside from observations made on highway wildlife mortality, probably there has been more attention given to use of highways by game birds than to any other form of wildlife. Linder, Lyon and Agee (1960-33), reporting on studies in south-central Nebraska, stated that roadsides which comprised less than 1.5 percent of the total acreage had 23.6 percent of the total observed pheasant nests. They indicated that one of the reasons roadsides assumed this importance was the presence of cover remaining from the previous year which was available for early nesting. Baxter and Wolfe (1973-11) reported similar findings from Nebraska, i.e. that roadside nests produced about 25 percent of the pheasants; in Colorado, however, Snyder (1974-43) indicated that the annual production of pheasants from roadside nests was relatively low due to predation and nest abandonment. Chesness, Nelson and Longley (1968-16) noted in Minnesota that although dogs, cats, skunks and other predators took their toll, the number of successful nests in road ditches ranked second to those found in agricultural crop fields and produced a significant part of the pheasant crop. A pheasant study in Brookings County, South Dakota, revealed 2.82 pheasant nests per acre of roadside cover--a high ranking among the various cover types searched for nests (Trautman, 1960-45). Also in South Dakota, Hanson and Progulske (1973-28) found, through radiotelemetry, that roadside and drainage ditch cover ranked next to alfalfa as the most extensively used cover by pheasants during all periods of the day, but especially during darkness. Likewise in Oregon, Eklund (1942-24), found that only fence rows and hayfields had more pheasant nests than roadside cover. Wright and Otte (1962-48) in a study of nesting pheasants in central Iowa, showed that roadsides sheltered the highest percentage of nests on a per-acre basis and that most nests were located in cover from 16 to 22 inches in height. Buss and Swanson (1950-14) mentioned use by pheasants of scattered wheat spilled by trucks on southeastern Washington highways and of grit available on the highway shoulders. Dalke (1938-17) and Kopischke and Nelson (1966-31) also reported on the use of roadside grit by pheasants.

In studies of resident game species in North Dakota, Hammond (1941-27) reported that graded and graveled roads were important locally to the welfare of Hungarian partridges (Perdix) because they provided the only grit ordinarily available during winter and he indicated that when the snow was deep, the windswept roads were apparently used as feeding areas, also. Upgren (1974-46) confirmed the use of such roads as feeding areas and suggested that the open stretches of highway absorb heat and probably are comfortable loafing sites on cold, but sunny days.

Dalke et al (1960-19) mentioned the use by sage grouse (Centrocercus urophasianus) as strutting grounds, of roadside sheep bedding areas and of old burns where openings have been created in otherwise nearly solid cover of sagebrush. They stated that in some cases, in Idaho, they observed the road itself being used as a strutting (display and mating) area.

In discussing the effects of flooding--and in particular, Hurricane Beulah, on the Attwater prairie chicken (Tympanuchus cupido attwater), Lehmann (1968-32) indicated that after the September 1967 floods, 55,000 acres of the Arkansas-Refugio-Goliard prairie in Texas were checked for these birds by helicopter and only 49 were found--all on or near elevated roads, knolls, ridges and/or inside brushland. Although it might be observed, parenthetically, that elevated roads provide a means of keeping these now relatively rare birds out of flood water, their presence on the road subjected them to highway mortality and one of the questions Lehmann said needed to be answered by research is: "Can birds be attracted away from heavily-used roads and airstrips with artificial booming grounds created by mowing, fertilization, or controlled burning?"

Another use of roads--especially dirt or sandy rural roads--by game birds, is for "dust bathing." Although this has been observed by many wildlife biologists and others, Campbell (1954-15) reported the apparently selected use by scaled quail in New Mexico of oily spots (some deliberately made by the investigator as an experiment by pouring used motor oil on the ground) in favorable dusting areas. He stated: "It would appear that quail find the 'de-lousing baths' of definite benefit (to discourage ectoparasites), and return to them time and again for treatment."

Use By Waterfowl

As in the case of upland game birds, some waterfowl make use of right-of-way vegetation for nesting. Thus, Milonski (1958-37) noted that near the Delta Marsh in Manitoba, roadsides ranked next to stubble fields in total number of nests found in upland cover. Stewart and Kantrud (1973-42), in a study of breeding waterfowl populations in North Dakota, found that although road ditches and drainage channels represented less than 0.5 percent of the total wetland in the area, they attracted about 2 percent of the breeding pairs. Oetting and Cassel (1971-38) in studying 630 acres of roadside along 23 miles of Interstate 94 in Stutsman County, North Dakota, found 422 duck nests that had an overall success of 57 percent in 1968, 1969, and 1970. Page (1971-40) pointed out that, in North Dakota, the acreage in rights-of-way represents an essentially unstudied resource of high potential for nesting habitat. In a 21.5 mile section of the Northern Pacific Railway's main line right-of-way in Stutsman County, he found 9.6 duck nests per 100 acres on hayed areas and 55.6 nests per 100 acres on unhayed areas. The acres mowed for hay produced 0.64 duckling per acre; the unmowed portion, 3.93 ducklings per acre. Duebbert and Kantrud (1974-515) also found high duck nesting densities in Minnesota roadside cover.

Use By Other Birds

While the presence of deer and other big game on highways may result in accidents, causing human deaths and damage to vehicles, as well as the loss of big game animals; and while pheasants and some other large birds may result in cracked windshields and other damage, use of the highway and highway right-of-way vegetation by other birds generally is less of a problem to motorists and can enhance the pleasure of motorists.

As pointed out by the former chief biologist of the U. S. Soil Conservation Service, Edward H. Graham (1947-520): "Anyone who has traveled the broad highways of Texas, for example, can scarcely fail to notice the number of birds' nests in the shrubs and trees that have been planted there. This is especially notable in the prairies and other treeless sections where woody cover is scarce. Even in the semi-arid western part of the state, Texas highways are dotted with clumps of trees and shrubs wherever, along the road, a low place indicated enough drainage water would collect to warrant the planting of them."

As indicated previously, highways destroy habitat and they create new habitat. Thus, starlings have been observed feeding young in cavities on rock faces formed in highway construction (Michael, 1971-35). I observed, for years, bank swallows nesting in a bank cut by U. S. Highway 50 west of the Chesapeake Bay Bridge in Maryland, but recent grading and revegetation apparently has destroyed the habitat for these swallows. Other swallow nesting sites in roadside cuts were observed by the author on a recent trip to Canada.

Emlen (1954-25) Dobson and Peake (1967-23), Alsop (1970-9) and Wallace (1970-47) have reported cliff swallows (<u>Petrochelidon pyrrhonata</u>) nesting under bridges in various parts of the United States. In the case of Alsop's observation, it represented the first nesting record of this species in Knox County, Tennessee. The barn swallow (<u>Hirundo rustica</u>) also frequently nests under highway bridges. An example is the observation made by Denton (1967-22) in Georgia where barn swallow nests were noted on the flanges of the several I-beams of a bridge.

Martin (1974-34) indicated that at one time the cave swallow (<u>Petrochelidon furlva</u>) was considered to be potentially endangered because, in Texas, it was thought to be restricted to sink holes and caves for breeding. Recently, Martin stated, the cave swallow has been found nesting in culverts which are also used by barn swallows and cliff swallows, a situation which he thinks may be hazardous to the species involved because of increased competition, vulnerability to disease or parasitism and breakdown of reproductive isolating mechanisms.

With respect to the exotic, or introduced, starling, Miller (1975-36) observed that the automobile age had proved a boon to this adaptable species by enabling people to live in suburbs with lawns abundant in seeds, insects, worms and grubs eaten by these birds, and by providing, through superhighways, thousands of miles of wide, grassy shoulders and median strips where starling food is available, and topped off by insects killed by cars. He stated, page 43, "The architects of today's elevated expressways, overpasses, roadway ramps, and bridges now provide drier shelter and more ample perching space than the birds had in Victorian times. Horizontal steel I-beams, supporting wide slab roofs of cement, make excellent sleeping quarters, protected from wind and rain...What is so striking about New York's starlings is that in a square half-mile of intersecting traffic arteries over the Harlem River...the birds have discovered an area with fewer humans afoot than any within miles of the city..."

Carbyn (1968-245), Hubbard and Hubbard (1969-261) and others have reported meadowlarks, ravens, crows, hawks and other birds feeding on carcasses of animals killed on roads. Hodson (1962-259) suggests that song thrushes in England use the bordering kerb-stone of roads as "anvils" for breaking snail shells and mentioned the consumption by members of the crow family of earthworms which frequent highway surfaces after a rain. In this connection, observations by Tabor (1974-44) also in England, would seem to indicate a relationship between moisture of freeway banks, vibration of traffic, the "surfacing" of earthworms and the number of crows and rooks attracted to the freeway (M4). Under dry conditions, the earthworms burrow deeper into the soil where traffic vibrations do not affect them.

A study in West Virginia (Ferris, 1974-26) indicated that the red-tailed hawk (*Buteo jamaicensis*) and the sparrow hawk (*Falco sparverius*) are observed more frequently within highway rights-of-way than would be expected by random distribution alone. He suggested this was due to the availability and vulnerability of prey within the right-of-way and, in the case of sparrow hawks, which, so often, are seen perching on utility lines, the availability of perch sites. The author suggested that highway rights-of-way could be of importance to red-tails and sparrow hawks if suitable vegetation is planted to encourage prey populations, and if perches are left during construction.

Use By Mammals

Rabbits and many other small, as well as larger, mammals frequent roadsides; some of them such as the rabbit (Beule and Studholme, 1942-12) have their nests in roadside cover. As in the case of birds, highways have destroyed habitat for some mammals and improved conditions for others. Baker (1971-10) pointed out that because such rodents as the voles or meadow-mouse (*Microtus*) and cottonrats (*Sigmodon*) occupy lands highly prized by man, farming, ranching and suburbanization have encroached on their habitats; but, on the other hand, forest clearing, irrigation, encouragement of grasses along highway and railroad rights-of-way, and introduced grasses such as bluegrass (*Poa*), quackgrass (*Agropyron*) and brome (*Bromus*) which provide attractive foods, have opened up new territory to these grass-eaters. We have already observed how construction of a highway in the dry Imperial County, California-Yuma, Arizona area resulted in increased moisture conditions which permitted the spread of the fossorial pocket gopher (Huey, 1941-30). Some burrow-digging rodents such as the woodchuck (*Marmota monax*) find the well drained embankments of highways and railroads suitable for their burrows and they make use of roadside vegetation. Thus, observations made by Manville (1966-271) along the Taconic Parkway in

New York State suggested a maximum woodchuck population of one per 46 acres along this parkway. He indicated that the woodchucks were so well adjusted to the traffic that a passing vehicle did not seem to disturb them.

In Arizona, Davis and Cockrum (1963-21) reported the use of bridges by bats for day roosts. Although they indicated that most bridges apparently provide sufficient shelter for night-roosing of bats, only two types seem to furnish the necessary conditions to allow them to serve as day-roosts; one is an open expansion joint bridge which has one to several open transverse expansion joints which are closed above with paving material but are open below and thus accessible to bats; and the other type, rare in Arizona, which has "...inspection openings at each end which open into rather large cave-like chambers formed within the terminal foundations of the bridge." The authors state: "Because of a recent trend toward the use of metal longitudinal under-supports, most newer bridges are not suitably constructed to serve as day roosts."

Broadbrooks (1958-13) suggests that for many years the northward extension of the Kangaroo rat (Dipodomys ordi) apparently was blocked by the Columbia and Snake Rivers. He speculates that this animal may have succeeded in crossing these rivers via bridges, but recognizes that there are other possibilities, also.

Robinson (1935-41) observed that truck trails and firebreaks on the Santa Barbara National Forest did not drive out deer; rather, the change in ecological conditions produced a new mixed growth of which the deer were quick to take advantage. (The same might be said of ruffed grouse and other wildlife in many areas.)

Dalke et al (1965-18) intimated that deer will come to a salted highway for salt, thus increasing the likelihood of accidents and stated that in the history of big game salting programs, this is one of the justifications of salting on big game areas, i.e. to hold game away from snow-cleared railroads.

Discussion of other uses of highways will be included in the section "Highway-Wildlife Mortality and Effects of Highways on Animal Behavior." Although undoubtedly other references could be found on use of highways by wildlife, they must mostly be buried in the literature and consist largely of incidental mention of highways. The highway right-of-way habitat, however, is sufficiently extensive and important that more attention should be paid to it in wildlife studies.

EFFECTS OF HIGHWAYS AND HIGHWAY CONSTRUCTION ON FISH AND WILDLIFE

Some of these effects have been mentioned previously under "Highways and Highway Rights-of-Way and Their Use by Wildlife," others will be mentioned under "Vegetation Management for Erosion Control and Other Purposes" and in sections of this report dealing with management opportunities for fish and wildlife.

Displacement and Alteration of Habitat

The most obvious effect of highway construction is the clearing, grading and surfacing of thousands of square miles of habitat, whether agricultural, forest or grassland--a process that is still continuing at a rapid pace. In Highway Statistics-1973, the U. S. Department of Transportation (1973-5) listed for 1973, the mileage of built on roads not on state highway systems as 73,538 graded and surfaced and 4,712 miles as graded and drained. Mileage built on primary state highways, including municipal extensions, totaled 19,088. For all secondary state roads, including county roads under state control, the total mileage reported graded and surfaced was 7,686 and the total mileage graded and drained, 29. Within the National System of Interstate and Defense Highways, rural, there were 5,720 miles of surfaced, undivided highways and 28,062 miles of surfaced, divided highways reported as of December 31, 1973. Approximately 46% of the undivided highways had surfaced widths of between 24 to 26 feet and most of the divided highways had surface widths of 48 feet or more.

Bruna (1969-95) reported that interstate and access roads constructed under the Appalachia Program in Kentucky would destroy some fish and wildlife and result in easier access to recreation areas. Based on State plans at that time for additional toll roads, he calculated that over 40,000 more acres of land would be paved and in highway rights-of-way by 1971 and--figured at one rabbit per five acres and one covey of quail per 40 acres, "this destruction will have cost the sportsmen the loss of 9,256 rabbits and 1,157 coveys of quail annually."

Walcott (1974-793) discussed changes in bird life on two originally similar six-acre tracts in the Cambridge, Massachusetts area over the period 1960 to 1964. Effects of urbanization--including city streets and plantings--are noted and effects of two exotic species (house sparrow and starling) and the use of insecticides on native species are discussed. In the course of the study, the bird life of the residential area changed from 26 nesting species, mostly summer residents, and a few transients, to nine nesting species composed of a majority of permanent residents and outnumbered by transient species.

As another example of changes in fauna brought about by urbanization, Minton (1968-776) recorded two species of salamander, six species of anurans, six species of turtles and seven species of snakes in an area on the edge of Indianapolis in the period of 1949-58. During 1963 and 1964, only two species of anurans, one species of turtle, and four species of snake were recorded. He considers modification of the aquatic habitat on this urbanizing area to have been the most important factor in reducing the number of species.

Klemmedson (1967-103) stated: "New super and interstate highways occasionally pass through winter range (of big game). When they do, habitat is destroyed at the rate of several acres per mile. To minimize winter maintenance, highways are more often than not located on south-facing slopes, much to the detriment of the winter range."

With respect to rare and endangered species, the U. S. Department of the Interior (1975-106) in a news release dated May 21, 1975, stated: "Sea turtles, which can grow to 1,500 pounds, rarely come on land except to lay eggs. Human development of coastal areas for industry and tourism has destroyed many of these nesting sites. Along shorelines, bright city and highway lights confuse hatchlings and attract them inland where they die."

Aside from destruction of vegetation and displacement of habitat, erosion and sedimentation resulting from highway construction are primary effects of highway construction.

Erosion, Channelization, Drainage and Sedimentation Effects

Many of the articles noted dealt with erosion, sedimentation, and various other hydrologic impacts of highways and highway construction without reference to effects on fish and other aquatic organisms.

Vice, Guy and Ferguson (1969-90) in a study of the Scott Run Basin, Fairfax County, Virginia, found that highway construction areas, varying from less than one percent to more than 10 percent of the basin at a given time, contributed 85 percent of the sediment. The sediment yield was about 10 times that normally expected from cultivated land, 200 times that expected from grassland, and 2,000 times that expected from forest land. Parizek (1971-69) found that the presence or absence of deep cuts and extensive fills in highway construction can produce a large variety of transformations on the terrain and in the hydrogeologic environment, including the beheading of aquifers, development of extensive groundwater drains, damage and pollution of water supplies, changes in groundwater and surface-water divides and basin areas, reduction of induced streambed infiltration rates, siltation of channels, obstruction of groundwater flow, and changes in run-off and recharge. Lanyon (1972-65) pointed out that the modern highway has a high efficiency of stormwater drainage which is beneficial to the highway, but detrimental to the waterways into which the runoff is discharged.

He indicated that the associated landscaping near the highway often reduces the natural storage of rainwater and reduces the rate of rainwater infiltration, causing additional problems of increased flow in the waterways. In an inventory of roadside erosion in Wisconsin, Briggs (1973-54) found erosion to be prevalent, but that 73 percent of the erosion occurred along town roads and 24 percent along county roads. If similar disparity exists between effectiveness in erosion control for local and state or interstate highways in other states, it would seem that greatly increased attention is needed for erosion control along local roads.

Anderson (1974-50), in a study of sediment deposition in California reservoirs, found that roads located near streams contributed the most to deposition--twice as much as roads located elsewhere--and that improved secondary roads near streams were the single greatest contributor.

Younkin (1973-93), who conducted a study to obtain the relationship between highway construction and change in suspended sediment yield in stream systems, concluded that sediment supply to streams increases with rain energy, clearing and grubbing, embankment work, and proximity of construction to the stream and that results of the study may be employed as a means of predicting whether highway construction would be a significant pollution source for a particular site, a criterion to be considered by an engineer during location studies, and a basis to evaluate the effectiveness of attempts to control sediment yield from construction areas.

The Office of Water Resources Research (USDI) (1971-89) has issued a bibliography of 116 abstracts of current and earlier pertinent reports on urbanization and sedimentation. Also, the American Association of Highway Officials, Subcommittee on Roadway Design (1973-49) has developed guidelines for hydraulic considerations in highway planning and location.

Some articles, however, including several concerned with construction of logging roads and channel alterations, mentioned effects on fish and other aquatic organisms.

Platts (1968-74), in reporting on an aquatic habitat survey in which he evaluated sediment accruement, movement and damages, stated that the major causes of death or low production in anadromous salmon, steelhead trout and resident salmonid populations can be summed up in five areas: reduction of population size by extreme floods; status of water levels during early stages of incubation and its effects on the survival of deposited eggs; rate of permeability of the intragravel waters in the spawning area and resulting fry production; loss of carrying capacity due to decreased rearing and production potential from adverse conditions within the watershed; and restriction of passage and access (as through road culverts) of both adults and juveniles between their rearing and production areas. He indicated that much of the South Fork Salmon River sediment is due to landslides and slumps associated with intensive storms coupled with lands disturbed by road construction, mining, logging, fire, and domestic livestock, and he stated: "Sediment (all streambed or water suspended solids 9.51 mm or less in diameter) ...especially in spawning areas, can cause serious mortalities among salmonid embryos, alevins, and fry still in the gravel. The crusting of sediment over spawning areas kills the alevins by filling the interspaces and thus not allowing them to emerge to surface waters. Sediment has great effect on the permeability and rate of water interchange through spawning gravels and flood rearing areas. Sediment also clogs up the spaces within the gravel, decreasing permeability and adversely affecting the survival of salmonid embryos and other aquatic organisms."

Burns (1972-464), in a study of northern California streams, found logging to be compatible with anadromous fish production when adequate attention was given to stream protection and channel clearance. However, he noted that extensive use of bulldozers on steep slopes for road building and in stream channels during debris removal caused excessive streambed siltation in narrow streams.

Tebo (1955-86), in studying a logged area in North Carolina, found a significantly lower standing crop of bottom organisms below the mouth of the logged area compared with an area not subjected to siltation from the logged area where logging roads and skid trails were the chief sources of sediment.

Barns (1969-51) pointed out that successful development in and escape from the intergravel environment poses specific problems to salmonid larvae and adaptive responses have developed to cope with these problems.

Whitney and Bailey (1959-92), studying the detrimental effects of highways and construction on a Montana stream, found reductions in game fish in the area, including trout and mountain whitefish (*Prosopium williamsoni*) amount to 94 percent in both numbers and weight of the large-sized fish, to 85 percent in number and 76 percent in weight of the small-sized game fish. Irizarra (1969-61) made similar observations in Idaho.

Shannon (1967-80) pointed out that logging roads, skid trails and landings located in the streambed or on its bank are particularly bad from the standpoint of sedimentation of fish-producing streams.

Dr. Ruth Patrick (1973-71) has provided a concise and authoritative analysis of effects of channelization on the aquatic life of streams. She states, "The chief effects of channelization are as follows:

1. Removes the natural diverse substrate materials that allow the development of many types of habitats for aquatic organisms;

2. Increases sediment load that decreases light penetration and primary production;

3. Creates a shifting bed load that is inimical to bottom-dwelling organisms;

4. Simplifies the current pattern and eliminates habitats of diverse currents;

5. Lowers the stream channel and often drains adjacent swamp areas and aquifers that help to maintain stream flow during times of low precipitation;

6. Destroys floodplain ponds that are the breeding ground for aquatic life and that act as a reservoir of species for the river proper; and

7. Reduces the stability of the banks and causes cave-in of trees and other overhanging vegetation that are an important food source for stream life and whose shade reduces high stream temperatures during the summer months."

Dr. Patrick points out that usually channelization is done to increase the rate of flow in streams but sometimes to obtain road-building materials. She indicates that snagging and removing vegetation from the banks produce profound changes in the ecosystems of the streams and that removal of floating debris eliminates an important habitat for aquatic organisms. The removal of sand and gravel from the stream bed for road improvement often is done without regard to the gradient of the stream and to natural bed contours. Large holes may result in areas where stagnant water accumulates without the necessary oxygen for aquatic life..."When a channel is straightened the banks are often riprapped with quarried stone at a vertical angle. The result is that the sun reaches the water surfaces for an insufficient period of time to support algae growths that are important as food for animals in the ecosystems. If the banks were riprapped at an angle of 30 to 45 degrees with natural water-worn stones, current patterns would be produced that favor native stream organisms...If dredging is done, attempts should be made to restore the natural contour of the channel bed, for example, create pools and slackwaters in shallow streams or restore the roughness of the channel bed. That would interfere very little with the carrying capacity of the channel under flood conditions, but would greatly improve the bed habitats for species occupancy."

Other comments on stream channelization or specific examples of effects of stream channelization on aquatic organisms follow.

Peters and Alvord (1964-72) indicated there had been 1,987 individual alterations in 768 miles of stream channel inventoried along 13 Montana streams and that road construction ranked next to agriculture and railroad construction as a cause for the alteration. As a result of man-made alterations, channels were shortened by 68 miles and standing crops of game fish were several times less abundant than in natural, meandering channels.

Menendez (1968-67) reported on a survey of 19 dredging and stream bank stabilization projects involving a total of 22,400 feet of stream alterations. He attributed as losses caused by these projects 27.2 acres of water valued at $81,600; annual fish population losses of $3,517.22, plus additional expected losses of $1,679.04; and 140 man-days of angling per acre per year valued at $1,522.80.

Schubel, Auld and Schmidt (1974-79) reported that in the laboratory, concentrations of up to 500 mg/l of suspended sediment did not significantly affect the hatching success of yellow perch or striped bass eggs, but that concentrations of 1000 mg/l did significantly affect their hatching success.

Funk (1973-503), in a paper dealing with characteristics of channels for warm-water fisheries, emphasized that the diversity of the fish community is due to adaptation of the individual species to the great variety of physical, chemical and biological conditions in various stream environments and that man-made channels cannot equal natural channels in diversity.

Tarplee, Lauder, and Weber (1972-84), based on studies in North Carolina, described detrimental effects of stream channelization on aquatic organisms, but indicated that following channelization and with no channel maintenance, nature can ultimately restore a coastal plain stream and its fish population to a stage reasonably near its natural condition. Schubel, Auld and Schmidt (1974-79) found that under laboratory conditions, natural fine-grained sediments of up to 500 mg/l did not significantly affect the hatching success of yellow perch or striped bass eggs, but that concentrations of 1000 mg/l did significantly affect their hatching success.

An annotated bibliography of selected references on effects of suspended and deposited sediments on estuarine organisms (Sherk and Cronin, 1970-82) may be of value in considering erosion and channelization effects on aquatic organisms. Also, for one of the most comprehensive reviews on channelization, the reader is referred to the report prepared on this subject for the Council on Environmental Quality by A. D. Little, Inc. (1973-506).

Other Detrimental Effects of Highway Construction

Berryman (1963-94), in discussing road construction and resource use, pointed out that, in addition to the direct loss of land in highway construction, there is an indirect loss due to residential business and industrial developments which follow new highways. He observed that loss of farm land is important to upland game and that if isolated islands of habitat are created through highway construction, game management and harvest is impractical. He mentioned, also, the interference of highways with the semi-annual migration routes of big game animals, problems of fencing, and drainage of swamps and marshes, as a consequence of highways and related developments.

Norman V. Hancock (1963-100) expressed the view that Federal highways planned to be completed by 1973 in Utah, in addition to using 28,950 acres of land, would render present hunter-access roads useless because of access restriction of freeways; increased high speed would account for increased mortality of game; and fences built along these highways would interfere with migrations of big game and pose major law enforcement problems as a result of migrating game concentrating at fences. Hay (1960-735) felt it was the responsibility of Federal land use agencies to improve existing roads and provide new ones in the West where there was limited access to hunting and fishing areas.

Gilbert (1975-98) and DeLeonardis (1970-96), in writing of potential impacts of the Alaska pipeline and related highway developments, expressed concern over the new people pressures that would be placed on wildlife and wildlife habitat. DeLeonardis listed the following problems or potential problems: (1) although the actual physical "take-out" of habitat is relatively insignificant, human activity may influence a much larger area; (2) stream bed gravel, perhaps the best source of gravel for pads on which construction may be accomplished without melting the permafrost, if extracted improperly, can cause degradation of downstream spawning beds and trap downstream-migrating smolts in poorly designed temporary streamside pits; (3) garbage dumps attract bears, foxes, and other furbearers which must be removed or destroyed when they become pests; (4) harassment and excessive take of wildlife, legal or illegal, could have severe consequences for wildlife populations; (5) the network of roads and connecting feeder pipelines, built on elevated gravel pads may tend to restrict caribou movement along the slope; and (6) oil spills on the tundra could have long-lasting detrimental effects.

As pointed out by Sutton (1955-104), both farmers and highway construction engineers are interested in having drainage channels and outlets large enough to handle the flow from the drainage system, whatever that might be. He indicated that a problem has been encountered where highway, road or railroad culverts were placed too high or were too small and had to be replaced with difficulty and considerable expense. He cited the

Ohio Turnpike planning and construction as being exemplary because the engineers, at the outset, planned for adequate bridges and culverts to take care of existing drainage systems and provide for future requirements.

In connection with highway drainage, Harmon (1971-101) stated: "New highway construction in the prairies (the pothole area of the Dakotas, western Minnesota and parts of Manitoba, Saskatchewan and Alberta) threatens vast numbers of wetlands. Less obvious a threat than ditches dug solely for drainage, these projects can place drainage outlets within easy reach of most landowners. Federal funds go to both county and state highway departments to help expand the road system. Along with the money come certain engineering specifications conducive to increased drainage." He went on to explain how "a single road construction project, six miles in length, is now in the process of eliminating waterfowl habitat that produced more than 2,000 ducks per year."

A task force of the U.S. Department of the Interior, Fish and Wildlife Service (1975-107), based upon a sampling of 28,953 miles of highways--2,777 state and federal, 9,797 county, and 16,379 township--in 19 western Minnesota counties, estimated that 99,292 acres of wetland had been drained as a result of highway construction at the rate of 2.33, 2.62, and 4.10 acres, respectively, per mile of highway.

The task force stated: "Wetland destruction has been most severe where neither NEPA nor the Department of Transportation Act apply. Generally, but not exclusively, locally financed township and county roads which are not part of the federal and state highway system have successfully circumvented environmental safeguards."

Dryden and Jessop (1974-97) discuss another problem involved in highway construction--the impact of culvert design and effects on hydrology and fish. They defined fish migration discharge design as required by the Fisheries and Marine Service, Environment Canada, for northern culverts and stated that at this or lower discharges, flow conditions must allow for the upstream passage of fish. In a study of Frog Creek, Northwest Territory, they calculated the fish migration discharge as 800 cfs and stated that if the Dempster Highway Culvert in Frog Creek had been designed to allow fish passage at this discharge, the delay to fish migration would have been only 3 to 4 days. Water velocities in the Frog Creek culvert during 1973, however, exceeded the maximum allowable velocity of 5 fps for 40 days (from May 26 to July 5) and bank erosion downstream from the culvert caused retreat of the river bank at a rate of 15 cm (6 inches) per day. They pointed out, further, that ice buildup inside the culvert occurred primarily during early spring as a result of over-ice flow and that high water velocities within the culvert blocked the spawning migration of approximately 600 northern pike, <u>Essox lucius (L.)</u> and appeared to block movements of some broad whitefish, Coregonus nasus (Pallas). Fish passage did not become possible until July 5, when velocities of less than 5 fps were attained.

The U.S. Department of Agriculture, Forest Service (1974-105) (California Region), in an inventory of fish and wildlife habitat improvement needs, stated: "Many fishes in the course of their life cycle, migrate upstream at certain times of the year to reach suitable spawning or feeding areas. Their access to these waters is often prevented by various stream crossing structures installed by man, such as culverts, weirs, dams, and certain types of bridge abutments. Most such barriers can be modified at reasonable expense to provide adequate fish passage. Elimination of these barriers is an important factor in restoring and maintaining our trout and salmon resources."

Further discussion of fish passage facilities is included under "Other Opportunities for Managing for Fish and Wildlife."

EFFECTS OF HIGHWAY MAINTENANCE AND OPERATION ON THE ENVIRONMENT

De-Icing Chemicals and Their Effects

According to Field, Masters, Tufuri and Struzeski (1974-123): "Currently about 9 to 10 million tons of sodium chloride, 0.3 million tons of calcium chloride, and 11 million tons of abrasives are used annually (for highway de-icing purposes). Highway salting rates range from 400 to 800 pounds of salt per mile of highway application, and many roads annually receive more than 50 tons of salt per mile." These authors point out that de-icing salts are often stock-piled in open areas without suitable protection, and that salt-laden drainage has easy access to nearby water supplies. They indicate that sodium from road salts entering streams can overstimulate the growth of blue-green algae and that sodium and calcium ion exchange with mercury could, under special sediment conditions, release highly toxic mercury or other heavy metals to the overlying fresh waters. They state, further: "Ferric ferrocyanide and sodium ferrocyanide (anti-caking additives, common in road salt) are soluble in water and can generate cyanide in the presence of sunlight... . Further research is needed to establish the ultimate fate of these cyanides in the environment."

Hanes, Zelazny and Blaser (1970a-126) observed that cyanide ions are extremely toxic, especially to fish. They mentioned, also, that a rust inhibitor added to the de-icing salts, contains phosphorus which serves to stimulate excessive aquatic plant growth in freshwater lakes and leads to "algae blooms" and further problems. Schaufnagel (1967-146) and Wolsko, Nelson and Habegger (1974-724) had further comments concerning effects of de-icing chemicals on fish and wildlife and water quality.

Sharp (1971-145) stated that Diamond Lake in Hennepin County, Wisconsin, which receives the discharge of a major storm sewer, now has a chloride content of 2.270 ppm, equivalent of 3,780 ppm sodium chloride. To place these values in perspective, however, he indicated that in terms of fish tolerance, bluegills will tolerate 10,000 ppm sodium chloride and rainbow trout sustained 20 percent mortality at 12,000 ppm.

Hawkins and Judd (1972-128) found the chloride content of the water at Meadowbrook, New York reached a high of 11,000 ppm in December, 1969. They stated: "Salt runoff entered a small lake, and flowed directly to the lake bottom. The buildup of high density saline water in the lower portion of the lake prevented complete mixing in the spring. Incomplete mixing led to anoxic conditions in the lower lake strata. The populations of benthic fauna of the lake was changed by the flow of salt water into the lake. From a total of 10 species of dipteran larvae and olegochaetes, only 4 species remained."

Trainer and Karstad (1960-148) diagnosed salt (NaCl) poisoning in wild rabbits, pheasants, quail and a pigeon in Wisconsin during the winter of 1958-59. Affected animals showed signs of severe derangement of the central nervous system. A similar disease was experimentally produced by the administration of sodium chloride to wild rabbits and pheasants but the source of sodium chloride in the naturally occurring disease was found to be salt spread on highways to control slippery road conditions. The authors believed that unusually severe weather and heavy snowfall predisposed to the poisoning of wildlife by creating "salt hunger" and restricting water intake in the affected animals when the only source of water is snow. They consider salt poisoning in wildlife an accidental disease of unknown frequency of occurrence due to the difficulties encountered in detecting and estimating mortality in wildlife populations.

Roberts and Zybura (1967-144) stated that more than 24,000 pounds of sodium chloride per mile of four-lane highway had been used per year for ice removal on some sections of Interstate 80 in Iowa--enough to prevent establishment of certain types of grass cover along the highway. They indicated that up to 600 ppm sodium chloride in the soil stimulated growth of grasses, but injury became more pronounced as salt levels increased from 1,000 to 5,000 ppm. Kentucky 31 fescue appeared to be best suited where roadside soils are contaminated by salt.

As was true in most of the literature reviewed in connection with this project, there were far more articles (see bibliography) which dealt with the extent of use of de-icing salts and its transport into water or its effect on soil and vegetation than those which dealt with effects on fish and wildlife, either direct or indirect. Many of the summaries provided by HRIS on de-cing chemicals were not included in the bibliography.

Adams (1973-108) seems to sum up the situation by stating: "Dissolved salt entering streams, rivers, ponds, and lakes acts as a weak electrolyte, thereby changing the electrical conductivity of the aquatic system. In concentrations greater than 1 percent, all freshwater species of bacteria, algae, invertebrates, fish, and higher plants are placed in immediate jeopardy. Science simply does not know what the long-term effects of small amounts of artifically induced salts are on species of freshwater organisms. We need to know which species are relatively resistant and which species are slightly or seriously affected, and most of all we need to know the effect of salt on fundamental evolutionary processes of selection and adaptation... the most obvious effect on roadside vegetation is that susceptible species such as white pine, hemlock, sugar maple, red maple, and most ornamentals respond with symptoms of chronic toxicity, burned or browning foliage. Salt apparently interferes with normal photsynthesis and respiratory processes and, at acute levels of toxicity, will kill the leaves directly. Small amounts of salt absorbed through roots or exposed vegetation will lead to premature coloration of leaves and early leaf fall in the next year. With acutely toxic doses, the plant dies and, unless the dead portions are removed, the salts contained therein will be recycled to the roadside environment...in all probability, salt has the potential for acting as a selection agent in the natural environment."

Several of the authors suggest ways of minimizing de-icing chemical use: Transportation Research Board (1974-149), Field, Struzeski, Masters and Tafuri (1973-123); or of reducing damage (Rich, 1973-142); and the Environmental Protection Agency (Field et al, 1974-122) has initiated several projects to attempt to better understand and control the road salt problem. Several review type articles and general references are available in the bibliography and others were surfaced by the HRIS literature search. Anderson and Auster (1974-109) state that given the findings in their study of costs and benefits of road salting, "...it appears that the use of salt for de-icing should be curtailed."

Roadside Rest Areas and Parks - Waste Disposal

Roadside rest areas and parks are a familiar part of the highway system. Not only do they offer the traveler a place to rest but, situated as they often are in wooded or otherwise attractive areas, they afford an opportunity for the motorist to view at first hand some of the vegetation and wildlife he has been speeding by on the highway. Picnicking facilities, including the usual garbage cans, may result in visits by bears, raccoons and other wildlife-seeing which could be the highlight of the day for some travelers. In the case of bears, however, it could mean trouble if the travelers are not taught to regard them as wild animals and as possibly dangerous. Information on vegetation and wildlife of the area, if made available in roadside parks, could add to the value of the stop for many people.

There may be problems of water supply and waste disposal in developing and maintaining these areas. Several publications dealing with these problems were included in this bibliography, among which were those of the Federal Highway Administration (1971-162); Parker (1974-158), who deals with the feasibility of water reuse at highway rest stations; Solomon (1974-159); Sylvester and Seabloom (1972-161); who consider alternative methods of wastewater disposal at rest areas; and Stuart (1970-160) who conducted research to establish design parameters for applications to rest area sewage treatment facilities.

Other Pollutants Resulting From Highways - Effects

A voluminous amount of literature is being produced on pollutants from the operation of automotive vehicles. Many of the 382 document records provided by HRIS, dealing with air pollution, were not included; however, several representative articles dealing with air and water pollution are incorporated in the bibliography, whether or not they include information on effects on the biota; most of them do not. However, given information on the levels of pollutants reaching soil and water from the highway system, readers may gain some insight as to the potential effects on organisms by referring to the 594-page report, "Water Quality Criteria: by the committee on Water Quality, Environmental Studies Board, National Academy of Sciences/ National Academy of Engineering (1973-195).

Among the most comprehensive of the reports reviewed which deal with contributions of street or urban roadway usage to water pollution, are those by Sartor and Boyd (1972-209) and Shaheen (1975-211). They point out that there are many sources of surface contaminants, which are deposited on roadways within an urban area, including industrial operations, land use activities, and fallout of air pollutants, in addition to roadway usage. These materials are then carried into receiving waters by storm runoff where they constitute a substantial portion of the overall water pollution problems of cities. For urban areas, Shaheen states: "Less than 5% of the weight of traffic-related deposits originate directly from motor vehicles; however, these pollutants are among the most important by virtue of their potential toxicity." He goes on to make the following points: "Much of the grease and all of the petroleum and n-paraffins result from spills or leaks of motor vehicle lubricants, antifreeze and hydraulic fluids. Traffic-related lead is deposited principally through the use of leaded fuels, however, some results from the wear of tires in which lead oxide is used as filler material. Zinc is also used as a filler in tires and at high concentrations in motor oil as a stablizing additive. Copper, nickel and chromium are wear metals from metal plating, bearings, bushings, and other moving parts within the engine. Considerable copper is deposited as a result of wear of brake linings which have copper added to increase mechanical strength and promote more rapid dissipation of heat. As reported in recent studies of motor vehicle operations, asbestos arises from wear of clutch and brake linings (1) and tire wear is the source of traffic-related rubber found in roadway deposits, (2)." Recommendations to reduce or eliminate contributions of motor vehicular traffic to urban roadway runoff are given. Effects of the pollutants on the biota along roadsides and streets or in the receiving waters are not dealt with, but one of the author's recommendations was that a study be initiated in the near future to determine the physical, chemical and biological alterations induced by the highways, both during runoff events, and on a long-term basis.

The U.S. Department of Transportation, Federal Highway Administration is currently funding a research project being conducted by Envirex, Inc., entitled "Effects and Evaluation of Water Quality Resulting from Highway Development and Operation." The major objectives of the research are to: (1) identify and quantify the constituents of runoff emanating from highway facilities; (2) determine the physical, chemical, and biological characteristics of the runoff constituents; (3) establish what effects these constituents have on the quality of surface waters; and (4) identify the impacts on the environment due to any changes in water quality. This three year study coupled with other research projects will aid in determining the impact of highway operation on the environment and help establish methods to mitigate detrimental impacts.

Sartor and Boyd (1972-209) pointed out that much of the overall pollutional potential is associated with the very fine silt-like material, much of it near the curb, which conventional street sweeping operations are rather ineffective in removing.

Many of the articles referred to in this bibliography focused on heavy metals--particularly lead. Davidson, Huntzicker and Friedlander (1974-173) in a study of trace elements in Los Angeles and surrounding areas indicated that at least three of the 5.8 tons of Pb which are blown out of the urban basin each day are transported large distances from Los Angeles before being removed from the atmosphere. Lagerwerff and Specht (1970-188) showed that concentrations of Cd, Ni, Pb, and Zn in roadside soil and grass samples from several locations decrease with distance from traffic and also with depth in the soil profile.

Lazrus, Lorange and Lodge (1970-189) analyzed, by atomic absorption, atmospheric precipitation samples collected at a nation-wide network of 32 stations and found that among lead, zinc, copper, iron, managaneses and nickel, the concentration of lead, only, was significantly high with respect to the allowable concentrations in drinking water. However, they indicated that there was evidence that lead forms insoluble materials in surface waters and is removable by sedimentation or by filtration.

Motto et al (1970-194) found that lead contents in soils and plants sampled along heavily traveled highways tend to increase with traffic volume and decrease with distance from the highway. Much of the lead, they state, was present as a removable surface contamination on the plants and the major effect of traffic was limited to a zone within 100 feet of the highway. Apparently plants may obtain lead through both leave and roots and there is little translocation within the plant.

A pond near Michigan City, Indiana, along the Indiana Toll Road, was found by Peyton and McIntosh (1973-201) to contain, in the upper 10 centimeters of sediment, 1.40 ppm cadmium, 251 ppm zinc and 126 ppm lead (dry weight basis)--considerably lower concentrations than found in samples from a borrow pit near Gary, Indiana, exposed to both automotive and industrial aerial deposition of trace elements.

Sylvester and DeWalls (1972-218), based on preliminary study results in the Seattle, Washington area, concluded that a major portion of vehicle emissions are apparently carried off the road surface by air currents and by splashing, the larger sized particulates settling close to the road surface. If they settle on a soil surface it is likely that most of the particles are retained in the soil. They believe a significant portion of the soils, heavy metals, and nutrients are absorbed to particulates and other solids.

Smith, Szajnar and Hecker (1970-214) studied lead levels in a large number of experimental animals (guinea pigs and rabits), comparing lead levels of animals in chambers where they were breathing air from an intersection in central Detroit with levels in animals maintained in identical fashion, but breathing filtered air assumed to contain no lead components. Analysis of tissues from the two groups of animals revealed higher levels in the exposed group, particularly in the bone lead levels. Their study seemed to indicate that, although the lead intake via ingestion was considerably greater than that by inhalation, the more efficient absorption of the inhaled lead accounted for the difference in lead levels in the two groups of animals.

A number of publications dealing with effects of lead on wild animals were noted. Two studies (Giles, Middleton and Grau, 1973-181), and (Price, Rathcke and Gentry, 1974-204) provided evidence of accumulation of lead by insects in areas of high traffic density, and biological concentration of lead from herbivore to carnivore (predator) trophic levels.

Two articles dealt with lead concentrations in tissues of roadside populations of deer mice (Peromyscus spp.). Welch and Dick (1975-213) in England found that accumulations of lead in mouse liver, kidney and bone, but not in brain, lung, stomach and muscle, were related to both traffic volume and nearness to highway. Mierau and Favara (1975-193), although finding elevated levels of lead in the bones of roadside mice in Colorado, could not demonstrate lead poisoning in the mice; in fact, the exposure level required to produce recognizable lead poisoning in captive deer mice was approximately five times greater than that encountered by the wild roadside population.

Williamson and Evans (1972-225), reporting on lead levels in roadside invertebrates and small mammals, found concentrations of lead in invertebrates to be generally below 50 ppm (up to 700 ppm in woodlice or Isopoda) and 30 ppm or less in the tissues of small mammals--less than the levels found in many of their prey. They found no evidence of decreasing populations of invertebrates with increasing levels of lead in soil and vegetation close to roads. Thus, we have what so often seems to obtain, conflicting information, in this case, on biomagnification of lead levels from one trophic level to another.

That there is some cause for concern, however, was brought out in a study in Gish and Christensen (1973-182) in which they quantified the presence of certain heavy metals in earthworms collected from the soil along two Maryland highways. They stated: "Earthworms accumulated up to 331.4 ppm of Pb and 670.0 of Zn, concentrations which may be lethal to earthworm-eating animals." They observed that earthworms are food items for many birds as well as certain amphibians, reptiles, and mammals, but the toxicity of metal residues in worms to such animals has not been studied.

Several other studies dealing with effects of heavy metals, not necessarily related to highways as a source of pollution, on fish and wildlife were noted. Sanderson and Thomas (1961-208), for example, suggested that, although raccoons appear to be resistant to high levels of lead, lead intoxication, along with other factors may be a cause of mortality in wild populations. Cook and Trainer (166-177), in experimental lead poisoning of Canada geese (Branta canadensis) found normal lead levels to be 0.018 - 0.137 mg/100 g blood and that the lead levels of lead-poisoned geese reached a peak between the third and tenth day, and ranged from 0.320 - 1.680 mg/100 g.

Rolfe, Chaker and Ewing (1972-206) have constructed a model to simulate movements and predict accumulation points of lead in a watershed ecosystem which may be helpful in the study of pollutant transport and accumulation in ecosystems. William Smith (1975-217) points out that while our appreciation of the distribution of lead in the roadside ecosystem is good, our understanding of its chemistry and the effects on the biota are deficient.

Eisler's (173-175) annotated bibliography on biological effects of metals in aquatic environments and the United States Department of the Interior's (1970-221) bibliography on mercury contamination may prove helpful to researchers and planners concerned with highway-wildlife relationships.

There are other pollutants and adverse effects stemming from highway systems, including pesticides used for controlling insects and diseases of rights-of-way vegetation, noise effects, effects of bridge demolition, and litter. Because of the large volume of literature on insecticides and other pesticides, including much which deals with side effects on fish and wildlife, references on this subject have been generally excluded from this bibliography. Readers are referred to the U.S. Fish and Wildlife Service, Washington, D.C., 20240, as a major source of information on the latter subject. The "Bibliography of Research Publications of the U.S. Bureau of Sport Fisheries and Wildlife, 1928-72" (Eschmeyer and Harris, 1974-405) lists many relevant references. With respect to urban/suburban sources of pesticide pollution, Jacobson (1972-185) points out some of the hazards of pesticides in water and indicates that although the addition of activated carbon to the waste water treatment system decreases the amount of pesticides in water, the amounts of carbon required are large.

Gamble et al (1974-180) provide considerable information on noise pollution arising from automotive vehicles. Likewise, Kugler, Bolt et al (1974-186) assess the relative noise of traffic and its impact on people exposed to alternative highway locations or designs and control of highway noise through highway design. Memphis State University (1971-192) in a literature search for effects of noise on wildlife and other animals, prepared a bibliography on this subject for the Environmental Protection Agency, Office of Noise Abatement and Control. Also, references are made to effects of noise on wildlife under the heading, "Effects of Animals on Plantings and Other Aspects of the Highway System: Problems of Control."

Another cause of pollution, not usually associated with soil erosion or automotive traffic, is that of bridge demolition. Poche and Hensley (1975-202), recognizing that bridge demolition mobilizes large amounts of stream sediment in the immediate area of the structure, made an ecological assessment in terms of stream macroinvertebrates and suspended solids shortly before, shortly after, and eight months after demolition of a bridge deck in Virginia. They reported that no environmental damage was indicated even though suspended solid levels exceeded 200 ppm shortly after demolition, and stated that the U.S. Environmental Protection Agency's proposed limits for suspended soils appeared to be too low for short-term stream disturbing events. They found populations of Diptera, Trichoptera, Ephemeroptera, Coleoptera and other aquatic organisms in the stream, which they considered indicative of excellent water quality. Recommendations for use of rock berms in bridge demolition and for ways of monitoring future bridge demolition were suggested.

Wolsko, Nelson and Habegger (1974-724) state that although solid waste generated by ground transportation systems at first appears to be rather insignificant, parts of vehicles, such as wheels, tires, and mufflers, as well as an assortment of litter from passing vehicles, are scattered along the rights-of-way. They state, "Considering the more than 100 million vehicles on the road in the United States today, approximately 200,000 cu. ft. of rubber from tires is dispersed each day into the air as particulates. The cubic feet of particulate brake lining is on the order of thousands of cubic feet per day. In Cook County alone, the State of Illinois has a maintenance crew of over 100 men who work full time cleaning the shoulders along highways. The County of Cook and City of Chicago also have men who are employed to clean the same highway rights-of-way. In 1967, 16,400 tons of debris were found along the highways in Cook County by the State of Illinois maintenance crews. This amount of debris is equivalent to the solid waste that would be generated by a city of 22,000 people." Junked cars visible from highways are "eyesores" and often harbor rats; those thousands scattered in fields and farm yards undoubtedly supply some cover for rabbits and other wildlife, but better use might be made of them.

Highway Wildlife Mortality and Effects of Highways on Animal Behavior

One of the most direct--and final--effects of highway use on wildlife is the annual toll resulting from vehicle-wild animal collisions or accidents. We have included under this heading in the bibliography, 78 references which deal with mortality of wildlife on highways, and the effects of the highway itself on animal behavior. Other references related to this subject are included under the headings of: "Highway and Highway Rights-of-Way and Their Use by Wildlife" and "Measures for Reducing Animal Mortality and Animal-Vehicle Accidents."

Relatively few of the highway-animal mortality references provide any considerable detail as to reasons for seasonal variations in the wild animal mortality rate or on the effects of the mortality on the respective populations of animals involved; nor, generally, do they provide quantified information on the effects of weather conditions, vegetative cover, volume and speed of traffic, or other factors involved in highway mortality of wildlife. Rather, most of the articles reviewed are accounts of dead animals seen on sections of highways over a given period of time.

Davis (1940-248), by extrapolation and extension of mortality rates of wild mammals found on sample sections of highways, gave an estimate of the state-wide loss in Texas. Scott (1938-284) estimated that wildlife casualties probably exceeded 160,000 per year on improved rural roads in Iowa. Aldrich (1975-228), as Chairman of the ad hoc Committee on Scientific and Educational Use of Wild Birds, American Ornithologists' Union, quoted from a manuscript of one of the Committee members, Richard C. Banks of the U. S. Fish and Wildlife Service, who estimated that the annual bird mortality from traffic on highways was 57,179,000. This manuscript, to be submitted soon for publication, and kindly provided to me by the author, gives further details. Some 37 years earlier, another author (Simmons, 1938-290), estimated the total destruction of vertebrates in the United States from traffic accidents to be about six million. This would seem to illustrate some of the uncertainty as to the extent of wildlife mortality from highway accidents.

Impressive as some of the estimates of highway wildlife mortality are, it is probable that for most species, the loss is not significant, because of the relatively small proportion of the ranges of the respective wild animal species affected by the highways. Leopold (1936-268) pointed out that the killing of an animal by a motor car usually is noticed by its occupants, and if the body remains on the highway, by occupants of hundreds of subsequent cars. He states that this unusual visibility gives rise to widespread alarm over the destruction, but other more important invisible factors are at work which go unnoticed. He calculated that in the case of rabbits, a frequent victim of vehicular accidents, highway accidents might account for 10 percent of the mortality, probably less; but he did indicate that the application of mineral salts to highways to reduce dust, may attract deer to highways and result in heavy losses to vehicular traffic at night.

In the case of rare and endangered species of wildlife, highways and the development that frequently accompanies them, may be a more serious problem. For example, the National Marine Fisheries Service (1975-274) as mentioned previously, has described how coastal developments and highways are endangering rare marine turtles.

Serious, also, is the number of accidents involving automotive vehicles and big game animals which, in addition to killing or maiming the animals, often result in damage to vehicles and, sometimes, in the death of humans. A letter and other information provided by Reuben M. Harding (1975-254), of the U. S. Department of Transportation, National Highway Safety Administration, indicated that, for 1973, the number of human fatalities resulting from accidents involving the striking of animals (presumably, mostly deer), totaled 118 on or off roadways; 7,778 accidents resulted in injury of humans; and 65,381 accidents resulted in property damage.

Although many of the authors reporting on highway losses of wildlife list the total numbers and species of animals observed dead on a section of highway, the mortality will be treated here by groups of animals and various factors affecting animal behavior in response to weather, season of the year, relation to breeding and hibernation periods, cover alteration due to farming operations, and effects of the highway itself will be discussed. It should be emphasized that there is much to be desired in the accuracy of, and methods used, in reporting animal highway accidents, even in the case of big game.

Big Game Animals

Thompson (1966-295) stated that in the first national survey of deer loss resulting from deer-vehicle accidents, the deer loss was reported to be 71,073. By 1966, the 48 states reported the actual or estimated loss of deer to be 119,198, a minimum count, he felt, because injured deer may die at some distance from the highway. Other big game animals killed in 1966 from highway accidents included 108 elk, 229 antelope, 37 bear, and 4 mountain lions.

Puglisi (1974-280) stated that deer-vehicle collisions have been a long neglected and frequently underrated highway safety problem and that approximately 130,000 accidents of this type occur annually, resulting in an estimated national property loss in excess of $34,500,000. He indicated that in Pennsylvania, deer-vehicle collisions increased 218 percent from 1960 to 1967, and 17 percent from 1967 to 1972, with a total of 26,435 accidents. He stated that 58.4 percent of the deer-vehicle accidents occurred where both sides of the roads were in fields and that a relatively small number of accident sites accounted for a high percentage of the total number of deer-vehicle collisions. The estimated number of deer-vehicle collisions per mile was twice as high on divided highways as on other roads. Bellis and Graves (1971-237) found the numbers of deer killed per month were strongly correlated with the numbers seen grazing on the planted right-of-way of Interstate 80 in Pennsylvania. He noted that mortality was highest in sections of highway that lay in troughs formed by steep median strips and in steep rights-of-way, where troughs ended by a lowering of the median strips, and through flat areas where both sides of the highway and the median strip provided good pasture. In a later paper, Carbaugh et al. (1975-244), also in Pennsylvania, reported that the impact of the highway itself on deer abundance and distribution and the relationship between deer activity and deer-automobile collisions are functions of highway location relative to deer requisites such as feeding areas other than rights-of-way.

Reilly and Green (1974-282) reported on highway deer mortality in a deer wintering area in Michigan intersected by two highways--the Mackinac Trail (formerly U. S. 2) and Interstate 75. With the construction of Interstate 75 in 1963, deer kills in the study area increased about 500 percent over the average of the previous four years, declined slightly in 1967, and then fluctuated about an average approximately twice that of the pre-Interstate yearly mortality figure.

Pojar, Reed and Reseigh (1972-279) stated: "In Colorado it is estimated that between 5,000 and 6,000 deer-vehicle accidents occur annually...Deer-vehicle accidents result in about 1.6 million dollars of property damage annually. In deaths of deer, they result in loss of between 5 and 10 percent of the annual legal harvest." They pointed out that not only were deer-vehicle accidents costly financially--the mean actual cost to repair 903 vehicles involved in collisions with deer during 1967, 1968 and 1969 being $293--but they were costly, also, aesthetically.

In Oregon, Zalunardo (1965-305) reported that of 752 marked mule deer (Odocoileus hemionus), the subsequent mortality of 179 over a period from June 1960 to October 1963 was learned. He stated that five of the 179 (2.8%) were killed by automobiles compared with 126 (70.4%) taken legally by hunters. Jahn (1959-263), in analyzing records of 6,585 white-tailed deer killed by motor vehicles on Wisconsin highways from 1946 through 1955, determined that this number constituted slightly less than one percent of the deer estimated to have been taken by hunters during that period. In commenting on the reasons for variation in the monthly rate of mortality, he suggested that, for adult males, the high kill in October and November (more than twice that of the other 10 months) probably was associated with the rutting reason; likewise, he felt that adult does, more vulnerable in March and April when they dispersed from wintering yards prior to dropping their fawns, may have, during the late stages of pregnancy been attracted to the succulent green forage first available on open road cuts, bringing them in close proximity to moving vehicles.

As indicated earlier, (Thompson, 1966-295), reported 108 elk killed on highways in 1966. Ward (1973-300) found that Interstate 80 acts as a barrier to elk movement but that traffic on Forest Service roads in the Medicine Bow National Forest in southern Wyoming has little effect on elk activity, especially beyond 300 yards. In a later article Ward (1975-301) reported a mean monthly mortality of 9.4 deer, 2.9 antelope and 0.2 elk on a 55-mile section of I-80 in Wyoming after it was opened and indicated that most antelope mortality occurs in the spring when the animals can cross over the usually prohibitive right-of way fences. He indicated that elk mortality occurs mostly at night and that both elk and antelope are reluctant to use underpasses.

In a study of mortality of northern Montana pronghorn antelopes (Antilocarpa americana) in 1965, Martinka (1967-272) concluded that malnutrition was a principal cause of death, but he reported at least 300 pronghorns killed along railroads and highways in that area.

Small Mammals

MacNamara (1962-270), who kept a count of animals killed each month from March 1961 to March 1962, along a 20-mile stretch of U. S. 46 in New Jersey, found 173 cottontail rabbits, 86 squirrels, 54 opossums and 50 skunks. Haugen (1944-255), who recorded animal mortality on 124 miles of state highways in Barry County, Michigan, from April 1 to September 20, 1940, found 180 farm fowl, 120 cats, 12 dogs, and 3 pigs, in addition to 168 cottontails, 42 squirrels, and a total of 90 other wild mammals and birds. He concluded that the greatest mortality of cottontails, fox squirrels, muskrats, opossums, skunks, and raccoons is associated with increased activity that occurs during the breeding season and periods of dispersal. He believes that the ultimate effect of highway mortality on small game in southern Michigan, especially cottontails, is insignificant in consideration of the total population susceptible to hazards of highway traffic.

A 16-month record, kept by Evenden (1971-250), of animal mortality along 1.5 miles of suburban roads in Montgomery County, Maryland revealed a kill of 46 individuals of 12 species. Mammals comprised 76%, birds 22%, and reptiles 2%, of the total recorded kill, with gray squirrels and cottontails at the top of the list. Abbott (1958-227), who kept traffic casualty records for one year on an 11-mile stretch of the Mt. Vernon Memorial Highway, Fairfax County, Virginia, also found gray squirrels and cottontails ranking first and second among the victims.

During an 18-month research project on the Gray Lodge Waterfowl Management Area, Butte County, California, Lechleitner (1958-267) found over 100 carcasses of the black-tailed jackrabbit (Lepus californicus) on the roads of the study area, and on rural roads leading to the towns of Gridley and Live Oak. The age classes and sex ratios of these carcasses were similar to those of the study population and no differential mortality could be detected. Except for the Thousand Springs area where the Lost River outlets seemed to be associated with extremely high concentrations of rabbits and high road kill, Williams and Nelson (1939-304) found most rabbit carcasses on U. S. 30 in Idaho to be in sagebrush plateaus. They stated that the optimum environment apparently consisted of open sagebrush and a scattered understory of grasses and other herbaceous plants; fewer carcasses were found in cultivated areas.

Brockie (1960-239) found that the hedgehog (Erinaceus europaens L.) accounted for 84.5% of the total mammals and birds killed on two study roads in New Zealand. He thought the drop in number of animals killed from mid-June to mid-September was related to the period of hibernation and he attributed the abrupt rise in number of dead animals in the early spring to increased activity following emergence from hibernation. Also, he felt that the high mortality rate that occurs before the advent of the litters probably is a reflection of increased activity associated with the breeding season.

Based upon trapping, observation, and road mortality studies, Oxley, Fenton and Carmody (1974-277) concluded that: small forest mammals such as the eastern chipmunk (Tamias striatus), and the white-footed mouse (Peromyscus leucopus) were reluctant to venture on to road surfaces where the distance between forest margins exceeded 20 m; medium-sized mammals, such as the woodchuck (Marmota monax), porcupine (Erethizon dorsatum), raccoon (Procyon lotor), and skunk (Mephitis mephitis), crossed wider roads; road mortality increased with increasing road improvement for medium-sized mammals and was highest when traffic was high and young were emerging; and a four-lane, divided highway may be as effective a barrier to the dispersal of small forest mammals as a body of fresh water twice as wide.

With respect to the barrier effect of highways in relation to gene flow between populations of small mammals on either side of a highway, the authors stated: "If large gene pools are important to the survival of animals living under 'harsh' environmental conditions, roadways may have important effects on these populations due to fragmentation of gene pools. This is important and should be considered when roads are being planned, especially in game reserves or parks..." They commented further: "By regular mowing and spraying, vegetation along the road verges is often kept short resulting in increased road clearance. Plants other than grasses and, in particular, ground-covering shrubs, would simultaneously reduce the costs of road maintenance and the road clearance. Reduced road clearance would result in more movements of forest mammals on to and across the road and also in higher road mortality. It remains to be determined if the increased mortality is more or less detrimental than the fragmentation of gene pools. In any case, the effects of roadways on the movements of animals should be considered by the planners and builders of roads and by biologists concerned with the impact of man on the environment."

Among other observations made by these authors were that: traffic volume alone does not inhibit road crossings by mammals; road surface apparently is not a critical inhibiting factor, i.e. whether asphalt or gravel, but the road surface does affect volume and speed of traffic and hence influences road mortality; and light intensity, by itself, apparently is not a critical factor in the daytime crossing by gray squirrels and red squirrels.

Birds

We have mentioned the estimate made by a member of a committee of the American Ornithologists' Union (Aldrich, 1975-228) of the number of highway casualties among birds in the United States--over 57,000,000 annually. Although there are numerous articles and notes in the literature dealing with loss of birds on highways, few provide an analysis of the conditions prevailing and reasons for the mortality rates. Hodson (1962-259), however, has made some interesting observations and suggestions along these lines. Along a two-mile section of rural roadway in the vicinity of Corby, Northants, England, during 1960-61, he observed 644 birds of 31 species killed. Of these, 320 were house sparrows and, by comparing the mortality rates in 1962 with those in 1959, he found that populations of the house sparrow and the highway mortality rate had increased as the Corby housing estates extended towards the road (recently occupied and unfinished houses were utilized for nest sites). House sparrows were found to be especially vulnerable to automotive vehicles as they flocked to grainfields along the road to feed. The position of the dead birds was recorded in relation to the various types of cover on both sides of the road and analysis showed that much higher numbers of deaths occur opposite gaps and openings than along stretches of roadway with a uniform border.

Among the reasons suggested by Mr. Hodson as to why birds become casualties of the highway are: feeding on the remains of other highway victims, or on earthworms which frequent highway surfaces after a rain--crows, ravens, etc,; use of the bordering kerb-stone of highways as "anvils" for breaking snail shells--song thrushes; dust-bathing or taking grit from roads--game birds, finches, and sparrows; low-flying birds being hit as they cross the roads--finches, sparrows, game birds, thrushes, and hirundines (swallows) in particular; pursuit of flying insects; displaying on the road during breeding season--English blackbird; young of ground-nesting species being killed as they are led across busy roads by their parents--partridge; barn owls swooping towards a moving light, (car) during the breeding season, especially; indecision on the part of some birds when crossing roads ahead of traffic; and striking telegraph wires beside a road, then falling to the highway surface and being crushed by a passing vehicle.

Haas (1964-253), in 46,000 km of travel on European highways during 1956-1963, observed as highway casualties, 1,850 birds of 97 species and 832 mammals of 22 species. Stoner (1941-293), in travel (four round trips) between Albany, New York and Iowa City, Iowa, stated that of 2,975 freshly killed vertebrates seen on highways, 1,781 were birds.

Schorger (1954-285) pointed out that the highway kill of the red-headed woodpecker he had observed on roads between Madison, Wisconsin and Freeport, Illinois over 18 years, had paralleled the decline of the species, but the highway mortality rate of the pheasant had not. Hicks, Leedy and Strode (1941-257) in connection with a roadside inventory of living birds in western Ohio, found pheasants dead on highways at the rate of over 24 per 1,000 miles. By walking along railways in mid-day, they observed 573 dead pheasants per 1,000 miles. The fact that the dead pheasants were not subjected to further obliteration as obtains with animals killed on highways, may account, at least in part, for the much higher mortality rate observed along railways. Stewart (1971-292), for example, found that remains of English sparrows purposely placed on a busy highway were not evident from a moving car 90 minutes later, but that dead birds placed on the road shoulder were observable for up to 16 days. Information of this type is important in determining the value of highway animal mortality records for animal population estimates.

Amphibians and Reptiles

J. J. van Gelder (1973-296) pointed out that amphibia, and particularly the common toad (Bufo bufo L.), are run over in great numbers by automotive vehicles when they have to cross a road during the breeding season. In an apparently well designed study in the Netherlands, it was estimated that about 29 percent of the females and a like percentage of the males were run over. On this basis, van Gelder calculated, if the traffic volume were one car a minute, rather than ten cars per hour, as many as nine adult toads out of ten might be killed under the conditions described. After observing mortality of the grass snake and common frog on a two-mile section of roadway in England, Hodson (1966-260) stated that if the same mortality rates occurred on the thousands of similar sections of roadway throughout England a very large mortality is revealed.

Bugbee (1945-241), in 260 miles of driving along gravel and asphalt roads in Kansas, observed 57 snakes that had been killed by automotive vehicles under wartime reduced traffic.

An article in the Washington Post from Reuter, date-lined Munich, West Germany, April 15, 1975 (Anonymous, 1975-235), indicated that police had closed an expressway in Bavaria for about eight hours that day, diverting hundreds of vehicles so thousands of toads could cross safely to their breeding grounds. This decision was made after many toads had been run over.

Other Observations Concerning Highways, Road Kill and Animal Behavior Relationships

This section includes observations on highway-wildlife relationships that may be helpful to planners and highway engineers in selecting highway routes and in developing measures for reducing animal-vehicle collisions in highways. Implications for the roadside censusing of living animal populations are noted, also.

Dickerson (1939-249), in analyzing available information on road kills of wildlife made the following pertinent observations: (1) Animals may be destroyed on highways under conditions that make the automobile a secondary, rather than primary, factor. He cited an instance of 75 kangaroo rats trapped within a mile's distance on a New Mexico highway in bituminous road oil which had been spread late in the evening; (2) The distance from the road to escape cover is of considerable importance; apparently the closer the cover to the traffic lane, the greater the hazards; (3) Cars traveling at speeds above 35 to 40 miles per hour appear to be critical hazards for both song birds and rabbits; (4) The blinding of small mammals in the glare of approaching headlights is undoubtedly an important factor in their destruction; (5) Climatic conditions may be expected to have a marked influence on the occurrence of animals on the highway.

Alkon (1965-229), Kline (1965-266), Lord (1959-269), Newman (1959-275), and Payne (1968-278), have all written on effects of weather and other variables on the roadside activity of cottontail rabbits. Rain, heavy fog and wind apparently reduce the activity of these animals. Lord (1959-269), in comparing a series of early morning and spotlight nighttime roadside censuses of cottontails in Illinois, showed that greater numbers of rabbits are observed at night than in daytime during eight months of the year. Kline (1965-266) indicated that for a time in summer, rabbits probably are attracted to road surfaces in the morning because these surfaces are relatively warmer and drier than adjacent terrain.

McClure (1951-273) felt that highway losses were fairly directly related to the experience or lack of experience of wildlife with fast-moving vehicles; to the wildlife populations adjacent to roads; to the habits of each wildlife species; to the age composition and density of wildlife populations more than to the amount of traffic; to the interspersion of soil types; and to the density of the adjoining cover.

Siegler (1944-289) felt that highway mortality counts do not indicate the relative abundance, relative vulnerability to traffic, or relative mobility of one species as compared with another; he did think, however, that such counts, over a period of years, are helpful in tracing extensions of range of some species.

Buchner (1957-240) indicated that in the case of small mammals, such as the red-backed vole (Clethrionomys gapperi) and the field vole (Microtus pennsylvanicus), these animals may utilize portions of their range on either side of a barrier, such as a roadway but that the area of the barrier itself is "vacuum" territory in home range establishment.

In observing deer behavior in relation to an irrigation canal in Nebraska where some deer became trapped, Schult and Menzel (1969-286) found escape structures in the canal to be of little value. They indicated the best way to prevent deer drownings was to exclude the animals by fencing or by covering the canal and stated that, evidently, some deer were unable to recognize existing earth-covered bridges as places where the canal could be crossed.

Klein (1971-265), in reporting on reindeer (Rangifer tarandus) in Scandinavia, stated that the usual amount of traffic does not appear to significantly disturb reindeer or moving nearby, but highway traffic kills a considerable number of them. For one reason, reindeer appear to be attracted to roads as routes of travel.

Ward, Cupal, Lea, Oakley and Weeks (1973-302) found that elk in Medicine Bow National Forest, near Laramie, Wyoming, did not spend much time feeding in areas where traffic noise from Interstate 80 was greatest. They suggested that in elk habitat, considerations should be given to keeping roads away from elk feeding sites on open meadows and along stream courses.

There has been some speculation that the noise of heavy traffic, such as on a busy beltway, may interfere with the normal defense of territory among breeding birds.

HIGHWAY RIGHT-OF-WAY VEGETATION MANAGEMENT FOR EROSION CONTROL AND OTHER PURPOSES

The management of the vegetation along the nearly 3.9 million miles of rural and municipal roads and streets reported by the U. S. Department of Transportation (1973-5) requires much man-power, equipment, materials, time, and money. The way in which the vegetation is managed--the extent, size, types, mixtures and condition of the plants, the amounts and kinds of herbicides and insecticides used, the mowing and cutting schedules, the amount of fertilizer used, and whether or not burning is practiced--has an important bearing on the highway right-of-way wildlife habitat, as well as on the aesthetic values and effectiveness of the vegetation for erosion control and other purposes.

Although many of the hundreds of references available on vegetation control--particularly through use of herbicies--were selected for inclusion in the annotated bibliography which constitutes a large part of this report, treatment of vegetation in this section of our report is relatively brief and without much reference to wildlife; in fact, there is not much consideration of wildlife in the bulk of the literature dealing with management of highway vegetation. We have commented on possible relationships to wildlife and wildlife habitat, however, when deemed appropriate.

Information on the extent to which insecticides are used on highway rights-of-way, or the extent of roadside burning, is not readily available. Apparently, in many cases, insecticides are applied to roadsides as an extension of insecticide applications by farmers in adjoining fields, i.e. the control is at the local level. We have not delved deeply into the problem of side effects of pesticide application on desirable forms of wildlife. There is a large volume of literature on this subject and, as a start, the reader is referred to the U. S. Fish and Wildlife Service, Washington, D. C. 20240, for additional information. Suffice to state, many pesticides, particularly insecticides, as they are commonly applied, have undesirable effects on wildlife.

Burning, a means of vegetation control commonly used before air quality control regulations were enacted, can, like the use of herbicides, be either beneficial or detrimental to wildlife. For information on how controlled burning can be used to benefit wildlife, readers are referred to the annual proceedings and special publications of the Tall Timbers Conference , Tall Timbers Research Station, Tallahassee, Florida. There are many other sources of information on this subject, also.

Plantings for Erosion Control and Other Purposes

From the standpoint of wildlife biologists and ecologists, the apparent trend towards use of native vegetation for roadside plantings and in roadside maintenance is encouraging. Deakin (1958-316), for example, stated that: "Acquisition of sufficient right-of-way to allow a wide median strip on multilane highways, while more costly than a narrow right-of-way, may ultimately pay for itself through a number of advantages of the wider median. First, the profiles can be better adjusted to existing terrain, which saves construction costs and enhances safety. Second, native vegetation can usually be preserved, which saves on replacement, seeding, and maintenance costs. Third, planting in wide medians is more effective in screening traffic noise and headlight glare." Webster (1975-341) recommended prairie grasses for roadside plantings and hard-to-mow areas. He indicated that these plantings increase the soil moisture content, increase the soil stabilization, increase roadside beauty, have low maintenance costs, serve as food and cover for wildlife, and crowd out unwanted weeds.

Several references are included in the bibliography which deal with plantings and vegetation maintenance in terms of aesthetics. The American Horticultural Society (1975-307) has developed a manual on transit planting which illustrates how urban transportation facilities can be developed "practically and esthetically, using plant material designated by the Society as particularly suitable for specific kinds of public transportation facilities." Helpful suggestions are given for site analysis and planting procedures and plant species are suggested for planting in different regions of the United States and southern Canada. No reference is made to wildlife values. Davidson (1970-315) provides useful information for tree and shrub plantings to enhance the beauty of America's Great Plains. Rhodes (1971-335) and Noyes (1971-333) have discussed landscape aesthetics in urban areas. Andresen (1974-308) has prepared a 195-page bibliography on community and urban forestry which contains many articles on landscape design and roadside development. In this connection, also, Moorhead (1971-332) has considered problems of accidental fires in the natural fuels of grass, shrubs and forest floors in urban areas.

Much of the published material deals with plantings for erosion control or for multiple purposes, some relating to situations in certain states such as Beayers and Cox (1968-311) for Louisiana, Dickens and Orr (1969-317) for Alabama, Amein and Chu (1970-306) for North Carolina, Richardson and Diseker (1965-336) for Georgia, White and Smithberg (1972-343) for Minnesota, Zak et al (1972-346) for Massachusetts, and Artz et al (1970-309) for Nevada.

Lindsay (1971-328) has given attention to protecting and managing trees and wooded areas subjected to heavy recreational use; Zak and Bredakis (1965-344) to problems of sand dune erosion control; Hunter (1962-324) to roadway planting design in control of drifting snow; Jurka (1962-325) and Cook and van Haverbeke (1972-314) to the effectiveness of trees and shrubs in curbing traffic noise, and Heggestad, Santamour and Bernstein (1972-321), Santamour (1971-337), and Weinstein and McCune (1970-342) to air pollution with respect to plants, including their ability to withstand air pollutants and to reduce air pollution.

Several articles, including those by Spooner and Murdoch (1970-338), McNully and Bowmer (1969-330), Kidd and Haupt (1968-327), Goss (1970-320), Gallup (1974-319), Meyer, Wischmeier and Daniel (1969-331), the Highway Research Board (1973-322) and Butler and Yoerger (1962-362) went into some detail on planting and vegetation maintenance methods, including the role of mulching in establishment of plantings.

Although most of the literature in this section of the bibliography includes no reference to wildlife, the subjects treated do have implications of interest to wildlife managers; and certainly wildlife biologists could contribute information of value to highway landscape designers and engineers with respect to ecological requirements of native vegetation and the value of different plants to wildlife.

Vegetation Control Through Use of Herbicides

Mr. A. P. Hicas (1974-363), Manager, Industrial Herbicide Sales, Ciba-Geigy Corporation, stated that an estimated 25% of all herbicides sold in the United States for non-agricultural purposes are utilized in highway and roadway programs. He indicated that contact and selective herbicides are applied to more actual acres than residual or soil-active herbicides. Herbicides have been called a boon to highways--a means of keeping roadside weeds and brush under control (Anonymous 1968-347). Fortunately, herbicides, as a group, are not as toxic to fish and wildlife as are many of the insecticides.

Norris (1971-367) stated: "An adequate evaluation of the hazard associated with the use of any chemical agent requires consideration of both the toxicity of the material and the potential for exposure of nontarget organisms. The hazard can be high only if both the toxicity of the chemical and the potential for exposure to a significant dose are high. The relatively large doses of 2,4-D, amitrole, 2,4,5-T, and picloram required to produce acutely toxic responses in most nontarget organisms are not likely to occur from normal chemical brush control operations on forest lands. The short persistence, lack of biomagnification in food chains, and the rapid excretion of these herbicides by animals preclude chronic exposure and, therefore, chronic toxicity." Yet we do not know all we should know about the effects of herbicides.

Goodwin and Niering (1959-360) recognized that herbicides are valuable in the maintenance of roadsides, but pointed out that common abuse of them marred the landscape and caused unnecessary loss of desirable vegetation. The heart of the system, they felt, is selective treatment of trees so as to preserve a good cover of brush and broadleaved forbs wherever possible. Fitzgerald and McComb (1970-357) reported that the injection by standard field methods of amine salts of 2,4-D into hardwoods for release purposes can result in damage or death to several species of southern pine, on different soil types. Since root grafts do not occur, they felt it is probable that the 2,4-D is translocated downward into the hardwood roots, exuded, dissolved in the soil moisture, and absorbed by the pine roots.

Another problem encountered in applying herbicides is that of drift, which causes the chemical to come into contact with nontarget plants. Care in application, and use of certain chemical additives can help alleviate this problem (Anonymous, 1973-349 and 1975-350).

With respect to two common herbicides, picloram and tordon, Sargent (undated-371) indicated that these chemicals and their salts exhibit low toxicity to fish and that certain formulated derivatives (especially esters) tend to be more toxic than acid salts as an impurity from technical picloram. Likewise, Elder, Lembi and Moore (undated-356) stated that 2,4-D and picloram exhibit low toxicity to all fresh water and marine algae species thus far examined at rates approaching the maximum solubility of herbicides in water, but that these herbicides present a low potential hazard from normal agricultural or industrial practice.

The use of combinations of herbicides may increase the toxicity and there is still need for research on potential effects on the environment. House, Goodson, Gadberry, and Dockter (1968-364) have provided a 371-page assessment of ecological effects of extensive or repeated use of herbicides, and the U. S. Department of Agriculture (1969-373) has prepared a suggested guide for weed control. The bibliography attached hereto contains many articles describing use of herbicides for vegetation control applicable for various situations on a state or regional basis. However, the picture is constantly changing as new materials are brought into the market, and as new pesticide regulations are implemented.

Vegetation Control Through Combined or Other Measures

Tests and experimentation have shown that, often, vegetation can be controlled more effectively through combining the use of various herbicides and growth inhibiting or thickening agents, or by combining herbicide treatment with mowing, cutting and other measures. Hottenstein (1963-390), for example, proposed a program consisting of zoning the right-of-way into mow and non-mow areas, using herbicies as a supplementary tool to mowing for eliminating weeds and encouraging desirable grasses, applying sterilants to eliminate vegetation and the need for hand mowing around posts and under guardrails, and employing equipment best suited to the character of the roadside area. In Texas, however, McCully and Bowner (1971-393) found that although mixtures of herbicides were effective, soil sterilants have limited use on roadsides. They stated: "In every case treatments giving acceptable soil sterilization moved downslope from the point of application, and the resultant bare soil was subjected to erosion. This adverse effect could not be overcome with spray volumes up to 400 gal/A nor with asphalt emulsion as a carrier or cap over the treated area."

Morre and Werderitsh (1972-397) indicated that findings from their study "...point to the possibility of an eventual three-year (environmentally safe) spraying rotation in combination with one-cycle mowing which can be developed into a maximum-benefit, low-cost maintenance program for Indiana roadsides with cost savings in excess of $300,000 annually."

Among several references dealing with the use of maleic hydrazide (MH) for spraying of roadside turf for the reduction of grass growth, Clapham, Wakefield and Bell (1969-380) indicated that, in New Jersey, the first two weeks in May proved to be the best season for MH application. They stated" "MH was effective in reducing growth of grasses for a period of approximately six weeks after application. The numbers of mowings for May and June were reduced about 50 percent." It would be interesting to know what the overall effect of this type of treatment is on wildlife. We noted no research results related to this. Reduction in the number of mowings should be a plus, but what other effects might there be, for example, on insect populations used as food by birds?

Parker (1962-398) pointed out that increased maintenance responsibilities with no appropriate increase in budget has caused the permanent Massachusetts' maintenance labor force to be kept at a minimum, necessitating some of the work to be done on a contract basis. He indicated that annual contract activities include tree removal, tree trimming, tree planting, DDT mist blower and aerial spraying for Dutch elm desease control (use of DDT no longer permitted), hydraulic soil sterilant, and custom spraying and fertilization, and grass mowing. "The policy for tree removal and tree trimming is described. The policy requires the removal of all dead, diseased and dangerous trees in an annual program, and by removing all dead, diseased, and broken branches in an annual tree trimming program, this has resulted in practically no work for tree crews during and following storm periods."

Certainly, while wildlife biologists would recognize the need for removal of dangerous trees from the right-of-way, they would point out that dead trees far enough from the highway as not to be dangerous, have considerable value for wildlife.

Hesse and Salac (1973-389) observed the response of 11 species of wild flowers in Nebraska to 12 mowing dates. They found that all species survived the mowing treatments but that plant vigor was generally reduced; the mowed plants showed no lodging problem and had more uniform height as compared to the unmowed plants; and the number of flowers produced per plant was generally reduced by mowing. The authors thought that the aesthetic value of the taller species was enhanced because mowing eliminated the open type of growth associated with lodging. It might be observed, however, that from the standpoint of wildlife, in addition to the mowing hazards per se, the more varied heights of the unmowed flowers create more diversity and thus have greater value to more species of wildlife than the more uniform vegetation left by mowing.

In a recent book entitled, "The Plight of the Rightofway Domain--Victim of Vandalism" by Egler and Foote (1975-384), reference is made to a bibliography of 79 papers by the senior author on right-of-way vegetation management. Among the "don'ts" and principles he summarized in this book from some of his previous articles were: "don't clearcut the land; don't scarify (bare) the soil; don't blanket-spray the land; don't plant shrubs; don't hedge-clip brush under wires; and don't take the low bid for a contractor job!" He re-emphasized that a graded U-shaped right-of-way in cross section is far better than a flat one with only two edges and that enough is known about managing ground cover to do a better job than is being done.

Summaries of several other articles dealing with highway vegetation management are included in the bibliography.

EFFECTS OF ANIMALS ON PLANTINGS, VEGETATION MANAGEMENT, AND OTHER ASPECTS OF THE HIGHWAY SYSTEM: PROBLEMS OF CONTROL

Just as highways, their construction and operation, may have detrimental effects on fish and wildlife and their habitat, so, also, may wildlife pose problems in the management of the highway system. Obviously, most of these problems arise through animal use of the highway and right-of-way.

Effects on Highway Plantings and Vegetation Management

From Michigan we noted a report (Anonymous, 1937-401) that hoofs of deer feeding on grass along highways had torn up sod placed to prevent erosion on steep slopes and that experiments had begun to find suitable vines that could be planted on backslopes in place of sod.

Deer and other big game animals, as well as smaller mammals, may also destroy plantings of shrubs and tree transplants. In this connection, Krefting and Stoeckeler (1953-411) indicated that in planting jack pine, red pine, white pine and white spruce nursery stock, the older age of planting stock--especially the transplant trees--should be used where white-tailed deer and snowshoe hare damage may occur, because they can better withstand browsing. In clipping experiments to simulate hare and deer damage, they indicated that white spruce was lowest in sensitivity to clipping because it has a good scattering of internodal buds capable of developing a new leader; in contrast, they found that the pines usually died back to the next node. They recommended that browse-tolerant plants should be selected where the animal damage problem is serious.

Also, although dealing with problems of reforestation and range grass plantings, reports by Garrison and Moore (1956-406) and Hooven (1971-408) may be relevant to highway plantings in areas where pocket gophers are abundant. Garrison and Moore (1956-406) indicated that establishment of natural reproduction between drill rows of crested wheat grass in eastern Oregon was impaired by pocket gopher activites and that when unprotected from gophers, new stands of tall oat grass were especially vulnerable. They found that seedbed preparations, which destroyed all broad-leaved herbs preferred by gophers, rendered new planting sites unattractive to gophers until the new grass stand was developed enough to be a source of gopher food. Hooven (1971-408) stated that efforts to reforest with ponderosa pine can be nullified if many pocket gophers are present, and in such localities, control efforts must be constant. In rangeland, Hull (1971-409) found that spraying of fleshy-rooted, spring-growing plants and annuals with two pounds per acre of 2,4-D over a period of years to kill these plants--a major source of food for pocket gophers--resulted in a reduction of gopher mounds by 93 percent and of winter casts by 94 percent when compared to the unsprayed areas. Johnson and Hansen (1969-410) found that treatment of perennial forb and shrub-grass ranges in western Colorado with 2,4-D usually produced an increase in grass cover and a decrease in the cover of most forbs and shrubs. The density and litter size of the deer mice in the area apparently were little affected; the density of pocket gophers and least chipmunks was reduced; and the population of voles (*Microtus montanus*) increased following treatment of the range.

Animals may also have an impact on highway plantings by eating seeds when seeding is used as a means of revegetating roadsides. Smith and Aldous (1947-420) listed a total of 44 small mammal and 37 bird species found to eat seeds of conifers. Their report includes references to sources of information, discusses the quantities of seed consumed, and gives consideration to control measures. With respect to controlling damage by birds in longleaf pine reseeding efforts, Meanley, Mann and Derr (1956-416) and Mann, Derr and Meanley (1955-414) discuss use of chemicals as seed coatings to repell the birds. Morkit, one of the repellents which showed good results has been withdrawn from the United States market, but Arasan (tetramethyl thiuram disulphide) gave even better results.

In the use of all of these chemicals, care must be taken in their application and due attention given to regulations governing their use to avoid undesirable side effects, hazard to the applicator, or violation of the law.

Other Animal-Caused Problems

Birds may cause problems when roosting on highway structures, and possibly health hazards by their droppings on truss members on the underside of the bridges. Clougherty (1970-404) reported that about 200,000 starlings roost every night on truss members under the Fore River Bridge in Quincy, Massachusetts where, he indicated, the corrosive effect of their droppings makes it impossible to keep a protective coat of paint on the truss members and the birds harass bridge maintenance men. Control methods attempted were unsuccessful. Nummi (1972-417), however, reported on an apparently successful attempt to control birds in this type of a situation through use of a contact poison applied under supervision of licensed personnel. Also, Miller (1975-36), in reporting on starlings in New York City, stated that a painting contractor had told him in painting the George Washington Bridge in 1973, the painters "had to use cold chisels and hammers to crack off eighteen-inch-thick cakes of guano that had accumulated on beams and gusset plates."

Aquatic mammals may cause problems of a different sort--flooding of roads and the caving-in of road beds. Thus, Vesall, Gensch and Hyman (1947-424) describe an area in Minnesota which was futilely drained for agriculture. Subsequently, they report, control dams were installed in the ditches to reduce the fire hazard and improve the habitat for waterfowl and other wildlife. The beavers increased and, after some years, the authors observed damage to timber on about 19 acres for each mile of ditch and indicated that roads used for logging, patrol and fire fighting were inundated or undermined.

Laramie (1963-413) has suggested a means of dealing with the problem of road culverts plugged in connection with dam building beavers; if left plugged the result most likely would be flooding of the road. He describes use of fiber or wood pipes with multiple small openings along the bottom portion. The pipes are placed through the beaver dam along side the road in such a way that there is partial drainage without the need to destroy the entire dam. A device for clearing the debris from a small clogged culvert and means for preventing the beavers from rebuilding the dam in the culvert are suggested, also.

Kurth (1967-412) described an instance where muskrats by burrowing too close to road surfaces in Klamath County, Oregon, caused "instant pot holes." Apparently rising water levels in the adjacent marsh caused the muskrats to burrow higher and higher into the roadbed until the roads caved in over the dens, creating holes as large as four by four feet, which posed dangerous obstacles for motorists. The author stated: "A two-foot lift of a pit run base material was laid on the roadbed across the marsh but failures continued. Berms were constructed twenty feet wide adjacent to the road across the marsh. The berms were planned to be above the high-water level and provide dry homes for the muskrat populations during periods of high water. Muskrats will subdivide the new fill and, hopefully, lack reasons to continue excavations beneath the road surface."

Insects and plant diseases can cause several types of problems, the intended solution of which may have harmful effects on valuable wildlife. For example, they may damage roadside plantings and, less frequently, native vegetation and be treated with insecticides or other chemicals having undesirable effects on wildlife; and, as Chapman (1939-403) pointed out, they may be responsible for decreased palatability, premature abscission, decay before ripening or complete destruction of fruits. The presence of insects on roadside vegetation may also encourage insect control activites on adjacent croplands to be extended onto highway rights-of-way.

Pinnock and Cassidy (1973-419) indicate that in California, although most pest outbreaks in highway landscapes can be controlled by chemical pesticides, there is a tendency to diminishing periods of control following application. They point out, also, that chemicals may eliminate beneficial species of insects, some of which help keep injurious species in check, and that the pest may develop resistance to the insecticide used for control.

They state: "In California, where a large proportion of the most damaging landscape pests are the caterpillars of various moths, a bacterium, *Bacillus thuringiensis*, has been submitted as a first phase replacement for the chemicals previously used. This bacterium is apparently lethal only to the caterpillars and does not harm beneficial insects, fishes, birds, mammals or man."

Black cherry (*Prunus serotina*), a valuable wildlife food plant, seems to be particularly susceptible to tent caterpillar infestation, and for that reason, is given special attention by the Maryland State Highway Administration (1973-329) as a tree to remove on Maryland highway rights-of-way.

The reading of a recent report of a project supported by the U. S. Water Resources Council (1974-423) on mosquito prevention and control problems associated with stream modification projects suggested another way in which insect control can be associated with highway construction. One of the examples discussed in this report dealt with how stream modification in the Frenchman Creek Project in Nebraska, in connection with highway construction, had resulted in isolation of oxbows of the former stream with no provision for adequate drainage or other modifications that would have minimized mosquito problems. Although drainage or filling in of these old oxbows in which there was standing water would have aided in mosquito control, it would also have destroyed what appeared to be valuable wildlife habitat.

Readers who may have driven along lakes or marshy areas at the time mayflies and other aquatic insects emerged and took flight probably have been impressed by the numbers crushed against their windshields and on the roads, sometimes causing hazardous driving conditions. The writer of an article, "Battling the Budworm," which appeared in the April 28, 1975 issue of *Time* (magazine), Anonymous (1975-402) described conditions under which enornous "clouds" of these insects as moths, when they landed in northeastern United States in July, 1974 "...clogged factory ventilators and auto radiators; (and) their crushed bodies coated highways with a slippery, accident-causing goo..."

Animal Control Methods: Effects of Pesticides On Fish and Wildlife

There is a voluminous literature on animal control methods and on the effects of various pesticides on fish and wildlife which time and space limitations prevent reviewing and evaluating in any but a very superficial way here. Although mostly not directed to problems of wildlife control on highways or to the effects on fish and wildlife of pesticides applied on highways, much of it would be relevant. As one source of information, readers are referred to Pank (1974-418), who prepared a bibliography on seed-eating birds and mammals that affect forest regeneration. Many of the articles contained in this bibliography deal with bird and mammal control methods. Also, Eschmeyer and Harris (1974-405) compiled a bibliography of research publications of the U. S. Bureau of Sport Fisheries and Wildlife Service, 1928-1972, which contains many articles not only on bird and mammal control, but on vegetation management for wildlife, and on effects of insecticides and herbicides on fish and wildlife.

Mention has been made of problems of noise created by highway traffic and the fact that little is known concerning noise effects on wildlife. Limited research has been done on the possible use of noise both in protecting wildlife from the hazards of hay or roadside mowing and as a repellent for destructive rodents. Greaves, Rowe and Talworth (1969-407) in England, felt that responses of confined rodent populations to an ultrasound generator indicated some potential for this device to prevent or reduce invasion of premises with few entry points. Sprock, Howard and Jacob (1967-421), however, in their efforts to repel or control rats (*Rattus norvegicus*) with sounds, concluded that the necessary intensities of 130 db or above would be too costly and dangerous for use in the field. Likewise, Stewart and Dustman (1955-422) and Zorb (1957-425) in experimenting with various noises in conjunction with flushing bars on mowing machines to reduce mowing losses of wildlife, reported disappointing results.

Overall, wildlife research biologists have directed relatively little attention to solving animal damage problems relating to highways per se.

PART II

OPPORTUNITIES FOR ENHANCING FISH AND WILDLIFE AND MITIGATING OR REDUCING DAMAGE TO THE RESOURCE

Part I of this report has been devoted largely to the highway system and how highway construction, maintenance and operation affects fish and wildlife. We have noted the extent of highways and streets and how the highway system has displaced and altered fish and wildlife habitats. We have considered soil erosion, siltation and other pollutant effects, the destruction of wildlife on the highway and how highway right-of-way vegetation is managed; and we have reviewed the use of the highways, as now managed, by wildlife, and noted some of the detrimental effects animals may have on highways and rights-of-way.

In this part of the report (Part II) we shall attempt to review some of the efforts that have been made to offset the detrimental effects of the highway system on fish and wildlife and explore ways of protecting and possibly enhancing the fish and wildlife resource as it relates to the construction of new highways and to the maintenance and operation of existing highways. Considered will be ways of reducing highway mortality of wild animals, means of controlling erosion, other than those covered under vegetation management for erosion control and other purposes in Part I, means of assuring adequate fish passage through culverts, possible ways of improving highway vegetation management for wildlife, and other opportunities for fish and wildlife management in connection with highways.

FENCING AND OTHER MEASURES FOR REDUCING HIGHWAY ANIMAL MORTALITY AND ANIMAL-VEHICLE ACCIDENTS

Although millions of wild vertebrate animals are killed annually on the nation's highways as a result of animal-automotive vehicle accidents, and although these accidents result in loss of human life, extensive damage to property, and in aesthetic costs, wildlife biologists have devoted relatively little time on research to develop measures for reducing this annual toll. Recently biologists and highway engineers, largely with encouragement and support from the Federal Highway Administration, have been giving these problems more attention. Some of the approaches tried in the past, or that are being experimented with currently to reduce animal-vehicle accidents, are described in this section.

Fencing

The use of fence for confining or excluding wildlife and livestock preceded its use in highway management. Storer, Vansell and Moses (1938-452) described early use of an electric fence to protect beehives from bears in Shasta County, California. Another early reference to the use of the electric fence in wildlife management was that of McAtee (1939-436) who cautioned that the device needed perfecting and careful use. Many years later, Tate (1962-454) and Stewart (1973-451) reported electrocution of birds by improperly designed or improperly used electric fences. Garrett (1955-431) described a single strand fence that carries continuous, rather than intermittent, current for repelling deer, and Seamans (1951-449) developed a 77-page report, based on experience with 225 operating electric fences, in which he described how to install and maintain the type of fence he found best for control of deer damage--an outrigger arrangement.

Blaisdell and Hubbard (1956-429) described an outrigger type of fence which, although only 4.5 feet above ground, has an outrigger extension that slopes from the top of the fence to the ground, 8 feet from the fence. The idea is to keep the deer from getting close enough to jump the fence. Jones and Longhurst (1958-434) also described several sloping or overhanging types of fences constructed at the University of California's Hopland Field Station, and commented on their effectiveness against deer. Halls, Boyd, Lay and Goodrum (1965-438) provided detailed information on construction, materials and cost of a fence used for deer control in Texas, including building the fence across drainages. Blair, Hays and Brunett (1963-428) also described how to install fences across a stream channel so they would be deerproof and withstand floods. Other fences and their effectiveness in turning antelope and deer have been described by Spillet, Low and Jill (1967-450), Mapston et al.(1970-435); and Messner (1973-438). Spillet, Low and Jill (1967-450) pointed out that antelope readily crossed horizontal barriers such as cattle guards and simulated cattle guard devices, but they suggested that electric fences, dirt ramps, and horizontal panels appeared to merit further study. Use of guards 12, 18 and 24 feet long in preventing mule deer from crossing vehicle openings in fences 8 feet high was evaluated by Reed, Pojar and Woodard (1974-447) who concluded, also, that this type of guard, under the condition tested, could not be recommended.

It seems apparent that Dale F. Reed and his associates in the Colorado Division of Wildlife and the Colorado Division of Highways, with support from the Federal Highway Administration, have devoted more attention to ways of reducing deer-vehicle accidents than any other group of investigators. With respect to fences (see Bibliography under "Measures for Reducing Highway

Animal Mortality and Animal-Vehicle Accidents"), these several articles indicated considerable success in reducing mule deer-vehicle accidents after installation of fences at trouble spots along major highways in Colorado. For example, deer crossings were reduced 82% during the first March-May period after a 1.1 mile 8-foot fence was installed at a site on Highway 82; and the annual deer kill was reduced by 61% (Reed, Pojar, Heicher et al. 1973-445). They learned, also, that when deer manage to go around the end of a deer fence or come in from the opposite side and become trapped or funneled next to a highway, one-way gates may enable the deer to escape from the roadway (Reed, Pojar and Woodard , 1974-446).

Bellis and Graves (1971-237), based upon a study of deer morality on a Pennsylvania Interstate Highway (80), suggested that (1) most deer do not cross highways at right angles while moving to and from their feeding sites on the rights-of-way except, perhaps, where abundant food is provided on both sides of the highway; rather, many deer move along the highway, being channeled by local topography or attracted by the vegetation farther down the road; (2) deer fences along highways in forested regions be continuous over long stretches to prevent deer from going around the ends and being funneled along the highway by the fences; and (3) if the fences were constructed close to the highway, rather than where the right-of-way merges with the forest some distance away, a relatively low and, less expensive, fence might suffice to keep the deer from crossing the highway since their feed would be available outside the fence.

Also, with respect to highway fencing, Puglisi, Lindzey and Bellis (1974-281) stated: "Generally, high deer mortality occurred where the fence was located at the edge of a wooded area or within 25 yards (23m) from the nearest wooded area. Low mortality also occurred where the fence was located within the woods. The effect of vegetation on deer mortality was significant only where fencing was absent." They indicated that deer apparently cross fences (4 to 5.5 feet) readily when the fence is at or near the woods edge and when a good grazing area occurs on the highway side of the fence.

Highway Underpasses

Highway underpasses have potential for reducing animal-vehicle accidents by providing a means for deer and other animals to pass under the highway. Probably they are most effective when used in conjunction with fences to help guide the deer through the opening. Reed, Woodard and Pojar (1975-448) assessed the behavioral response of mule deer to, and the effectiveness of, a 10 x 10 x 100-foot long underpass under Interstate 70 in west central Colorado during four years after its completion in 1970. They indicated that the underpass was successful in permitting about 61% of the local deer population to migrate safely under the highway but noted, by means of a video time-lapse surveillance system which recorded behavioral responses during deer migration periods, that many of the animals were reluctant to go through a structure of this size and character. They recommended for future use, underpasses with at least 4.27m heights and widths and minimal lengths, and with dirt floors and no skylights or artificial lighting. Considerable use is being made by white-tailed deer of a bridge underpass, much larger than the Colorado underpass, on Interstate 70 west of Baltimore, Maryland.

Traffic Warning Signs for Animals

Green, Woodard, Reed and Pojar (1973-432) and Pojar, Prosence, Reed and Woodard (1975-439) reported on the effectiveness of lighted, animated deer crossing signs in reducing deer-vehicle accidents in Colorado. The slight reduction in speed of vehicles when the signs were lighted was not sufficient to affect the deer crossings per kill ratio. Since the lighted animated signs were not effective in reducing the number of deer-vehicle accidents, the authors question whether conventional deer crossing signs that have been widely used on public highways in an effort to reduce deer losses are effective either. They indicate, however, that in areas where deer-vehicle accidents are especially numerous, warning signs may be useful for public relations and liability reasons and, in view of the much greater cost for installing and maintaining animated signs, they suggest use of the conventional signs would be more practical.

Effective or not, van Gelder (1975-296) suggested use of signs warning against amphibians crossing highways as one means of protecting these animals during the breeding season.

Highway Lighting

Pojar, Woodard and Reed (1973-441) also assessed the effects of lights installed on a portion of Colorado 82 with respect to the rate of deer-vehicle accidents. Rather than decreasing, the numbers of deer-vehicle accidents were higher following installation of the lights than they had been the previous two years. Traffic Data Systems, Inc. (1969-456), based upon evaluations and tests of methods for the detection and counting of deer in deer-vehicle accident research, stated that the feasibility of an electronic scarecrow (for repelling deer) appears to be negative "since the animals are not disturbed by light or sound sources."

Roadside Mirrors

Queal (1968-443) reported inconsistent results in experimentation with roadside mirrors as a means of reducing deer-car accidents in Michigan and concluded that changes in deer numbers and distribution patterns probably had more influence on these fluctuations than the presence of mirrors. However, reports in <u>Better Roads</u> and in <u>American Highways</u> (Anonymous 1971-426 and

1972-427, respectively) indicate a degree of effectiveness in the use of deer mirrors by the Missouri Highway Department. According to these reports..."Headlights from passing cars reflect against the mirrors causing light beams to flicker into cuts, draws, and timber alongside roadways. These sharp, pencil-like light beams startle the deer and cause them to stop. Once the light beams stop flickering, the deer then cross in safety." New Jersey has experimented with roadside mirrors, also.

Other Measures

According to van Gelder (1973-296), during the migration of breeding toads across highways, the authorities may close or block the road temporarily. Another method is to help the animals across that part of the road where the toads cross it by use of barriers in conjunction with either a tunnel underneath the road or pitfalls into which the toads fall and are then emptied, i.e. the toads are removed daily during the migration period to the other side of the road. The author indicated that the latter alternative was preferred in Switzerland and would be applied there in many places.

Inasmuch as many of the measures described above have been unsuccessful, or only partly successful, it would appear that further consideration should be given to the animal-vehicle collision problem in the planning, site selection and construction of new highways and to the biology and ecology of the animals and their habitat. The situation seems to be nicely summarized by Franklin J. Svoboda (1974-453) in a publication of the Minnesota Highway Department. Svoboda states: "Solutions to the big game-vehicle conflict are inadequate at present and more research on big game behavior in relation to highways is required. Some measures presently available include installing bridge structures, warning signs, restrictive fencing and one-way gates, modifying highway design, location and width of the right-of-way and reducing attractiveness to big game."

"Highway agencies can help solve the problem by consulting with state conservation departments early in the planning stages of a new highway. Critical or problem areas may then be identified and avoided or safety measures designed into the new road. Existing roads may need some modifications to reduce the safety hazard in conflict areas. Maintenance procedures which perpetuate certain plant communities that have been designed to discourage big game use must be adopted and practiced regularly."

Couturier (1965-247) encourages the identification of accident-prone areas so that correctional steps can be taken. Reilly and Green (1974-282) of Michigan urge that proposals for construction of highways which would intersect deer yards should be evaluated in greater detail for the potentially serious detrimental effects of construction on deer movements and populations within wintering areas. Pojar, Reed and Reseigh (1972-440) offer sound advice to state conservation agencies on ways they can cooperate with, and assist, highway agencies in avoiding or alleviating some of these animal-vehicle collision problems. They cite the Federal Highway Administration's Instructional Memorandum 21-5-63 which directs all state highway departments to include recommendations from state fish and wildlife agencies in their requests for Federal appropriations on highway construction, and, also, the guidelines of the Council on Environmental Quality to state highway departments and FHWA that would assure that the human environment and national environmental goals are met when developing Federally financed highway improvements.

SOIL EROSION, SEDIMENT, AND POLLUTION CONTROL WITH SPECIAL REFERENCE TO WILDLIFE: MITIGATION AND REHABILITATION MEASURES

Soil Erosion and Pollution Control

Massie and Bubenzer (1974-480) emphasize that erosion control along town (local) roads has not kept pace with that along county and state roads and, drawing on an earlier Wisconsin study of which Massie was a participant, they recommended a program to : purchase and utilize specialized seeding and mulching equipment; control all erosion that can be a major source of sediment for Wisconsin's surface water within five years; consider the use of incentive funds to help reduce active erosion along town and county roads; build sediment-retention structures as a part of all new construction, and maintain them until permanent structures and vegetation achieve adequate control; establish vegetation on all new road cuts and fills, particularly along town roads; and secure wider rights-of-way where needed.

Recognizing that serious erosion and sedimentation problems frequently result from construction of logging roads, U. S. Forest Service personnel and other investigators have devoted considerable attention to ways of preventing or reducing this erosion and siltation and of rehabilitating damaged streams. Burns (1972-464), in discussing this problem with respect to maintaining anadromous fish production, suggested: some thinning when dense forest canopies along streams provide too much shade, but leaving a dense understory or buffering strip along streams where needed to control temperatures; avoiding the falling of trees into the streams; keeping timber and bulldozers out of the stream channels as much as possible; keeping bulldozer use on steep slopes at a minimum; building roads away from the stream; seeding disturbed areas with grass to reduce erosion and sedimentation; and completing logging operations in the shortest period of time possible, then leaving the watershed to recover.

Brusven, Watts, Leudtke and Kelley (1974-463) tested the use of log drop structures, debris jam removal, channel diversion, and gabion deflectors as to their effectiveness in stream habilitation. They found in-stream alteration and hydraulic structures increased sediment transport and improved insect and fish habitat. Other improved conditions for fish included increased pool-riffle ratios and a higher percentage of cobble in the streams.

Barton and Winder (1974-461) found that a stream rehabilitation structure that functions well in one situation may not function properly in another and that, generally, permanent, solidly constructed structures such as deflectors and check dams are best. They indicated that rocks placed in various patterns are also an effective and economical means of rehabilitating altered channels and suggested that banks should be established by planting vegetation or by installing rip-rap. Hansen (1968-472) considered rock rip-rap to be the best material for bank stabilization in most cases.

Packer (1967-483) has provided quantitative criteria needed for developing road design and location requirements for use in timber harvest operations in the northern Rocky Mountains to prevent damage to the soil and water resources of the area. Lantz (1971-477) has attempted to explain why certain logging practices in the West Coast Douglas-fir region are more desirable than others for protecting fish habitat and water quality.

In addition to the 146-page wildlife habitat improvement handbook of the U.S.D.A. Forest Service (1969-491), that Service has issued several coordination guidelines and other publications for use in various regions in the management of fish and wildlife habitat affected by road building and other activities.

Tuz (1972-490), Zirkle (1974-498), Ventura (1972-495) and Ekey (1970-468) have described the respective roles of temporary erosion check dams, settling basins or detention ponds, silt barriers, and other measures reducing sedimentation in streams. Zirkle (1974-498) points out that detention ponds can have multiple uses.

Other agencies such as the National Association of Counties Research Foundation (Powell, Winter, and Bodwitch 1970-485), the U. S. Department of Transportation (undated-493), the U. S. Environmental Protection Agency (1973-494), R. E. Thronson (1971-489) of EPA, and state agencies such as the New York State Department of Conservation (1974-482) have published materials helpful in the control of sediment resulting from highway construction. The community action guide book prepared by Powell, Winter and Bodwitch (1970-485) is intended to help local officials to organize, plan, finance, staff, and implement comprehensive sedimentation control programs in developing communities. The U. S. Department of Transportation (undated-493) points out that woody vegetation, usually wasted or burned during site clearing, can be converted to wood chips which can be used more effectively than standard wood fiber mulch in preventing erosion on newly graded areas. Lund (1974-479) recommends serration to help establish vegetation on cut banks.

A method for predicting erosion rates at any given construction site, and therefore, the need for runoff control, has been described by Swerdon and Kountz (1973-488) of Pennsylvania State University. Application of the method and installation of a system of ditches and impoundments in a section of I-80 in Pennsylvania, they feel, would have saved considerable money and satisfied State and Federal regulations.

Thus, it is apparent that attention has been given to many aspects of erosion control in addition to vegetation management. Much useful methodology has been developed. However, as pointed out by Foote (1973-469): "The most effective and cheapest way to limit the erosion and resultant sediment and water pollution during construction is by good contract administration..." and he goes on to give what appears to be some excellent advice for administrators.

Other references noted, and which will be dealt with briefly here, are concerned with porous pavements for urban runoff control, management of solid wastes, removal of trace metals from wastewater, and use of trees and shrubs in noise abatement.

Grover, Hoiberg, Haigh and Thelen (1972-471), in experimenting with different materials, found that a porous asphalt concrete containing 5.5 percent asphalt by weight and aggregate graded to allow a water flow of 76 inches per hour appeared to be the optimal porous road material. They suggested that the economics of porous pavement were enhanced by benefits from combined sewer overflow pollution relief, augmentation of municipal water supplies, improved traffic safety, preservation of vegetation, relief of flash flooding, and the aesthetic and directional benefits of a colored porous surface.

Results of the survey by Cannella and Friedman (1974-465) of how the 50 states deal with solid wastes incident to highway construction and maintenance should be value in highway management, and, as indicated earlier, has some relationship to wildlife in that animals may be attracted to the roadside by bits of food thrown out of cars or put in containers at highway parks.

One use of discarded automotive tires (DAT), a solid waste disposal problem of enormous proportions, as stated by Netzer, Wilkinson, and Beszedits (1974-481) may be to help remove trace metals from wastewaters. Continuous bench-scale studies by these authors showed that "removals in excess of 99.5 percent for most of the metals can be achieved by treatment with lime and DAT."

With respect to noise abatement, Leonard (1971-478) indicated that trees and shrubs may play an important role if they are correctly utilized. He states: "Fairly dense groups of trees may serve as effective sound reducers along highways, particularly on level areas or where the sound source is at an elevation lower than the receiver. Cook and van Haverbeke (1971-467) pointed out that the screening effect is most pronounced when trees and shrubs are combined with other soft surfaces as an alternative to an expanse of hard-surfaced material, which, otherwise, might be used to surround a recreational site or roadside development. They stated: "Under these conditions, apparent loudness may be reduced 50 percent or more."

Rehabilitation of Channelized and Other Altered Streams

Many streams are diverted, channelized or otherwise altered as a result of highway construction, and some attention has been given to means of rehabilitating these streams for fish and other aquatic life. Funk (1973-503) as did Patrick (1973-71), already cited, emphasized that the diversity of the fish community is due to adaptation of the individual species to the great variety of physical, chemical, and biological conditions in various stream environments. He indicated that man-made channels cannot equal natural channels in diversity, that streams should be channelized only as a last resort, and that channels should be made as diverse as possible. Yet, with favorable laws and the cooperation of the various agencies involved, much can be done to rehabilitate altered streams. Thus, as a result of Montana's stream preservation law, passed in final form in 1965, Peters (1970-507) reported, as accomplishments under the law: moving of proposed bridge realignments to avoid encroachments on several rivers; designing and building of meanders so the channel was as long after construction as before; building and/or planning of extra bridges to preserve natural meanders; replacement of brushy floodplain vegetation removed to facilitate construction; and limiting channel excavation to those times of the year when trout are not spawning and eggs are not in the redds.

Barton and Winger (1973b-502) showed, that with instream rehabilitation structures such as deflectors and check dams, hydrologic features of the channelized portion of the Weber River under study in Utah soon were similar to those of the unchanged areas. After six months, with substantial stream flows and stabilization of the substrate, no differences in numbers, weight, or species diversity could be detected between the benthos of the changed and the unchanged sections. Fish populations also, apparently were similar and rehabilitation structures did provide holes and riffles in the changed sections. However, the authors suggested that channelization should be avoided, if at all possible, since other deleterious effects still occur, such as loss in stream length, loss of cover, loss in streamside vegetation, and loss in aesthetic value.

Hunt and Graham (1972-505) recommended that in designing channels to restore fish habitat in man-made streams, the meanders should be similar to those found in comparable natural sections of the river.

Shelton and Pollock (1966-508) in studying effects of siltations on fall chinook salmon eggs in an incubation channel, found as much as 85 percent mortality of the eggs when 15 to 30 percent of the voids in the gravel bed were filled with sediment. With one 70-foot section of the channel used as a silt-settling basin, the mortality was reduced to 10 percent or less. On the basis of this controlled experiment, they suggested that a siltation control system consisting of a flushable sandtrap and settling basin constitutes the most economical means of reducing the amount of sediment entering this or similar channels. The implication is that settling basins might be helpful for controlling sediment in certain streams subjected to sedimentation, also.

Barton, Peters, White and Winger (1972-498) prepared a bibliography on the physical alteration of aquatic habitat and stream improvement, and other literature is available. Workman (1974-509) in Montana, a state with considerable experience stated: "In situations where stream channels must be altered or relocated, future maintenance problems can be diminished and fish population recovery enhanced if the physical characteristics of the original channel are retained insofar as possible or transmitted to the new channel. Stream discharge and basic sediment load are not permanently changed in highway construction, therefore, it is necessary to maintain the same width, depth, meander wave length and gradient characteristics of the original channel in order to maintain stability in the river system. The final channel design should incorporate needs of fisheries, e.g. pool riffle ratios, bottom configurations or thalweg location...In implementing this it is recommended that, if a stream must be rechanneled, the new channel be meandered so the original stream length is maintained..."

In summary, there would appear to be general agreement in the desirability of creating, in channelized or new stream beds, conditions as nearly as possible the same as in the unchanneled streams, assuming that the original streams were productive of fish and other desirable aquatic organisms. This is not be say that some "natural" streams cannot be improved for fish production, given the methodology presently available. More information is needed on rehabilitation and mitigation measures, however, in situations where streams must be altered and mitigation attempted.

PLANTS AND WILDLIFE

Plants serve both as food and cover and are an essential part of wildlife habitat. Vegetation management is one of the most important ways for managing wildlife. To date, management of the millions of acres of vegetation in highway rights-of-way has been with relatively little regard for wildlife. There are opportunities for further consideration of wildlife in highway vegetation management.

In dealing with plant-wildlife relationships in this part of this report, we shall review some of the highway vegetation management efforts specifically designed to enhance conditions for wildlife; present some selected information on plantings and vegetation management for wildlife which, although not carried out on roadsides, may have application there; and provide other information on wildlife use of certain plants or types of vegetation which may be helpful to highway department personnel in their highway plantings and vegetation management programs. Readers are referred, also, to the section dealing with the use of highways by wildlife.

Right-of-Way Vegetation Management With Specific Reference to Wildlife

Apparently more observations and experimentation on highway vegetation management for wildlife has been done with pheasants and waterfowl than for other species. Joselyn, Warnock and Etter (1968-528) compared densities of ring-necked pheasant nests on unmowed roadside plots seeded to a grass-legume mixture with nest densities on unseeded and unmowed plots and on unseeded, but mowed plots. They found nest densities and pheasant production higher on the seeded roadsides. As a result of their study, they suggested that a minimum mowing schedule for highway rights-of-way and the seeding of selected grasses and legumes could provide cover for a variety of species such as quail, pheasants, rabbits, and some song birds. In a later study, Joselyn and Tate (1972-527) pointed out that 94 percent of the farmers in the pheasant management unit under study in east-central Illinois had participated in the experiment and had agreed to delay mowing of their roadsides each year until July 31 when most of the pheasants would have hatched. Cost for the project at the time (1968), including seeding of bromegrass and alfalfa was $139 per mile for one side of the road or, amortized over a 10-year life expectancy of the seedlings, about $700 per acre per year.

The date of highway vegetation mowing is important because much wildlife is killed and many nests are broken up by the mowing operation. Trautman, Dahlgren and Seubert (1959-544) recommended refraining from mowing roadsides until July 10 in South Dakota. Other authors made similar recommendations. Joselyn (1969-525) pointed out that, primarily due to economic considerations, many states are altering their programs of vegetation management on roadsides by reducing the frequency of mowing which he believed would substantially increase acreage of available nesting cover.

On the basis of Colorado studies, (Hoffman 1973-513) three cover types--alfalfa-crested wheatgrass mixture, intermediate wheatgrass, and tall wheatgrass, have definite possibilities for replacing weedy cover along roadsides for pheasant nesting cover.

Linder, Lyon and Agee (1960-33), however, pointed out the importance of fireweed (Kochia sp.) blown into roadside ditches during the fall and winter which probably served as a deterrent to mammalian predators the next nesting season. Dr. Linder indicated that roadsides in south-central Nebraska would be hard to improve as they stand for pheasant cover, because they are not mowed, and are burned occasionally which helps keep them in forbs or native grasses.

With respect to maintenance of remaining tracts of native prairie grasses valuable for prairie chickens (Tympanuchus cupido) in Minnesota, Tester and Marshall (1962-543) recommended a four-year rotation of spring burn, no treatment, graze, and no treatment. With perhaps some modification, this type of program might be applicable to maintaining some of the remaining native prairie grasses in odd tracts within highway rights-of-way.

Oetting and Cassel (1970-538) found that ducks responded quickly to cessation of mowing when alternate miles of the right-of-way and half the interchange triangles were left unmowed along an interstate highway in North Dakota. Seventy-four percent of the ducks chose unmowed nesting sites. It was of interest, also, that 82 percent of 182 motorists interviewed had not noticed the mowed-unmowed conditions of the highway. Oetting indicated that the big ducks--mallards, pintails, and gadwalls--were especially responsive to cessation of mowing (cover changes), whereas shovelers and blue-winged teal were not. Martz (1967-532) made similar observations concerning gadwalls (Anas strepera). On the basis of their studies, Oetting and Cassell (1971-538) strongly recommended "...no mowing of ditch bottoms or back slopes, minimal mowing of inslopes, and no mowing before July 20 to enhance waterfowl nesting and to reduce maintenance costs of highway rights-of-way in duck producing regions."

Many articles included in the bibliography suggest opportunities for highway right-of-way vegetation management to enhance wildlife but fail to give pertinent details. Long-time investigators of right-of-way vegetation and its management are Dr. Frank E. Egler of Aton Forest, Norwalk, Connecticut, Michael Way of England, and W. C. Bramble, formerly of Pennsylvania State University and, subsequently of Purdue University. Both Egler (1958-519) and Way (1970-546) indicate that if botanists were consulted there could be better right-of-way management for wildlife habitat. In his articles, Egler (1953a-516, 1953b-517, and 1957-518) indicates that enough information is available to do a better job than is being done in vegetation management. He suggests that the first step in such management would be the discriminate elimination of the undesirable woody plants. He suggests that selective basal spraying is as cheap, in the first conversion stages of the vegetation to trees, as blanket spraying, and it provides edge effects valuable to wildlife. He points out, also, that indiscriminate blanket spraying with herbicides often results in the root kill of desirable shrub cover before the tree roots are killed and that these shrubs do not seed again, whereas trees do. He points out, further, that most of the upland grasslands are easily invaded by a few species of trees in contrast to certain shrublands which are relatively sealed against tree invasion and that no one treatment is the whole answer; treatments must be adapted to the site and the vegetation. Basal spraying has been found to be an efficient root-killer.

Niering and Goodwin (1974-534) describe how, through employment of ecologically sound techniques and selective application of herbicides, shrub communities with high stability and wildlife values have been established on a demonstration area in Connecticut. They indicated that clones of several shrubs, once established, have virtually no tree invasion, and listed among such shrubs: huckleberry, greenbrier, low blueberry, witch hazel, speckled alder, sheep laurel, gray dogwood, and nannyberry. They stated that pure stands of little bluestem (Andropogon scoparius) exhibit remarkable stability also. Establishment of such cover on roadsides would reduce vegetation maintenance costs and contribute to maintenance of habitat diversity. Young (1972-548) stated that the annual national maintenance cost for mowing, cutting and burning for vegetation control in rights-of-way of transportation and the transmission systems was estimated to be at least $200 million and if all burning and spraying were stopped voluntarily or by law because of concern for air and water pollution, the annual vegetation maintenance bill might be $1 billion. He suggested that consideration be given to the production of currently non-commercial tree and shrub species on rights-of-way and their use for paper and paperboard products as well as for wildlife.

Bramble, Byrnes and Hutnik (1958-512) described how, by cutting and various spray treatments, edges and interspersion of cover types favored by such species as wild turkey, rabbits, deer and grouse could be developed in rights-of-way. Gysel (1962-521) in studying a power line right-of-way in southern Michigan where vegetation was controlled by herbicides, concluded that animal use apparently was affected by the composition and density of the vegetation but he detected no direct effect on the animals of the herbicides.

Hankla (1959-522), in North Carolina, found that sericea lespedeza used on rights-of-way provided excellent cover and some food for rabbits and quail; and it prevented tree invasion. He indicated that fescue-ladino clover plots provided superior habitat, for they became invaded by legumes, weeds and brambles, but resisted tree invasion.

Although Joselyn, Warnock, and Etter (1968-528) recognize that attracting birds such as ring-necked pheasants to roadsides as a result of cover management might result in highway hazards, Young (1972-548) does not consider that managing rights-of-way as small game habitat created a significant accident problem.

Besadny, Kabat and Rusch (1968-511) described a cooperative program of selective brush management in Wisconsin that might be useful for adoption, at least in part, in other states. The program, involving 19 public and private agencies, was designed to increase the aesthetic quality of the country road, make management of roadside right-of-way easier, help reduce soil erosion, and provide wildlife food and cover. The authors stated: "...The program grew out of a reevaluation of existing maintenance practices which completely eradicated native woody vegetation along rights-of-way and the concurrence that this cover should be maintained and developed for its multiple natural values, including the practical, biological, cultural and other related aspects."

Steps for implementing such a program are given, including how to select, mark and maintain the roadside vegetation; and how to carry the project through to development of a manual useful in highway right-of-way management. Attention is given to such details as removal of trees on the south side of the road which might slow the melting of ice on the road surface; removal of vegetation next to fences to prevent damage to the wire; removal of vegetation which might interfere with water drainage; and development of a maintenance cycle which is effective for brush management. Consideration is given, also, to problems that might be created by disease-carrying shrubs such as buckhorn (Rhamnus cathartica), wild gooseberry (Ribes sp.), and Juniper (Juniperus sp.); to drifting snow; and to driver visibility. Finally, attention is given to special types of vegetation which offer management possibilities, such as remnants of native prairie vegetation found along some Wisconsin roadsides. The authors indicate that management of such vegetation consists essentially of burning--as early in spring as possible--on a three-or-four year rotation, depending on the accumulation of dead plant material.

Vegetation Management and Plantings for Wildlife--General

Plantings

Planting to improve food and cover conditions for wildlife is an old practice and remains as one of the techniques of wildlife management. As in the case of roadside plantings for soil erosion and other purposes, wildlife food and cover plantings are not always successful; sometimes revegetation of an area by native plants through natural succession results in as good or better food and cover at less cost. An examination of back issues of various wildlife journals, including Wildlife Review from its beginning in 1935 up to 1975, showed considerably more attention to wildlife plantings in the latter 1930's and during the 1940's and 1950's than there is now. Many of the plantings were sponsored by the U. S. Soil Conservation Service for soil erosion control and wildlife and by state conservation or fish and game departments for wildlife food and cover. Some of the knowledge gained through these early and continuing efforts to establish valuable food and cover for wildlife and to control erosion should be of value in the highway plantings of today--especially the information on wildlife values of certain plants, site requirements, ecological aspects, planting and handling techniques, and the spreading tendencies of some plants.

For years multiflora rose was hailed as an excellent plant for living fences and as wildlife food and cover; and it was widely planted for these purposes in such states as Illinois and Missouri and on to the east and southeast. Steavenson (1946-621) is one of many who discussed its use and characteristics. Baskett (1953-533) experimented with pruning as a means of thickening multiflora rose hedges. About that time, however, Rosene (1950-614) warned about the spreading tendencies of the plant in the Southeast, and Dickey (1952-565) stated that it had become a serious pest to farmers in at least two sections of the Northeast. In discussing wildlife plantings, he pointed out that before anything new is introduced, one should be very sure it will not get out of hand; he cited the European barberry and its role in propagating the destructive black stem rust of small grains as an example. Klimstra (1956-590) and Scott (1965-618) also pointed out problems in the use of multiflora rose and suggested that it be used only under certain circumstances where its spreading would be unlikely, such as in areas where there is frequent plowing, or along pasture fields with dense vegetative cover.

Numerous articles have been written, also, about use of various lespedezas and how and where to plant and maintain the plantings--see, for example Davidson (1942-563) and (1945-564); Rosene (1952-615), (1955-616) and (1956-617); Hunter (1954-586); Gehrken (1956-575); and Haugen and Fitch (1955-584). Lespedeza bicolor is known to be a good quail food in the Southeast, and other lespedezas, such as sericea which can become established on poor eroded soil, provide good wildlife cover; yet Gehrken (1956-575) reported that farms in Virginia having plantings of bicolor lespedeza apparently had the same trends in quail populations as those farms without such plantings. Rosene (1956-617) indicated that although bicolor lespedeza could be helpful where food is scarce, factors such as time and intensity of controlled burning, amount of cover available, land use practices, and disturbances have greater effect on quail populations than the presence or absence of bicolor.

Dobie and Marshall (1954-566), nearly 20 years after spot planting by the Civilian Conservation Corps of white spruce (Picea glauca) and northern white cedar (Thuja occidentalis) for game food and cover in the Paul Bunyan State Forest, Minnesota, attempted to assess the project in terms of wildlife value. They felt that the plantings had not contributed appreciably to game cover primarily due to the inability of small conifers to withstand shade of the aspen over-story, or to survive on dry sites;

and secondarily, due to pressure from high deer and rabbit populations. Presumably, therefore, the plants did provide food.

Likewise, Dambach (1948-562) appraised the success of 33 wildlife-erosion control plantings made on Ohio farms from 1935 to 1940 where 125 species of shrubs and woody vines had been used in various planting sites. He indicated that adaptation to site, proper handling of stock, and protection from fire and grazing were the principal factors limiting success and he gave the relative performance and site adaptation for the species he observed. He indicated that multiflora rose, Tartarian honeysuckle and four shrub dogwoods were the only species he observed which had a wide range of tolerance and were suitable for both erosion control and wildlife.

Baskett (1955-554) reported on survival and vigor of experimental wildlife food and cover plants in Missouri after 10 to 13 growing seasons. He observed that multiflora rose, gray dogwood, and wild plum had good survival and growth over a wide variety of conditions; Tartarian honeysuckle and a variety of black raspberry showed good survival and growth in moderate to good sites; red cedar and oriental arbor-vitae had only moderate survival, but produced dense, rather durable cover; and most of the plants which were aggressive enough to grow well under varied and often severe conditions, tended to spread within the plantations. He observed, also, that a sizable number of native species performed at least moderately well in the wildlife trial plantings, serving as a reminder that many odd areas contain at least part of their own planting stock.

Dr. Charles V. Riley (1957-612) has experimented extensively with the revegetation and reclamation of coal strip-mined lands in Ohio with reference to wildlife. Some of these lands are not unlike some of the cuts and other highway-disturbed areas and his findings probably have relevance to highway plantings. Of five species of lespedeza studied, bicolor and sericea were the most successful and adaptable to varied sites; Korean lespedeza did well in soil having a high percentage of calcareous materials. Yellow and white sweet clovers were successful on a wide variety of sites and soil conditions and had high seed production. Alsike clover grew well in moist ravines and depressions. Seven species of pine and Norway spruce, growing in pure or mixed stands, provided valuable winter cover, especially when planted in clumps. Black locust did well and by the tenth to fifteenth year, after invasion by native species, extremely dense undergrowth had developed.

Old wildlife plantings in Kalamazoo County, Michigan were reported on by Gysel and Lemmien (1955-580). Plants involved were Amorpha fruticosa, Caragana aborescens, Cornus ammomum, Rosa multiflora, Lonicera tatarica, Elaeagnus augustifolia, and Sorbus acuparia. The authors indicated that survival and growth of the plants was generally good; that each of the plantings added to the diversity of cover in the area; and that indigo bush was the only planting that had increased in size from seedlings and root suckers. From trapping records and observations, they reported that each of the plantings was used by a variety of animals--mainly small insectivores, rodents and songbirds, but also by rabbits and deer, in the case of the multiflora rose.

Findings from a study of mourning dove production in a central Nebraska shelter belt might be indicative of the type of benefits that can be derived from tree plantings in the Plains states. La Pointe (1958-597) found that in this planting--perhaps larger than most highway plantings (1.3 acres)--there were 98 dove nesting attempts, or 75 per acre. The average nest height was 8 feet. Although only 14 percent of the trees in the shelter belt--not including a plum thicket--were American elms, 47 percent of the dove nesting occurred in this species. Also Ponderosa pine, comprising 13 percent of the trees, contained 32 percent of the observed nests. Comparisons were made with other dove studies in shelterbelts in which American elm, Chinese elm, Russian olive, Osage orange, mulberry, and juniper were listed as preferred trees for mourning dove nesting.

Wandell (1948-627) reported on songbird use of wildlife habitat improvement plantings in Urbana Township, Illinois. Observations of these plantings in 1947 showed an average of 105 pairs of songbirds per mile of cover with mature Osage orange hedges having only half as many. On an acreage basis, he reported that fence row and stream bank improvements (the type which could be developed in connection with highways) had more than three times as many pairs of songbirds as did block plantings.

Thus, we see that some wildlife plantings are used extensively. Food plot plantings may attract wildlife to an area temporarily without necessarily increasing the overall population, but use of plantings for nesting, as in the case of birds, presumably does contribute to increased production.

The bibliography contains summaries of many other articles dealing with valuable wildlife food and cover plants, selection of species for various purposes, and methods for handling and planting them. Some of the guides are designed for particular regions--Fox (1935-571), for example, provides recommendations for the Dakotas, and Gill and Healy (1974-577) for the Northeast. The 141-page book, "Wildfowl Food Plants: Their value propagation and management," by W. L. McAtee (1939-601), deals largely with aquatic plants of value to wildfowl.

Other points gleaned from literature related to early wildlife food and cover planting attempts, but perhaps worthy of noting here, follow. Spooner and Yeager (1942-620) found that farmers on the Illinois prairie were generally opposed to the planting of Osage orange, black locust, and other large-growing species--except that some wanted pines or other evergreens--but were agreeable to the planting of small shrubs such as rose, hazelnut and gray dogwood. Edminster and May (1951-568) indicated that where natural stands of desired native shrubs are already present in borders, hedgerows, and odd areas, the cutting of overtopping trees may be all that is needed to make such areas as good as any that could be planted. Pearce and Spaulding (1942-609) emphasized need for selection of hardy disease-free stock of plants for wildlife management purposes, and for sanitation and care in handling. Wilde (1946-629) emphasized the importance of adequate soil fertility. Cook and Edminster (1944-560) indicated that for planting and establishment of hardwood trees and shrubs for wildlife, plowing was the best method of site treatment. They stated that scalping was only a little better than slit planting in undisturbed sod. Agee (1951-549) and Van Dersal (1937-624) commented on planting of shrubs and trees with respect to their value as windbreaks and control of snow drifting.

Controlling Vegetation with Herbicides

Eologists and wildlife biologists recognize that when misused, or used without adequate consideration for wildlife, herbicides may have undesirable effects on wildlife. Thus, Goodrum and Reid (1956-578) pointed out that extensive hardwood and brush control programs, through use of herbicides, to rid farm, range and forest lands of so-called culls or weed species, may not give due consideration to wildlife values. They were concerned, in particular, with the removal of various oaks which provide diversity and food for wildlife in southern pine forests. Likewise, Klebenow (1970-588) reported that spraying with herbicides to control sagebrush was detrimental to sage grouse in that nesting ceased when one area was sprayed and another contained a nest five years after spraying. Allen (1953-550), in discussing how general use of herbicides was hurting habitat, and recognizing that herbicides can be used beneficially, admonished wildlifers to get busy and develop information on which more realistic recommendations could be made to those who are doing the spraying. Twenty-two years later it would appear that wildlifers have not done a great deal towards this end.

We have noted some of the recommendations made by Frank E. Egler and W. C. Bramble with respect to herbicide control of vegetation and wildlife values and would observe that Krefting, Hansen and Stenlund (1955-594 and 1956-595) have illustrated how herbicides can be used to stimulate regrowth of mountain maple (Acer spicatum) for deer browse.

Warbach (1953-628) found that a low percentage of 2,4-D water spray applied to Japanese honeysuckle growing in bicolor lespedeza would selectively control the honeysuckle without injuring the lespedeza. Jenkins (1956-587) reported aerial applications of herbicides to be useful for converting certain low-grade aspen stands into lush fields of sprouts fine for deer and that, by repeated applications, areas could be converted to grassland desirable for sharptail grouse.

Mueggler (1966-605) and Lyon and Mueggler (1968-600) reported on herbicide treatment of browse on a big-game winter range in northern Idaho. Six years after treatment with 2,4-D, 2, 4, 5-T and a mixture of these two chemicals, the authors found some lag in the mortality of some undesirable plant species coupled with generally poor persistence of sprouting and relatively quick recovery from crown dieback in the desirable species. Also, they found that redstem ceanothus (Ceanothus sanguineus), the most desirable plant tested, was killed by all treatments. The authors pointed out that indiscrimate herbicide application to all species, without careful consideration of treatment date, composition of the existing plant community, and ultimate result desired, could easily cause an overall loss of both browse forage and cover. Thus again, we note the dangers of blanket spraying and the need for attention to individual species, if we wish to obtain the desired results. McConnell (1968-602), in discussing the manipulation of forest vegetation with modern herbicides, pointed out that individual trees may be treated in various ways with many different chemicals to eliminate them from forest stands.

Cutting and Other Methods of Vegetation Control for Wildlife

Arner (1966-551) pointed out that, although utility line right-of-way development for wildlife has been the subject of numerous papers, and that while techniques involving bulldozing, discing, selective basal spraying with herbicides, mowing, fertilizing, seeding and prescribed burning have been described and acclaimed for their dual role in producing game food and retard-invasions of unwanted vegetation, only a fraction of the several hundred thousand acres of utility-line rights-of-way in the southern states have been cooperatively managed for dual use. The same observation could be made for highway rights-of-way, I feel sure. Arner offered suggestions on how to implement cooperative right-of-way maintenance programs and indicated that, based on his findings, prescribed burning was the most practical of all the maintenance techniques studied.

With limitations imposed by air quality regulations, the old-fashioned methods of trimming and cutting remain important in vegetation control. Knierim, Carvell and Gill (1971-591) have discussed how thinnings in oak and cove hardwood stands stimulated production of both seedling-and-sprout-origin browse in the southern Appalachians. Christisen and Korschgen (1955-557) have stated that, from a wildlife management point of view, it is desirable to maintain a variety of oak species in oak-hickory forests so that complete failures of acorn production will be unlikely. They suggested, also, that some oaks from the black oak group should be retained inasmuch as acorns from these oaks do not germinate until the spring and, therefore, are available to wildlife throughout the winter when other food supplies are scarce. Goodrum, Reid and Boyd (1971-579) suggest that, in the South, oaks on upland pine sites, particularly away from stream bottoms where the trees of larger form normally occur, should be left standing to provide food for wildlife and offer diversity in cover in an otherwise pine monoculture.

Frequently, the ruffed grouse (Bonasa umbellus) may be seen when driving along roads through forested areas. Korschgen (1966-592) thought that preservation of the hop hornbeam during forest management operations (and perhaps highway tree clearing operations as well) could materially improve the habitat for this grouse. In addition, he suggested that preservation of productive oak trees and release-cuttings around subdominant oaks may increase acorn production; improvement of timber stands, bulldozing small clearings, and maintaining open timber stands would encourage tick trefoils, bush clovers, fragrant sumac, and native roses; and that wild grape, bittersweet, shadbush, flowering dogwood, and hazelnut fruiting quality may be measurably improved by timber stand improvement or release cutting in the immediate vicinity of selected, large vigorous plants.

Other papers reviewed concerning release cuttings, logging, effects of shade, and forest clearings are included in the bibliography--see, for example, Cook (1939-559), Cypeat (1949-561), Gill (1957-576), Baker and Frischknecht (1973-552), Halls and Alcaniz (1968-581), Harshbarger and Perkins (1971-583), Garrison (1953-575) and Regelin, Wallmo, Nagy and Dietz (1974-611), Larson (1966-598), and Morton and Sedam (1938-604). Murphy and Ehrenreich (1965-607) observed that six of the plant species used by squirrels in the Missouri Ozarks were most abundant in the bottomlands, but were not fruiting. They suggested that removal of the non-commercial overstory would promote fruiting.

Of possible interest to roadside landscape design personnel, are five other articles. Hooper, Crawford and Harlow (1973-585) found that with 49 species of birds nesting in 30 forest recreation areas in the southern Appalachians, the percentage of cover provided by foliage less than 12 feet high accounted for 56 percent of the variation in densities of nesting birds. The mixture of coniferous and deciduous foliage more than 12 feet high accounted for 66 percent of the variation in diversity of birds. They suggested that clumping of understory shrubs is important to birds in open, parklike recreational areas. Tomoff (1974-623) found that along a gradient of habitat complexity in desert scrub communities of the Sonoran Desert in southern Arizona, nest sites and food niches become more diverse, and breeding bird population density and species diversity increase. He stated: "Birds are highly specific in their selection of plants for nest placement; densities of most species are strongly related to densities of nest plants." He stated further: "A significant relationship is found between physiognomic coverage diversity and breeding bird diversity. This index, based on a system of plant life forms, quantifies critical environmental features used by birds in habitat selection. A model that combines aspects of foliage-height diversity may provide greater accuracy and wider applicability for predicting bird species diversity."

It would seem that knowledge of this index would be helpful in designing roadside and wildlife planting programs for desert scrub areas to favor certain bird species. Here, plant species composition is highly significant in regulating breeding bird communities--much more so, apparently than in a deciduous forest where a tree species may not be as important as the structural quality of the branch on which a bird nest is built.

Conner, Hooper, Crawford and Mosby (1975-558), in studying woodpecker nesting habitat in Virginia woodlands, found that all nesting cavities of four species of woodpeckers--common flicker (Colaptes auratus), pileated woodpecker (Dryocopos pileatus), downy (Dendrocopos pubescens) and hairy (D. villosus)--were excavated in decayed wood of trees infected by fungal heart rots. They stated: "Timber management may be detrimental to woodpeckers if all decayed trees are removed. Uncut filter strips along streams and roads appear to be of value as woodpecker nesting habitat."

Petrides (1942-610) concluded that hedgerows in the shrub stage are of most value to wildlife and, that for greatest efficiency in soil and wildlife conservation, should be composed entirely of shrubs and vines from 6 to 10 feet high, 12 to 15 feet wide and of good density near the ground.

Bradbury (1939-555), in discussing management of apple trees for wildlife, found that they should not be pruned, because pruning impairs persistency of the fruit and lowers its availability during the snowy season. He suggested a 50 percent release from surrounding vegetation and removal of competitive ground cover and warned that mangement of wild apple trees should be carried out only in forested or wild areas 500 yards or more from a commercial orchard because of apple pest problems.

Some Plants and Their Use by Wildlife

Highway landscape designers and officials in charge of highway plantings and vegetation management programs may find useful some of the literature selected from a wealth of material related to plants and their use by wildlife, even though these references do not relate specifically to highway vegetation-wildlife relationships. Included among these publications are the following: a 500-page book by Martin, Zim and Nelson (1951-650) entitled "American Wildlife and Plants" which, is, essentially, a guide to wildlife food habits--the use of trees, shrubs, weeds and herbs by birds and mammals; a 362-page U. S. Department of Agriculture publication by Van Dersal(1938-663) entitled "Native Woody Plants of the United States. Their erosion control and wildlife values;" "Soil Conservation" by Hugh Hammond Bennett (1939-633) which contains a 28-page chapter on wildlife and conservation, including lists of plants used in large numbers for soil and wildlife purposes; a publication of the U.S.D.A. Forest Service (1973-662) entitled "Wildland Shrubs--their biology and utilization; U.S.D.I Bulletin 7 by W. L. McAtee (1941-653) entitled "Plants Useful in Upland Wildlife Management" and a 153-page report by Graham (1941-642) on "Legumes for Erosion Control and Wildlife."

A cooperative study between the Soil Conservation Service and the State of Washington Department of Game, started in 1940, resulted in a publication by Miller, Ball and Knott (1948-654) in which the wildlife value as well as the soil conservation value of 470 species of woody plants are assessed.

Publications by Compton and Hamor (1972-636), Longenecker (1960-649) and Mason (1959-651) deal specifically with lists of shrubs and trees useful for attracting birds. Compton and Hamor (1972-636) provided information on ornamental value, adaptation to soil and sun (or shade), blooming period, height, and sources of availability for 17 plant groups and species suitable for attracting birds. The suggested plants are autumn olive (*Elaeagnus umbellata*), dogwood (*Cornus* spp.), Mountain ash (*Sorbus* spp.), firethorn (*Pyracantha* spp.), Russian olive (*Elaeagnus angustifolia*), sunflower (*Helianthus* spp.), crabapple (*Malus* spp.), elderberry (*Sambucus* spp.), American cranberry bush (*Viburnum trilobum*), cherry (*Prunus* spp.), wild plum (*Prunus americana*), cotoneaster (*Cotoneaster* spp.), Tartarian honeysuckle (*Lonicera tatarica*), red cedar (*Juniperus virginiana*), bittersweet (*Celastrus scandens*), holly (*Ilex* spp.), and hawthorn (*Crataegus* spp.).

Foods of the cottontail rabbit are discussed by Dalke and Sime (1941-638) and by Allen (1939-632). Allen (1939-632) found that in winter in Kalamazoo County, Michigan, in times of deep snow, dwarf and staghorn sumacs (*Rhus copallina* and R. *typhina*) were the most important woody food plants. Plants receiving moderate use by rabbits for food were red oak (*Quercus borealis*), ailanthus (*Ailanthus glandulosa*), cultivated apple (*Pyrus malus*), buckthorn (*Rhamnus cathartica*), wild blackcherry (*Prunus serotina*), gray dogwood (*Cornus candidissima*), silky dogwood (*Cornus ammomum*), black elder (*Sambucus canadensis*), fox grape (*Vitis vulpina*), black raspberry (*Rubus occidentalis*) and Scotch pine (*Pinus sylvestris*).

Nixson, Worley and McCalin (1968-655) found that in 833 gray and fox squirrels collected in southeastern Ohio during all seasons of the year, the important foods, in decreasing order of occurrence, were hickory nuts, beechnuts, acorns, fungi, black walnuts, plant leaves, yellow buckeye nuts, tulip tree samaras, flowering dogwood drupes, ironwood nuts, and hop hornbeam nuts. Terres (1939-661) found elm buds and samaras were relished by gray squirrels in parts of New York and Pennsylvania during the spring.

Hanson (1960-646), one of many authors who has written on foods of bobwhite quail, stated that of more than 350 plant species investigated, 40 seemed promising for use in improving quail habitat in Oklahoma. He indicated that native plants are more useful, in general, than introduced species, and stated that western indigo and sensitivebriar appeared to be the most important native herbs, while hairy vetch and Austrian winterpea showed promise among the naturalized herbs. Sand plum, he felt, is the most important plant for resting and roosting cover. Lehmann and Ward (1941-648) listed as important winter foods for southwestern bobwhites, panic grass (Panicum texanum), sorghums, and doveweeds (Croton spp.). He indicated that clumps of woody cover three to ten yards in diameter that provide concealment, freedom of movement underneath, and good visibility are ideal for mid-day resting or "loafing" cover, and he stated that black brush, lasajillo, and wild rose often meet these requirements.

Oefinger and Halls (1974-656) and Grelen and Duvall (1966-643) have prepared guides useful for identifying woody and other plants valuable to wildlife which are found in southern forests and in the longleaf pine-bluestem range. Other works describing local plants of value to wildlife include reports by Lamb (1971-647) on woody plants of New Mexico, and by Christensen (1967-635) who prepared a bibliography of Utah botany and wildlife conservation.

Reports on the use of specific plants or groups of plants by wildlife were prepared by Deck (1938-641) on the hawthorn; Borrell (1951-634) on Russian olive; Handley (1945-645) on Japanese honeysuckle; Van Dersal (1940-664) on oaks which constitute, he stated, the most important and the most abundant and widely distributed genus of hardwood trees in the north temperate zone and on which records show 186 different kinds of birds and mammals feed; and Gysel (1971-644) on beechnuts in Michigan. He found that the proportion of nuts utilized by animals in the trees generally was greater than 30 percent.

Dambach (1948-639) investigated, over a three-year period, the possibility that animal pests injurious to field crop production, might be fostered by field border vegetation favorable to farm game species. He found that use of woody field border vegetation involved less risk to grain and forage crops than did the use of herbaceous vegetation. Presumably the same relationship would obtain with highway right-of-way vegetation and adjacent grain and forage crops, i.e. woody vegetation would be less likely to harbor pests injurious to agricultural crops.

OTHER OPPORTUNITIES FOR MANAGING FOR FISH AND WILDLIFE

Provision of Fish Passage Facilities

As mentioned under the heading, "Other Detrimental Effects of Highways, Their Construction and Maintenance," highway drainage structures can be an impassable barrier to the migration of anadromous fish and thereby damage the fisheries resource of an area. Salmon, steelhead, and other migratory fish must be able to swim to upstream spawning areas. A culvert or other drainage structure, if the drop at the outfall is too great or if they are placed at an excessive gradient, may block the fish in their migration.

Several authors have discussed this problem and have suggested remedial measures. Metsker (1970-685) reported on construction of culverts in relation to unstable and stable streambeds and the swimming ability of fish. Lewis and Kay (1970-683) investigated forty existing drainage structures in California and indicated these structures could be designed so as not to be a blockage to migratory fish. They presented a design procedure which they believe will enable the engineer to determine if a given structure requires special consideration for fish passage.

Saltzman and Koski (undated-692) of Oregon stated that a bridge will usually cause the least problem of fish passage, but indicate, when it is necessary to build a culvert, the most desirable type of fish passage is a structural steel arch, set in concrete footings. A less desirable type, but usually satisfactory, they indicate, is the pipe-arch culvert with a flattened bottom, and a still less desirable type--but the one most commonly used--is the round corrugated pipe. Several guides have been prepared to help biologists and engineers deal with the practical problems of providing fish passage over obstacles in streams, including those suggested by Evans and Johnston (1972-674)--revised in 1974), Gebhards and Fischer (1972-675), and the Oregon Wildlife Commission (1975-689).

Kay and Lewis (1970-682), in reporting on a project jointly funded by the Federal Highway Administration and the California Department of Fish and Game, made several recommendations based on observations of the research staff's observations on forty existing drainage structures in the state. These recommendations included: (1) some oversizing of culverts when passage facilities are warranted, with the resultant effect of reducing velocities and simplifying the subsequent design of the passage devices; (2) where possible, depressing culvert grade lines below streambed fish entrance condition into the culvert; (3) in those installations where the total grade lines cannot be depressed, giving consideration to lowering of the outlet flow lines to provide for possible streambed degradation; and (4) because, for a given culvert installation at a specific discharge, the velocity will vary inversely with the roughness coefficient or "Mannings n," selection of a higher "n" value culvert-type may reduce velocities below the need for passage devices. The authors concluded that a satisfactory limiting discharge for fish passage is one that is equaled or exceeded 10 percent of the October through April time period.

As is so often true in highway construction activities, it is desirable that biological information be provided to the highway planners and engineers early in the planning process. In the case of fish passage problems, state fish and game departments or other agencies or organizations should be prepared to provide data on the habits and life cycles of anadromous fish, the physical capabilities of these fish for swimming past barriers and passing through culverts, and identification of streams normally used by these fish. Nowell (1966-687 and 1967-688) described the type of cooperative program inaugurated in 1963 by the New Hampshire Department of Public Works and Highways and the Fish and Game Department. He outlined some of the benefits that have derived from this arrangement, including fishways and low-water (v-bottom) channels used to allow fish movement at all levels. He emphasized the importance of cooperation during the planning and designing stages of highway construction.

Impoundments and Wetland Management

Among the other benefits and opportunities resulting from the cooperative New Hampshire program mentioned by Nowell (1966-687 and 1967-688) above, are rehabilitation of channelized streams and creation of duck habitat. Many other states have similar arrangements as pointed out by DeBates (1967-671). He stated that efforts to acquire wetlands for wildlife under Public Law 87-383 and other legislation are quite often involved or related to township, county, state and federal road construction projects. He considered that application for rights-of-way permits presents an opportunity to discuss wetland preservation with engineers of the various highway departments and indicated that Memoranda of Understanding had been signed by the U. S. Fish and Wildlife Service and the state highway departments in Minnesota, North Dakota and South Dakota to insure protection of wetland holdings, adjacent to state highways. As indicated previously, the Bureau of Public Roads Instructional Memorandum 21-5-63 requires formal coordination between the state highway and fish and game departments to minimize wildlife habitat losses. Despite these provisions and agreements, wetland losses still continue, particularly in connection with township and county road construction and related drainage. However, some progress has been made and other opportunities for fish and wildlife enhancement exist, as will be shown by a few examples.

Sullivan (1958-697), in urging state fish and game departments to take advantage of the opportunity of creating new wetland habitat in connection with highway development, estimated that although conservationists must pay the difference in construction cost, they would be getting five to 10 times their moneys worth. He indicated that as of January 1956, 45 of these projects had been completed in 10 states at an average saving of $23,000 per project for impoundments varying from one to 1,200 acres in extent and averaging 130 acres.

Uhler (1964-699) suggested that simple water control structures could be installed at the heads of secondary road culverts in many places to create small marshes and shallow ponds and that borrow pits along highways and fills made across swales are readymade sites for new waterfowl habitat. He cited as examples of aquatic habitat created by highway departments, the Thousand Acre Marsh in New Castle County, Delaware and White's Creek Impoundment in Marlboro County in South Carolina.

Reid (1955-691) stated: "The principle of utilizing road fills for impounding water by the simple installation of an elbow on the upstream end of the culvert pipe, with the addition of a vertical riser if greater depth is desired, can be used in countless places where existing roads cross small rivulets, as well as in construction of new roads. It presents a splendid opportunity to transfer the effect of a road from the debit to the credit side in our stream accounting."

Bergstrom (1971-668) brought out the fact that wetlands created in conjunction with highway construction provide scenic enhancement of the highway and, when combined with rest stops, provide recreational opportunities to travelers as well as the local citizenry.

Heusmann (1970-677, 1971-678, and 1973-679) has discussed some of the engineering aspects of damming drainage ways by highway fills or flooding of borrow pits to create impoundments for wildlife use. He suggested that the desired use of such impoundments as wildlife areas can be promoted by voluntary cooperation, regulation by police powers, and by acquisition. Aus (1969-667) stated: "Highway construction projects modify and destroy wetlands. Improved coordination among governmental agencies helps reduce the impact of road construction, but in nearly all cases there is a direct loss. Local highway officials often oppose standards which are based on national resource needs. Frequently, road construction improves or provides outlets for indirect wetland drainage." He cites the Fairdale project proposed by the Walsh County (North Dakota) Water Management Board as a good example of how wildlife values can be upheld by close cooperation and coordination of efforts. This project involved cooperation of the State Game and Fish Department, Soil Conservation Service, Fish and Wildlife Service, and the Fairdale group. It must be recognized, however, that projects involving drainage or flooding effects on adjacent private land require careful consideration of property rights and damages and of the many values and interests involved. Solution of these problems does, indeed, require coordination and cooperation, but as that seasoned state game administrator, M. O. Steen (1966-695) put it: "Coordination can work wonders."

Probably the most widely known of the many developments of roadside borrow pits or lakes for fish and wildlife in connection with highway construction is that of the chain of lakes along Interstate 80 in Nebraska. Steen (1966-695) described the 75 or so crystal-clear lakes that had been created in excavating fill for the roadbed along 150 miles of this major transcontinental highway and indicated that Land and Water Conservation funds administered by the U. S. Department of the Interior's Bureau of Outdoor Recreation would contribute substantially to landscaping and developing the lakes for the use and enjoyment of interstate travelers as well as for Nebraskans. Similarly, Hill (1975-680) described a chain of lakes covering approximately 260 acres created along Interstate 29 in Harrison, Mills and Fremont Counties in southwest Iowa.

Moulton (1970-686) studied four borrow pit ponds created as a result of Interstate 91 near Whately, Massachusetts, to determine their fishery potential. He made management recommendations for increasing the fishery potential of existing borrow pits and presented guidelines for future construction and management to enhance fish production. Carlozzi et al (1971-703) observed that wetlands inadvertently created in the course of highway construction are generally poor in productivity as a result of poor location, morphometry, site preparation or a combination of these factors. Hence, biologists have an opporunity to provide the kind of information that would increase the value of such areas for fish and wildlife. A wetland area or borrow pit lake most valuable for fish probably would not be most valuable for waterfowl; depending upon the size and other characteristics of the impoundment, steep sides or slopes may be desirable for fish, whereas feather edges suitable for growth of various aquatic plants may be more desirable for waterfowl and mud flats or sandy beaches may be more suitable for marsh and shore birds. Decision on the use to be made of the impoundments should be made in the planning stages for highway route selection and construction.

Other opportunities to increase the value of these areas for fish and wildlife exist--construction of duck nesting boxes or resting platforms, for example. Shearer and Uhlig (1965-693) found that in the case of stock-water dugouts constructed for the purpose of livestock-watering in South Dakota and Minnesota, the addition of resting sites in the form of rafts made them more attractive to wild ducks than dugouts without such modifications. These stock-water dugouts are similar to most borrow pits developed in highway construction in that they do not provide the gentle slopes and mudflats preferred by many ducks as resting areas.

In addition to their use by fish and waterfowl, borrow pit ponds and other wetland areas created by highway construction may be used by a large number of other species, including muskrats. Arata (1959-666) found an average of 2.4 muskrat dens per 1,000 feet of shoreline in coal strip mine ponds in southern Illinois. Except, perhaps, for acidity, some of these ponds resemble those created by excavation for fill in highway construction.

Beneficial Use of Solid Waste Materials

Mention has been made, Netzer, Wilkinson and Beszedits (1974-481), of the possible use of discarded automotive tires in conjunction with lime to remove trace metals from waste water and, hence, enhance water quality for aquatic orgnisms. Several authors have suggested, also,that discarded tires can be put to constructive use in building fish havens or artificial reefs--Edmund (1967-673), Stone (1971-696), Turner, Ebert and Given (1969-698), and the U. S. Department of Commerce (1975-700).

Stone (1971-696) reported that biologists at the Sandy Hook Sport Fisheries Marine Laboratory had experimented with junk car bodies, concrete culvert, scrap ties, obsolete ship hulls, and tires in their possible use for improving the marine environment for fish. They found that these materials became encrusted with invertebrates and attracted fish but, with the exception of the tires, were difficult to handle. He described various arrangements for using the tires as artificial reefs. The U. S. Department of Commerce (1975-700) reported that tires, discarded at the rate of more than 200 million per year, can be put to beneficial use in constructing moored, floating breakwaters for protecting small boat marinas and shorelines vulnerable to erosion. This Department, based upon research at the University of Rhode Island, indicated that scrap-tire breakwaters offer an added bonus to sport fishermen in that seaweed and barnacles begin growing on the tires, providing food for small fish which soon attract large fish. Experiments have indicated that pollutants do not leach from the tires. Turner, Ebert, and Given (1969-698) reporting on man-made reef ecology, stated man-made reefs can turn "non-productive" areas of the near (ocean) shore into "productive" fishing areas. Among the materials they used for reef construction were automobile bodies, but they indicated that quarry rock was the preferred reef-building material, based on cost and ease of handling and the lesser disturbance of the bottom sediments.

Various sections of highways throughout the nation, including I-80 in Wyoming, are being built on fills comprised of garbage and other solid waste material (anonymous, 1972-726), but one wonders what the long-term effects might be on water quality.

Other Opportunities for Management

Concern has been expressed about failure of some of the new highways to provide access to hunting and fishing areas. Byrd (1960-669) discusses development of fishing access areas under a cooperative agreement between the State Conservation and State Highway Departments of Alabama as a practical and economical method of supplying one of the greatest needs of the State's fishermen--that of access to public waters.

Mention has been made previously of the Montana law (Peters, 1970-507) giving the State Fish and Game Department authority to influence highway and other construction, so as to minimize adverse effects on fish and wildlife. The same law affords Montana the opportunity, as some other States have, to use small parcels of land isolated by road construction for conservation purposes. In this connection, consideration may well be given to habitat management for game and non-game species of wildlife. Under certain conditions, establishment of small public hunting areas might be feasible. As indicated by Berryman (1963-94), however, size of these areas may be a limiting factor in terms of practical game management and the harvest of game crops.

In the case of rare and endangered species, state wildlife departments, fish and game commissions and other natural resource agencies could be helpful to highway planners by advising them of the location and distribution of such species; the characteristics of habitat required for supporting them, and by providing other timely information so that the routing and construction of roads can be accomplished without unnecessary habitat destruction or further endangerment of the species.

Chamberlain (1974-670), for example, has prepared a report concerning the identification, distribution, populations, and habitats of 23 rare and endangered species of birds in southern forests. Similar lists might well be prepared for other areas and brought to the attention of the Federal Highway Administration and state highway administrations or commissions.

Sheehan (1971-694) has described experiments in moving tortoises from the path of highway construction in the Mojave Desert to another area selected to match, insofar as possible, the previous habitat in an effort to conserve these animals. James R. Gordon, Chief of Environmental Planning, the State of California Department of Transportation, in a letter dated August 25, 1975, provided information on tortoise relocation sponsored by the California Division of Highways (now Caltrans). This concerned the feasibility of transplanting desert tortoises from the proposed freeway corridor of State Highway 58 to selected sites on the Naval Weapons Center in San Bernardino County.

It is my understanding, also, that the Wildlife Administration of the Maryland Department of Natural Resources has provided highway officials with information on the rare bog turtle that might be affected by the extension of Highway 70 through wet areas in Western Maryland.

Among the problems in providing information on many rare and endangered animal species is the fact that little is known about their numbers, habitat requirements, behavior, and the likelihood of success in transplanting them to other areas. Information of this kind can be acquired only through research and experimentation and it is difficult to get financial support for non-game animal research.

There are opportunities to promote the conservation of native plants as well as animals in the planning, construction and maintenance of highway systems. Mr. Ken Taylor, Environmental Impact Coordinator of the California Native Plant Society (CNPS), provided some relevant information about this in a letter of September 10, 1975. CNPS, an organization of laymen and professionals united by an interest in the plants of California, publishes a journal, Fremontia. It assists the State Department of Transportation in several ways: by reviewing first drafts of Environmental Impact Statements, by providing information on rare or endangered plant species that may be threatened by road construction, and by suggesting native plants for use in the landscaping of highway construction projects.

As an example of the activities of CNPS, Mr. Taylor reported that the Environmental Impact Statement for a section of a state route in northern San Benito County which was scheduled for realignment and reconstruction failed to note a rather rare form of Clarkia. This plant is one of a small genus of showy annual herbs on the Pacific slope of North America. It was believed that construction work would destroy most, and perhaps all, plants in the construction zone. Mr. Taylor stated that the District Highway Engineer was cooperative and expressed a desire to use Clarkia in landscaping after construction was complete. Inasmuch as commercial seed sources did not stock this species, a CNPS member collected seeds and supplied them to the Highway District where they were to be grown for seed production and used to reestablish the plant as part of the landscape design following construction of the highway.

Other considerations for fish and wildlife and environmental values in the course of road construction will be discussed in the next part of this report.

PART III

ENVIRONMENTAL CONSIDERATION AND EVALUATIONS IN HIGHWAY PLANNING, CONSTRUCTION AND OPERATION -- GENERAL

A review of the literature of recent years reveals numerous articles, books and reports that deal with environmental aspects of highways in a general, philosophical way; many which are concerned with environmental laws and environmental impacts; and others with policies, processes and procedures designed to decrease the destructive effects of highways and to protect and enhance the environment. An overall assessment of this literature encourages the reader to think that good progress is being made, especially in connection with interstate highway construction, in giving increased attention to environmental quality, to aesthetics, and, to some extent, to fish and wildlife values. No attempt will be made to digest all of this material here. Readers are encouraged, however, to review summaries, abstracts or annotations of the publications listed under this heading in the bibliography.

As background for this, we must realize that we live in a mechanized world of technology and gadgetry and that highways and automotive vehicles are an essential part of our environments. Aldo Leopold (1943-709), did when he wrote of wildlife in American culture. He indicated that fishing, except for motorized transport, seemed less severely mechanized than hunting and he stated: "Fox hunting with hounds, backwoods style, presents a dramatic instance of partial and perhaps, harmless, mechanized invasion. This is one of the purest of sports; it has real split-rail flavor; it has man-earth drama of the first water. The fox is deliberately left unshot, hence ethical restraint is also present. But we now follow the chase in Fords! The voice of Bugle-Anne mingles with the honk of the flivver..."

By 1955, the U. S. Fish and Wildlife Service (1956-720) estimated that hunters traveled 2,684,914,000 automobile miles and more than twice that many passenger miles in pursuit of this sport; and the mileage has gone up appreciably since then.

As brought out by the American Association of State Highway Officials (AASHTO, 1970-702), it is essential that the highway be considered as an element of the total environment, not apart or in conflict with it. All highway oriented disciplines should collaborate at all stages of highway corridor selection, location and design in order to obtain the maximum beneficial potential of the highway, its roadsides and its environment.

ENVIRONMENTAL QUALITY AND THE LAW--GUIDES FOR IMPLEMENTATION AND COMPLIANCE

The President's Science Advisory Committee, Environmental Pollution Committee (The White House, 1965-722) in its publication, "Restoring the Quality of the Environment," recommended that: Federal agencies neither expend funds on or grant financial aid to any construction project or program which does not include effective measures for minimizing production of dust or sediment (the Committee pointed out that temporary disturbance from highway and building construction now contributes large amounts of sediment, in some watersheds more than half the total) and that, especially in marshlands and coastal areas, minimizing the impairment of natural drainage patterns should be an important consideration in the building of Federally-supported highways.

A provision of the Department of Transportation Act of 1966 specifies that "the Secretary (of the Department of Transportation) shall cooperate and consult with the Secretaries of the Interior, Housing and Urban Development, and Agriculture, and with the States in developing transportation plans and programs that include measures to maintain or enhance the natural beauty of the lands traversed. The Secretary shall not approve any program or project which requires the use of any land from a public park, recreation area, wildlife and waterfowl refuge, or historic site unless (1) there is no feasible and prudent alternative to the use of such land, and (2) such program includes all possible planning to minimize harm to such park, recreational area, wildlife and waterfowl refuge, or historic site resulting from such use." The 1966 Federal Aid Highway Act includes similar provisions specifically aimed at the Interstate and Federal aid primary and secondary highway systems.

Mention has already been made of the Federal Highway Administration's Instructional Memorandum 21-5-63 calling for the state highway departments to include recommendations from state fish and wildlife agencies in their requests for Federal appropriations on highway construction, and, also, of the guidelines of the Council on Environmental Quality to state highway departments and the FHWA regarding the meeting of national environmental goals in Federally financed highway improvements.

As indicated by Lash (1973-708), Section 136B of the 1970 Federal Highway Act guidelines calls on each state to prepare an action plan that outlines the organizational arrangements and procedures the state will adopt to ensure that the four following fundamental objectives are accomplished in the development of a highway project: (1) state highway departments must develop a real competence to identify and objectively study economic, social, and environmental effects of proposed highways projects; (2) an interdisciplinary approach must be used in the development of highway projects from system planning to design; (3) other agencies and the public must be involved in system planning, location planning, and design; and (4) alternative solutions must be considered.

And then there are, of course, the National Environmental Policy Act of 1969 with its requirement for the submission of environmental impact statements (EIS) and many other environmental quality acts, including several dealing with air and water quality which have a direct bearing on highway construction.

Many guides have been developed for implementing these laws. A guide for highway landscape and environmental design has been prepared by AASHTO (1970-702). Wolsko, Nelson and Habegger (1974-724) prepared an environmental handbook for highway systems which provides a general background for transportation planners on the considerations that should be given to the environmental impact analysis of proposed highways. As one of several volumes on the Federally Coordinated Program of Research and Development in Highway Transportation (FCP), the U. S. Department of Transportation (1972-721) published Volume 3 dealing with environmental considerations in highway design, location, construction and operation. Sloss (1972-717) prepared a bibliography on environmental aspects of transportation planning--a revision of CPL Exchange Bibliography No. 218 of the Council of Planning Librarians--which gives special attention to air and noise pollution. The U. S. Department of the Interior (1974-719) published an environmental guidebook for construction "designed to help construction people understand how their work relates to the environment."

Arthur D. Little Inc. (1971-711) attempted to assess the effects of policy, programs, legislation, and administrative directives of the U. S. Department of Transportation with respect to environmental quality. Particular attention was devoted to Section 102 (2) (c) of NEPA. One of the recommendations of the study was that the quantifiable and nonquantifiable elements of environmental impact be delineated as clearly as possible and be evaluated as to their amount, effect and value. Leopold, Clarke, Hanshaw, and Balsey (1971-710) developed a procedure for evaluating environmental impact which has received considerable attention and may be useful with respect to A. D. Little's above recommendations.

The Council on Environmental Quality (1973-705) published in the Federal Register, guidelines for preparation of environmental impact statements, and numerous agencies have had training sessions on this subject. New England Research, Inc. (1974-712) prepared a student workbook for a training course on ecological aspects of proposed highway improvements.

States, technical societies, universities, and conservation organizations have devoted considerable attention to environmental impacts of highways, also. For example, M. E. Scheidt

(1967-716) of the American Society of Civil Engineers wrote on environmental effects of highways; the Colorado Division of Wildlife in cooperation with the Colorado Division of Highways (1975-704) developed a 110-page wildlife environmental analysis of proposed highway development; Laurence R. Jahn (1974-707) of the Wildlife Management Institute, reported on highway design and wildlife; and Roelofs and Jenkins, of the University of Nevada, (1975-714) prepared a 136-page bibliography dealing primarily with public policy relevant to environmental problems and the broader interrelations of the physical environment, social institutions, and humanistic values. At Virginia Polytechnic Institute and State University at Blacksburg, Giles, Smart and Jones (undated-706) have devised POWER, a man-computer interaction system which develops decision aid for the State Corporation Commission of Virginia (SCC) faced with the legislative mandate of evaluating the environmental impact of all transmission lines of over 200 kw. The authors describe how the system was employed in the location of a corridor and, at the same time, satisfied all environmental criteria.

With all of this attention to environmental impacts of highways, one would think the situation would be well in hand; but the real test comes in how effectively the various laws, directives, policies, and cooperative agreements are carried out at the grass roots level. This apparently varies in different states. Carlozzi et al (1971-703) reports on problems of policy; limitations in legal authorizations and funding, including use of Highway Trust Funds off the right-of-way; and coordination for accomplishing potential wetland development as an important secondary result of highway construction in Massachusetts. The authors indicate that, in practice, the State highway agency, after determining a basic route for a highway, and during the detailed engineering stage, sends a letter to the State Department of Natural Resources advising the Department of its plans after which the Department makes suggestions concerning the highway's potential impact on fish and wildlife. They urge that a closer working relationship be developed among Federal, State and local agencies which will insure early input into the planning process and continuing review of design plans. Results of a questionnaire sent to officials in 105 Massachusetts towns showed a willingness to use local public funds for recreation and conservation projects related to highway construction.

A state wildlife agency administrator discussed, in a letter dated July 18, 1975, some of the problems his agency had in dealing with highway officials in his state. He stated that most of the involvement they had was with consultants to the highway agency soliciting information from the wildlife staff but they received little, if any, feedback on how the information was used. He indicated that, usually, several years elapsed between the time his staff made recommendations and the time highway construction actually began, and that, meanwhile, there was a lack of interchange of ideas concerning progress in planning the highway.

Apparently he would like to have a formalized liaison requirement that the highway agency solicit, then adopt or reject, the wildlife agency's recommendations on a point by point basis. He pointed out, also, that there is built into highway planning a preference for development of new roads instead of upgrading old roads. The construction of new roads--often through good wildlife habitat--together with ancillary development generated by the new roads, causes more environmental destruction.

A different situation evidently exists in Wisconsin. Posekany (1973-713) discusses how the Wisconsin Department of Natural Resources interacts with the Department of Transportation and other agencies and organizations to prevent material damage to fish and wildlife and other environmental values in road construction. A highway liaison team of a district engineer and an experienced conservationist has resolved most problems at a local level. He indicates that over a period of 17 years the district highway engineer and his staff have learned that their counterparts in natural resources are there not to stop them,but to keep things from going wrong. He states: "Something one must see to believe is a district engineer proposing a new corridor through a heavily wooded area and finding that his natural resource counterpart heartily endorses extensive cutting because an overage stand of poplar is involved. Similarly, one should see the shock the district engineer exhibits when he proposes borrow pit lakes and is asked what he is trying to produce--boating ponds, reflecting pools, or fishing lakes? To him a lake is a lake! He is horrified to find that Wisconsin's fertile waters will not keep a reflecting pool reflecting long because a crop of aquatic plants will develop or that our harsh winters require a fishing lake to be 20 feet deep if winterkill is not to be a problem or that lakes that produce duck habitat will not necessarily produce fish. But after working with the conservationist for a number of years, the highway engineer learns either by his own experience or by advice from his predecessors that 'these' people know what they are talking about."

SOME ENVIRONMENTAL CONSIDERATIONS FOR THE PLANNING AND ROUTING OF ROADS

Reference has been made to the restrictions and limited conditions under which new highways may be routed through National Parks, Wildlife Refuges and similar areas. Special consideration must be given, for example, to rare and endangered species. As reported by the Wildlife Management Institute, (Anonymous, 1975-729), the first emergency action under the 1973 Endangered Species Act was taken recently to protect the habitat of the Mississippi sandhill crane whose last remaining bit of habitat is threatened by disruption of a Mississippi highway construction project. This nonmigratory bird, of which only about 38 to 40 are reported to remain in the wild, depends on a small area which has been designated "critical habitat" by the U. S. Fish and Wildlife Service. The emergency declaration will prohibit any intrusion into the area for 120 days during which time consultation with other agencies and the interested public will be sought. Such action is not limited to the United States. As reported in Engineering News Record (Anonymous, 1974-727) engineers in Mozambique, after designing a 25-mile railroad line, found that it would run along a lagoon which was a favorite haunt for elephants. The result was that the engineers will have to reroute the proposed line.

The U. S. Department of the Interior, Fish and Wildlife Service, (1973-747) has published a list of all known threatened wildlife in the United States. The location of the threatened species should be taken into consideration in the earliest planning stages of new highway development.

Jackman (1973-736) pointed out that construction of a new highway through a wilderness area, such as the route of much of the Trans-Alaska Pipeline System, starts an irreversible series of more or less predictable events. He indicated that healing of the construction scars takes place at varying rates, but can be accelerated by careful construction practices and selection of a route which avoids the worst permafrost areas and which takes gravel and other materials from concealed sites near, but not on, the right-of-way. He pointed out, also, that the greatest environmental problems are created by those people who will use the highway for purposes of access and exploitation of a hitherto inaccessible wilderness and that it is essential that there be a comprehensive land use plan which would allocate appropriate areas for all activities.

Special consideration should be given, also, to wetlands and the effects highways have on drainage. Some of the values of wetlands to modern society are described by the U. S. Department of the Interior, Fish and Wildlife Service (1962-746) along with some of the detrimental effects of highway construction. Patton and Judd (1970-744) in discussing the role of wet meadows as wildlife habitat in the Southwest, where such habitat is scarce, suggested that roads and trails be kept out of moist and wet sites and, preferably, be located back in the adjacent dry forest. Frederick (1969-733) pointed out that when wetlands are not too remote from highways, their acquisition preserves them for a natural ecological balance in addition to providing marginal and environmental controls.

Construction of logging roads and timber harvesting next to streams have been referred to several times as causes of much sedimentation in streams and in damage to aquatic organisms. A report by the Environmental Protection Agency (1975-749), as well as many by the U. S. Forest Service, may provide helpful guides for minimizing soil erosion problems encountered in constructing highways through forested areas. Likewise, a publication by the University of Maine (1973-738) may be helpful in the incorporation of ecologically sound forest management practices into the design, construction, and maintenance of highways to reduce pollution, among other things.

In his studies of highway effects on the behavior of elk in forested areas, Ward (1974-750) suggested that there should be a buffer zone of timber at least 100 yards wide between the road and known elk feeding sites.

Aesthetics and landscape values are important considerations in highway planning, construction and maintenance. Anderson (1973-725) stated: "An inventory of all natural and scenic features should be made during the early planning and location phases of highway development. If an existing highway is to be improved, the inventory should gather available data from other agencies and field check and expand these data as necessary. Field trips with natural resource personnel may also be necessary...We must maintain continual contact with all state and local planners and natural resource agencies so that we are aware of their plans and they aware of ours. Only through such an awareness can we see beyond the roadway right-of-way to the entire environmental picture..." Anderson advocated generous acquisition of land to preserve landscape features and to create necessary buffer and transition zones between the highway and adjacent areas.

Goode (1971-734) of Australia urged highway engineers to work with landscape architects, botanists, conservationists, and ecologists to include aesthetic, recreational, and good ecologically based land use values in the designing of engineering structures. He pointed out that landscape of exceptional aesthetic value, such as can be found in unspoiled natural areas, deserve special care, and stated: "Not only do trees and shrubs contribute to the absorption of the noise, exhaust smells, carbon monoxide and smoke, they also screen unsightly structures and poor land use. Ideally, indigenous species should be used. In a natural environment, bacteria, fungi, birds and animals live in a dynamic society, the basis of which is the trees, bushes, shrubs and grasses in which they live. Not only can the aesthetic values of a highway through native forest be destroyed by a thin planting of exotics along the road verge, but the introduction of non-indigenous species will upset the natural balance, usually with a deleterious effect." He suggested, also, that attractive rest areas can be designed into the borrow pit and fill areas resulting from massive earthworks along highways and if raw native topsoil is stock-piled and spread over bared areas, native plants can be re-established in place of the unsightly proliferation of weeds and exotic plants that usually occurs. He stated that if an attempt is made to re-establish the native habitat, then the traveler, while resting, should be able to observe bird and animal life in a natural setting. McHarg (1968-740) suggested a comprehensive highway route selection method in which the linking of scenic and recreational resources is one of the positive social influences a highway may produce.

Barnes (1973-730) mentioned the importance of soil, foundation and topography in highway site selection and the Highway Research Board of the National Research Council (Anonymous, 1972-726).

observed that even former sites of garbage dumps could be transformed into aesthetically appealing areas.

Wells (1971-751) discussed, in part, highway location with respect to noise and other problems, and Schell (1971-745), with respect to air pollution. Some consideration is being given to environmental advantages of porous paving (Anonymous, 1974-728) in areas where the climate will permit such use.

Finally, McHarg (1969-741) emphasized that the best route is the one that provides the maximum social benefit at the least social cost and Lawrence S. Hamilton in the foreword to a report by Lacate (1970-737) suggested, in planning highway route locations, the best approach is to establish where a highway should not be built. He indicated that public reaction to routes which would impair a scenic gorge, a valuable rainbow trout fishery, a wildflower preserve, a series of unique bogs, and high value agricultural land was predictable and sharp. He suggested that regional values of this kind should be identified and catalogued as a basis for a resource analysis approach to planning any kind of major development, public or private.

ENVIRONMENTAL IMPACT STATEMENTS, COURT ACTIONS AND OTHER MATERIAL RELATIVE TO HIGHWAY PLANS AND CONSTRUCTION

As background material and information of possible value to planners, designers, and people in charge of highway construction, there are included in the bibliography examples of environmental impact statements and court actions related to highway plans and construction.

Certain other publication references are included for their possible guidance in the regulation and accomplishment of highway construction, or for their value in describing ecological principles and environmental impacts of various types. Summaries of many of the sample EIS included would indicate that these statements do not contain all the desired detail necessary to predict environmental impacts on fish and wildlife habitat of proposed highway development. Better predictive models and more definitive information are needed in order for biologists to be as helpful as they could be in insuring protection and enhancement of the fish and wildlife resource in highway construction.

PART IV

CURRENT AND NEEDED RESEARCH ON HIGHWAY-WILDLIFE RELATIONSHIPS

CURRENT OR RECENT RESEARCH

At request of the Urban Wildlife Research Center for summaries of research registered with the Smithsonian Science Information Exchange, Inc. (SSIE), on the subject, "Effects of Highways and Highway Construction on the Environment, Particularly on Fish and Wildlife," the Exchange provided 129 "Notices of Research Project" (NRP's).

Upon review, these 129 NRP's were grouped into the following categories for further analysis:

- Vegetation for highway rights-of-way (54);
- Environmental impacts, systems analysis and planning methodology (28);
- Pollutants and their effects on the soil and biota (27);
- Fish and wildlife and aquatic plants (20).

Some of the latter appear to deal only peripherally with fish and wildlife.

Inasmuch as these NRP's are available from SSIE at 1730 M Street, N. W., Washington, D. C., 20036 (phone 202-381-5511), reference will be made here only briefly to the research described among these respective groups, with major attention to those projects dealing with fish and wildlife.

Vegetation for Highway Rights-of-Way

It was interesting to note that ten of the NRP's in this group dealt, at least in part, with the evaluation, selection, development, culture, and maintenance of new plant materials for landscaping, erosion control, and other purposes. Of these reported studies, three were being supported by the Federal Highway Administration, including studies of the propagation and culture of new species of drought tolerant plants for highways, as well as a study on the evaluation selection, and/or development of plant material for erosion control, revegetation and general landscape use. Two studies (SIE Nos. GY-561745- and GY-7323-4) sponsored by the State Governments of Nebraska and New Mexico deal with the evaluation, establishment and management of untried new and improved types and varieties of vegetation which have special significance in conservation, soil stabilization, and beautification; an Ohio State University study deals with the evaluation and selection of ornamental tree species and cultivars for street, highway and municipal area planting; a Cooperative State Research Service project

(University of Illinois, SIE No. GY-59039-1) deals with selection of salt tolerant grasses for roadside erosion control; a USDA, Cooperative State Research Service project in New York (SIE No. GY-57744-4) will determine the variants of woody plants best suited for street and highway plantings -- previous studies indicate that a number of perennial grasses such as certain species of Festuca, Hystrix, Miscanthus, Panicum, Pennisetum, Spartina, and Uniola, have landscape values that make them worthy of greater use --; another USDA Cooperative State Research Service-sponsored project (SIE No. GY-63829-1) deals with the selection and breeding of new plant forms to meet specific needs of landscape architecture, urban and highway beautification, erosion, and pollution control in arid regions; and a U.S. Forest Service-sponsored study (SIE No. GY-23192-6) deals with development of superior shrubs through selection and breeding for wildlife habitat and other purposes.

In this same broad grouping of studies dealing with various aspects of vegetation were twenty-four others being supported by the Federal Highway Administration at universities, USDA offices, or State Highway Departments. Among these were two investigations dealing with fertilizer practices and nitrogen management for highway landscape plantings; a study to determine the most effective method for controlling cogongrass; a study of plant species survival on landscape planting projects; another study on causes and control of the decline in woody plantings along roadsides in relation to cultural and planting and maintenance procedures being used; a study designed to improve methods of selecting and establishing, by direct seeding, drought-tolerant perennial plants which will survive with minimum maintenance; a similar study which focuses on native vegetation development; an interesting study (SIE No. GB-231417) to determine the effectiveness of "tubelings" -- a new dryland planting technique in which various species of shrubs and ground cover are planted with proper soil mixes, etc., in two-foot long biodegradable paper tubes which, when the plants are "fully developed," are planted in predrilled holes in selected areas along the highways; and many other studies designed to improve vegetation management for erosion control, landscaping and other purposes.

NRP's for nineteen other investigations of a similar nature, including the role of mulching, were noted -- two being supported by the State Government of Virginia, and one each by Colorado, Georgia, Iowa, Louisiana, Montana, New Jersey, New Mexico, North Carolina, Oklahoma, and Texas; four by the U.S. Department of Agriculture; one by the French Government; one by the Federal Republic of Germany; and one in Brazil -- source of funding unknown.

The German study (SIE No. GB-601181) is directed towards developing more effective ways to provide soil erosion control of roadsides through shrubs rather than grass, with the objective of reducing maintenance costs (mowing not required) and avoiding vehicular accidents said to be caused by grass mowing. Attention will be focused on low-growing shrubs resistant to deicers which could be planted instead of grass.

One of the Department of Agriculture studies being done by the U.S. Forest Service (SIE No. GY-142-5) has shown that 32 percent of the surface erosion on road fills can be eliminated by planting the deep-rooted ponderosa pine and that, by adding a straw mulch, 95 percent of the surface erosion can be eliminated. Study to date shows, also, that roads on slopes in the Idaho Batholith incise subsurface flow levels, thereby transforming subsurface flow to surface runoff on the road. Only about 15 percent of the total water available for runoff from one logging road in this area was found to be generated by reduced infiltration on the road; the remaining 85 percent was due to subsurface flow interception. As pointed out by the investigator, W. F. Megahan, application of these study results throughout the entire road development process of location, design, construction, and maintenance will help to materially reduce the erosional impact of road construction.

The Louisiana study (SIE No. GY-63973-1) will attempt to determine whether ground covers can be used in land-locked and difficult-to-mow areas to eliminate need for mowing and to reduce cost of maintaining problem areas.

The Montana investigation (SIE No. GB-213793-3) is directed, in part, to testing dry-land planting methods such as "tubed plants," condensation traps, interconnected root transplants, broadcast seeding of mixtures, sodding of native rhizomatous grasses, and "sprigging" rhizomatous shrubs.

Worthy of note is the fact that only one of these fifty-four NRP's describing research on highway vegetation management included mention of wildlife values in connection with selection of plant species or with respect to planting and maintenance. An Intermountain Forest Experiment Station (USDA) project (SIE No. GY-23192-6) in which roadside vegetation is but one of many considerations, aims to develop superior shrubs through selection and breeding for wildlife habitat improvement and other purposes; a Nebraska project description (SIE No. 56174-5) does mention wildflowers in connection with plant materials for highway landscaping purposes. Most of the research in this group of projects is being done at universities having considerable competence in fish and wildlife research. It would seem appropriate and desirable to have more communication among the highway engineers, horticulturists and other investigators engaged in environmental types of highway research and the fish and wildlife biologists and ecologists on the same campuses. Some imput from the latter could be made on a consulting basis, at little extra cost to the projects and result in increased value of some of the findings.

Of interest also, is that twenty-seven of the fifty-four research projects in this group of NRP's were being funded in part by the Federal Highway Administration.

Environmental Impacts, Systems Analysis, and Planning Methodology

Of the 28 NRP's included under this category, eight were on studies being supported by the Federal Highway Administration; eight were investigations being supported by other Federal agencies -- four by the U. S. Department of Agriculture, two by the U.S. Department of the Interior, one by the U.S. Environmental Protection Agency, and one by the Tennessee Valley Authority; four by foreign governments; three by State Governments -- Georgia, Oregon and South Carolina; two by private organizations; and three by unidentified sources of support.

All of the Federal Highway Administration-supported studies in this category would appear to deal with environmental systems analysis, evaluation of research needs in such fields as hydrology, and development of strategies and procedures for environmental organization and planning to implement various sections of the 1970 Federal Aid Highway Act concerned with environmental quality. One of these studies by Dr. A. D. Hasler of the University of Wisconsin will attempt to prepare a simplified methodology to describe and assess the primary and secondary impacts of highways and wastewater treatment facilities on other than urban streams, the methodology to be of a type which may be employed by Environmental Impact reviewers and persons charged with preparing EIS's.

Of the USDA-supported studies, one (SIE No. GY-58279-2) deals partially with remote sensing to estimate the amount and form of vegetative cover in the case of roadside revegetative research; and three with environmental effects of logging methods, road construction and other aspects of wood harvesting in relation to erosion, slope stability, interruption of subsurface movement of water, and water quality. A project of the Pacific Northwest Forest Experiment Station (SIE No. GY-4-6) will include studies on salmon streams -- effects of watershed characteristics and forest management practices on stream temperature, stream bottom fauna, and fish populations -- and will attempt to improve conditions in salmon spawning habitat.

Another Forest Service project (SIE No. ZUA-3047-1) of the same nature, by J. S. Rathacher, showed, in earlier phases of the research, that exposure for 24 to 96 hours of young salmon to TCDD (a contaminant of 2,4,5-T) in water at levels greater than 23 ng/g ppm is irreversible and death results in 10 to 80 days. TCDD in food at 2.3 ppm markedly reduced growth and survival of young rainbow trout after four weeks. No effect was observed at 2.3 ppb.

A U.S. Geological Survey study (SIE No. ZUA-3047-1) will determine the effect of off-road vehicle use on the soil, plants and water resources on public lands in California.

Another Interior Department (Office of Water Research and Technology)-sponsored project will deal with influences of subsurface water on the stability of steep forested slopes.

The TVA study (SIE No. ZT-54-13) is concerned with effects of intensive reforestation and simple erosion control measures upon the hydrology of small watersheds with highly erodible soils.

With respect to the state studies in this category, a Georgia project (SIE No. GE-233029) involves developing an environmental impact evaluation system and provides assistance in implementing the system into the State Highway Department's routine operations. An Oregon investigation (SIE No. GY-28798-4) will determine effects of logging and road building on stream temperature and sedimentation, and predict water temperature changes associated with cover type and vegetation density along streams. A South Carolina project (SIE No. GY-7880-5) by L. D. Reamer, under the McIntire Stennis Program, will study costs of construction and maintenance of forest access roads and include observations of wildlife during the winter months, on four miles of roads sown to grass.

The Canadian Government, through the National Research Council of Canada, is sponsoring a study by the University of Saskatchewan to develop terrain evaluation systems for road construction with the objective of minimizing environmental impacts and construction costs.

The Swedish Government has a project (SIE No. GB-601748) to quantify the influence of roads on the environment. Particular emphasis will be on plant and animal life, water, and ground water pollution. A general survey of wildlife will be made during the course of this study by G. Knutsson of the Road Research Division and G. Tyler of Lunds University.

The National Geographic Society is sponsoring a study by Rider College at Trenton, New Jersey (SIE No. AU-407), on the structure and function of a fresh water tidal estuary ecosystem. The study will provide information particularly important for a thorough assessment of the impact of construction of Interstate 295 and New Jersey Route 29 through the marsh as well as information on the effects of diverting effluent from the Hamilton Township Sewage Treatment facility into the Delaware River.

E. K. Sauer of the University of Saskatchewan (no formal support reported) is conducting a study (SIE No. GB-50905) of the effects of road construction on permafrost areas in the Yukon. Techniques will be developed to predict problems and avoid destruction of the habitat.

Another study for which no formal support is indicated, is being conducted by E. W. Houghton, civil engineer, University of Leeds, England. He will investigate the impact on the countryside of recreational motoring and the implications for planning policy. He will attempt to assess "environmental capacity" of rural roads having a recreational function.

Thus, in this group of twenty-nine NRP's, it will be noted that four of them mentioned fish and wildlife specifically, and two referred to problems stemming from outdoor recreation.

Pollutants and Their Effects on Soil, Water and the Biota

Of the twenty-seven NRP's placed under this category, half or more are concerned, at least in part, with air pollution problems caused by highway construction, maintenance and operation. Pollution-oriented projects being funded by the U.S. Department of Transportation totaled eight -- seven by the Federal Highway Administration and one by the Office of the Secretary; the U.S. Environmental Protection Agency, six; the U.S. Department of Agriculture, four; one each by the U.S. Department of the Interior (Geological Survey), U.S. Department of Health, Education and Welfare (National Institutes of Health), and the U.S. National Science Foundation; one each by the State Governments of Maine, Washington, and Wyoming; two projects - for which the funding source is not identified -- one at Pennsylvania State University and one at the University of Tennessee; and a United Kingdom project.

The Federal Highway Administration-funded projects are concerned with management of air quality in and near highway tunnels; air monitoring to determine the impact of highways on ambient air quality and to provide aerometric measurements for comparison to numerical predictive techniques; assessment of current highway pollution levels in relation to current and proposed regulations; prediction of air pollution concentrations from roadways for various road configurations, meteorologic conditions, and highway operations; highway location, design, and operation to reduce photochemical smog formations; effects of deicing salts upon trees, shrubs and soils; and abatement of acid and iron pollution resulting from oxidation of pyrite exposed through highway construction. Thus, the primary emphasis of the Federal Highway Administration in the area of pollution appears to be on air quality at present.

Of the six U.S. Environmental Protection Agency-sponsored projects reported, one (SIE No. AO-21408-1) deals with a field measurement program conducted at a number of highway sites to determine the effects on the transportation and diffusion of highway-emitted pollutants due to: (1) Highway configuration. (2) Wind speed and direction relative to the highway. (3) Highway traffic. (4) Surrounding topography, including buildings.

(5) Atmospheric stability. Data collected will be used to validate the numerous mathematical models designed to simulate the dispersion of pollutants near roadways.

The other five EPA-funded and/or conducted studies relate, at least in part, to pollution effects on laboratory or test animals. These projects (SIE Nos. ZMA-176, AO-17957-2, AO-17956, GMA-1895, and AO-17955) deal primarily with evaluation of the biological, biochemical, behavioral, and physiological effects of pollutants such as trace metals and emissions from various fuel combustion systems using various fuels, fuel additives, and catalytic converters.

As might be expected, the research projects being supported in this category by the U.S. Department of Agriculture deal primarily with the effects of highway generated pollutants on plants and the soil. Thus, studies by the University of Minnesota (SIE No. GY-10804-6) and the University of New Hampshire (SIE No. GY-64108-1) are concerned with the effects of road deicing salts on woody vegetation and on forest soils and vegetation, respectively. In earlier research, the University of Minnesota investigators, E. I. Sucoff and D. W. French, had determined that most highway-associated twig dieback occurs in midwinter in association with increases in the use of NaCl.

A USDA-sponsored study at the University of California, Riverside (SIE No. GY-58990-3) has as its objective the evaluation of heavy metal concentration in soils and vegetation adjacent to highways. The effect of heavy metal contaminants in soil on the growth and chemical composition of vegetation will be determined.

J. R. Gray of New Mexico State University is conducting a USDA-supported study (SIE No. GY-32997-1) on the impacts of nine groups of outdoor recreationists in a forested area and is determining changes in current policies and programs to reduce environmental degradation. In earlier phases of the research, three-quarters of the 860 recreational parties interviewed in the Sandia Mountain area of Central New Mexico were from Albuquerque. A preliminary programming model has been prepared in which 26 kinds of pollutants are identified and associated with 10 kinds of recreational activities. Techniques for including quantitative information on pollution generated by recreationists as well as the economics of minimizing these impacts are being developed for use in preparing environmental impact statements.

A U.S. Geological Survey investigation (SIE No. ZUA-3012-1) is the only study in this group specifically oriented to determining effects of highway construction and related stream channelization on sedimentation and water quality.

A National Institutes of Health/National Institute of Environmental Health Science study (SIE No. IES-973-1) has as its principal objective, the investigation of the effect of lead on photosynthesis. Previous work on lead inhibition on higher plants will be extended to algae.

An interdisciplinary study being conducted at Colorado State University under N.S.F. auspices emphasizes description of the atmospheric component of the environmental flow of lead from automobile exhaust. Atmospheric transport studies will concentrate on short range dispersal of lead from highways, and wind tunnel studies will simulate lead aerosol turbulent and advective transport in city canyons. Techniques of analytical chemistry will be applied to determination of lead in air, soil and biological material at the trace and ultratrace levels.

Two of the State-supported studies (Maine--SIE No. GB-219892-2, and Wyoming--SIE No. GY-57481-4) deal with effects of highway deicing salts on soils and vegetation. The Wyoming study also will investigate heavy metals from vehicle emissions along a recently opened section of Interstate 80 between Laramie and Walcott, where heavy metal and salt concentrations had been collected during 1970 as baseline material for comparison. The Maine study will compare methods of salt application in relation to rapidity of appearance of toxicity symptoms in conifers having different salt tolerances. The amount of salt deposited by spray from auto traffic in soil and in plant tissue at varying distances from newly opened highways will be determined. A Washington study (SIE No. GB-233502) is concerned with a critical review and state-of-the-art of mathematical diffusion modeling techniques for predicting air quality, as related to motor vehicle transporation.

Other studies under this category include a University of Tennessee investigation (SIE No. AS-999) on effects of particulate air pollution on vegetation; a project (SIE No. WZ-2769) by Pennsylvania State University (no formal support reported) on the generation and atmospheric dispersion of dust generated by automotive vehicles traveling on unpaved roads; and a United Kingdom project (SIE No. GB-62828) on methods of measuring diesel exhaust smoke.

Fish and Wildlife and Aquatic Plants

Of the 20 NRP's in this grouping, nine were of projects supported by the U.S. Department of Transportation -- eight by the Federal Highway Administration and one by the Urban Mass Transportation Administration; four by the U.S. Department of the Interior -- three by the Fish and Wildlife Service, Federal Aid Division, and one by the Office of Water Research and Technology; one by the U.S. Department of Agriculture, Forest Service; two by State Governments; one by the U.S. National

Science Foundation; two by the Government of the United Kingdom; and one by a state department of transportation (no formal support reported).

Three of the U.S. Department of Transportation-supported projects are continuations of the significant research being done with the State of Colorado on effects of lighted animated deer crossing signs and highway lighting and on use of deer underpasses to prevent deer-vehicle accidents. Different advisory signs for motorists will be used below the animated deer signs. The rationale for highway and highway right-of-way lighting is that the motorist will be aided in seeing deer and have greater reaction time in preventing the pending accident. The underpass project being supported by the Urban Mass Transportation Administration involves study of the use of a 10 x 20 foot structural plate pipe arch underpass by mule deer. Another Federal Highway Administration-supported study was proposed to be done by the State Department of Highways in Arkansas to determine the effect of an animated sign and high-watt lighting on the number and type of deer-auto accidents.

In California, the Federal Highway Administration is supporting research to determine the influence of erosion sediments and water-borne materials for roadway surfaces on productivity rates of aquatic flora.

One continuing FHWA-supported study is being carried out through the U.S. Department of Agriculture to determine the effects of highway construction and operation on game animal populations, including their movements, numbers, natality and mortality rates, and ability to secure suitable breeding, foraging, or protective habitats. Prediction of the game animal situation after a road has been built will provide assistance in the conception of its design, location, construction and maintenance.

The University of West Virginia, with FHWA support, is studying effects of highways on wildlife populations, particularly with respect to species which are intolerant of human disturbance. And, finally, Tulane University of Louisiana, with FHWA support is investigating the ecological impact of MSMA on areas adjacent to highway-rights-of-way where chemical mowing is practiced. Toxicity to selected aquatic species is being determined and measurements will be made of arsenic levels in soils and grasses and adjacent receiving streams of the study site.

Two of the U.S. Fish and Wildlife-supported projects are concerned with the value of roadside cover for pheasant nesting. An Illinois study (SIE No. GUN-9549-1) will compare the abundance of and pheasant production from nests in roadside cover with nesting in other cover on the Ford County Management Unit. The place of seeded roadsides in total pheasant production on the area will be evaluated also. The other study (SIE No. GUN-11351) being done in Iowa is determining pheasant nesting density and productivity in brome grass cover along interstate rights-of-way.

A third study (SIE No. GUN-8953-2) supported by the Fish and Wildlife Service's Federal Aid Division, in Virginia, is designed to evaluate effects of maintaining old logging roads with a brush hog and sunlighting and seeding and to determine whether or not the ruffed grouse population is increased due to maintaining these roads in various ways.

The Interior Department's Office of Water Research and Technology is supporting a study through the Virginia Commonwealth University (SIE No. GUW-4087) to evaluate the effectiveness of existing methods of erosion and salt control methods as used in highway construction and operation. Effects of silting on the fauna of aquatic ecosystems will be determined using fish and macrobenthos populations as indicators. Diversity and numbers of organisms will be calculated.

West Virginia State College, through NSF support, is conducting an ecological study (SIE No. GSA-30-1) on the wilderness type Cranberry Glades of West Virginia. Possible effects on the hydrology, physical properties and ecological values of the area of clear-cutting, road building and other human activities will be investigated. The Cranberry Glades has unique vegetation and is one of the four black bear breeding areas in the State.

USDA's Pacific Southwest Forest and Range Experiment Station at Berkeley, California, has a project (SIE No. GY-7-6) to develop methods to minimize local floods, erosion, and sedimentation, maintain water quality, improve timing of streamflow, and to predict the effects of forest and land management practices upon sedimentation and streamflow. The principal investigator, R. R. Ziemer, points out that the immediate impact of timber removal for road construction, road building, and bridge construction in an 80-year old second-growth redwood and Douglas fir forest is best reflected in the suspended sediment yield. Effects of logging on streamflow, sedimentation and fish habitat will be continued; soil moisture will be related to logging effects and to moisture storage opportunities for flood abatement. Preliminary studies indicated that road construction did not significantly affect the volume of living space for fish populations, but young-of-the-year-fish populations decreased immediately after road construction.

Iowa State University, through State support, (SIE No. GY-58672-1) has been examining natural vegetation for useful species, compatible with Iowa agriculture, which can be introduced into roadsides and other disturbed areas such as mud flats in flood control reservoirs. Observations will be continued on roadside stabilization using native prairie species. A 16 mm depicting roadside prairie plant research over a five-year period has been completed.

The University of California, at Berkeley, describes an interesting study (SIE No. GB-220115-2) to develop nonchemical means of pest management in the highway landscape. The investigator, D. E. Pinnock, points out that different disease organisms such as Bacillus thuringiensis can be used in place of chemical insecticides to control certain pest insects without harming natural enemies of the pests. Long-flowering plants are being evaluated for landscape planting to provide a nectar supply to increase the longevity of parasitic insects that help control the harmful insects. Benefits include reduced cost of materials and fewer pest control operations due to reduced pest resurgence (because natural enemies of the pests are not harmed); reduced chemical pollution of the environment; reduced exposure of personnel to chemical pesticides; and improved quality of the landscape.

J. M. Way of England, with United Kingdom support, (SIE No. GB-233631 and GB-66926) is comparing effects in plant communities on roadside verges of different chemical spray and mechanical cutting regimes and is studying the general potential of motorway banks for amenity and wildlife conservation in order to evolve management practices acceptable to highway authorities that will also produce viable wildlife habitats.

The State Department of Transportation in Pennsylvania (no formal support reported) is evaluating the ability of nine-foot fence in lieu of higher fence to control movement of deer and reduce traffic accidents.

Comments on Coverage of Recent or Current Research Reported

In summary, 52 (40.3%) of the 129 on-going, or recent, research projects registered with SSIE on the subject, "Effects of Highways and Highway Construction on the Environment, Particularly on Fish and Wildlife," were receiving financial support by the U. S. Department of Transportation. Many of the NRP's on file were for the fiscal year ending June 30, 1974 and some of the research described here may have been completed, but in most cases, not published; other NRP's were for the fiscal year ending June 30, 1975.

Undoubtedly, there are many on-going, related research projects which were not reported to the Smithsonian Scientific Information Exchange, or, if reported, the NRP's were described in such a way that they were not included in the print-outs produced by this search. We found in our literature research that the terms highways, roads, roadsides and rights-of-way are seldom used in scientific journal indices or abstracting journals in the fish and wildlife field, although many individual articles may relate directly or indirectly to highways.

As pointed out in the preceding pages, even when fish and wildlife are interpreted broadly to include insects and aquatic plants, only 20 of the 129 selected NRP's placed major emphasis on highway-wildlife relations; and five more were concerned with fish and wildlife, at least peripherally.

In addition, the Highway Research Information Service of the National Research Council made a file search for the Urban Wildlife Research Center on effects of highway use on wildlife and related environmental matters. Included among the print-outs related to air quality were summaries of dozens of recently published articles and a few descriptions of on-going research in this area. Most of the latter were on file with the Smithsonian Science Information Exchange. A majority of the projects dealt with topics somewhat peripheral to the main thrust of this bibliography and included many articles on exhaust emissions, emission control devices, effects of different fuels, fuel additives, and engines on the exhaust emissions, urban transportation planning and design of transportation systems, carpooling and other methods of reducing traffic volume, pollution measuring techniques, and human health aspects of air pollution.

A HRIS run (computer print-out) on the subject, "Highway and bridge design criteria in relation to wildlife and the environment," produced summaries of recently completed research or descriptions of sixty-three projects. Descriptions of the two on-going studies dealing with fish and wildife were included in the Science Information Exchange material already analyzed and the four fish and wildlife-related research summaries produced by this run are included in our bibliography.

Also, additional to the notices of current research projects provided by the Smithsonian Science Information Exchange, were the following provided by the Highway Research Information Service: five concerned with sewage and garbage disposal and waste disposal criteria for highway rest areas; four dealing with deicing chemicals (no mention was made of effects on fish and wildlife in the project descriptions); three concerned with road oil pollution; two dealing with heavy metals; 12 dealing with highway rights-of-way vegetation control, primarily with herbicides and including one project, HRIS No. 101220, directed towards use of native prairie grasses and other prairie plants as an alternative to broadcast spraying of chemicals in the control of roadside vegetation; and four concerned with environmental impacts, noise pollution, and an environmental simulation model. Under the search headings: environmental effects of runoff, erosion and sedimentation and effects of alteration of drainage patterns on water quality, and fish and wildlife, four current projects were listed dealing with runoff effects, including one dealing with chemical characteristics and toxicity to fish (HRIS No. 100904), two with hydrology, one each with watershed management, culvert design, pollution, eutrophication effects, solid waste disposal, and climatic/hydrology effects, and the following which involved fish and wildlife considerations -- rehabilitation of strip-mined area (HRIS No. 101113), sediment transport in stream channels and its effect on aquatic insects and fish (T. C. Bjornn et al, University of Idaho), with support from the Office of Water Research and Technology, USDI, a study by V. B. Richens to determine numbers and distribution of birds and mammals by habitat and proximity to the construction site of a Maine highway and to evaluate impact of highway on habitat and vertebrates before and after construction (FHWA support -- HRIS No. 08226 and 082230), prediction of water quality change in a stream due to highway construction on the drainage basin (FHWA support), chemical, biological and ecosystem analysis of waters from highway sources for environmental impact analysis (FHWA), a study by Santonas, Rawson and Dayfield, which includes offer of assistance to the West Virginia Department of Highways to protect wildlife values involved in highway construction projects (F.W.S. support, HRIS No. 100761), evaluation of stream improvement structures on Prickly Pear Creek and the East Gallatin River, Montana, with respect to fish production (F.W.S. support, HRIS No. 100898), a study to determine beneficial and detrimental effects and presence of a highway with special emphasis on white-tailed deer (also hunter use of highways) by Ed Michael of West Virginia University (USDA support, HRIS No. 108526), a study by B. Duke and J. Carr of the Arizona Game and Fish Department to determine effects of highway development on fish and wildlife (F.W.S. support, HRIS No. 111339), and research by R. B. Lewis and A. R. Kay of the California Division of Highways regarding designs for anadromous fish through highway drainage structures (FHWA and California Division of Highways support, HRIS No. 204018). Finally, a HRIS computer run on the subject "Extent of human and wildlife deaths and damage during highway-wildlife accidents," produced additional research descriptions as follows: three FHWA-funded projects, two dealing with fences as vehicle-deer collision deterrents (HRIS Nos. 083241 and 106331), and with an evaluation of deer underpasses and overpasses (HRIS No. 100769), a study by the Pennsylvania Department of Transportation concerned with the effectiveness of different heights of fence for deer control (HRIS No. 100792), and two studies by S. Muller funded by the EIDG Department des Innern, Switzerland, one dealing with electric fences for protecting wildlife (HRIS No. 111388) and the other, a broader study (HRIS No. 105852) designed to find criteria for the best and most effective arrangement of fences for roads and motorways to protect wildlife. The author is testing the effectiveness of mirrors and fences and studying the influence of time of day, soil cover, road-cross sections and speeds of vehicles when vehicle-animal accidents occur. Based on reports obtained in the study to date, the proportion of accidents involving animals is estimated at two percent; of accidents involving personal injuries (of passengers), 0.1 percent were connected with animals.

The searches for descriptions of current related research by the Smithsonian Sciences Information Exchange, Inc., and the Highway Research Information Service of the Transportation Research Board, National Research Council were very helpful in determining who is doing what types of highway-wildlife oriented investigations. Although there is considerable duplication of material provided by the two services, there is sufficient difference in the information on file or manner of retrieval at each organization to make it worthwhile for the researcher to avail himself of both services. The computers can print out only the information provided by the investigator in describing the research project, however, and, in many cases, the information provided, was minimal. The funding agencies, by requiring more detail on research objectives, study procedures and results of preliminary research, when appropriate, could considerably enhance the value of the project descriptions and probably reduce unnecessary duplication of research, thus increasing research efficiency.

Two other projects approaching completion at the time of this writing warrant special attention for their relevance to the subject of highway-wildlife relationships.

The American Association of State Highway and Transportation Officials (AASHTO) Task Force for Environmental Design was compiling a wildlife guide to assist transportation planners and designers to give attention to the preservation and perpetuation of wildlife habitats located within or adjacent to transportation rights-of-way. The Maryland State Highway Administration assisted in this project by compiling a selected short list of references having direct relevance to the relationship of transportation facilities to wildlife habitat. Information with respect to the publications recommended by the Maryland State Highway Administration was kindly provided to the Urban Wildlife Research Center for consideration in compiling the present bibliography.

The second project entitled, "Surveillance of the Environmental Effects of Building a New Highway -- a state-of-the-art report," was being conducted by the Ontario Ministry of Transportation and Communications. The abstract of this as yet unpublished report was provided by Mr. B. Sen Mathur, Head, Remote Sensing Section of the Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario. Readers of the present volume, especially those interested in remote sensing, may wish to obtain a copy of this Ontario report when it becomes available.

RESEARCH NEEDS

We have attempted to summarize much of the available literature dealing with highway-wildlife relationships; undoubtedly some important works were missed. We have included in our bibliography and state-of-the-art report literature which, although not dealing directly with highway-wildlife relationships, may have relevance. We have availed ourselves of the services of the Smithsonian Science Information Exchange, and the Highway Research Information Service, Transportation Research Board, National Academy of Sciences, to learn of current or recent relevant research.

In comparing completed research with current research, our analysis would indicate that on-going studies are, generally, "more of the same." There would appear to be more emphasis now on effects of automotive vehicles on air and water quality and, perhaps, on highway planning methodologies and systems analysis with respect to environmental impacts of highway construction and operation. Much of the emphasis remains, however, on how to manage and control highway right-of-way vegetation -- without reference to wildlife -- how to control erosion -- certainly a worthy objective -- and on pollutants stemming from chemical de-icing of highways or from automotive vehicles, again, mostly without reference to wildlife.

With respect to fish and wildlife and highways, much of the rather limited literature deals with observations on wildlife mortality on the highways, or the detrimental effects of highway construction on fish. Some interest has been shown in ways of reducing big game-automotive vehicle accidents, in managing roadside vegetation for certain upland game birds and waterfowl, and in creating impoundments valuable for fish and wildlife and recreation in the process of highway construction; but the emphasis has been on the negative, rather than the positive aspects of fish and wildlife-highway relationships.

Perhaps the greatest research need in this area is that of developing procedures and methodologies for getting highway engineers and planners and people from other disciplines, including wildlife biology and ecology, to work together more effectively. Laws, guidelines, and authorizations for this exist, but implementation leaves much to be desired. Through some means, members of the wildlife management fraternity should be urged to devote more attention to the opportunities which exist for managing wildlife on the millions of acres of highway-rights-of-way. The highway engineers and planners should recognize that, in the planning, routing, and construction of highways, wildlife, esthetic, and recreational values deserve consideration as well as the strictly utilitarian and economic or defense values of highways.

The question of research needs could be treated in many ways, but to be consistent, we shall follow, generally, some of the major subject matter headings used in this report. Some of our suggested research needs will be in the form of questions that should be answered; others will be given in more detail.

EXTENT OF HIGHWAYS AND STREETS

Considering the fact that there are well over 20,000,000 acres of highway-rights-of-way in the United States with some sort of vegetation, why not identify the value of this area for wildlife? What portions of this area contribute to wildlife production and use? What benefits are derived from motorists in seeing wildlife along the rights-of-way? Should highway rights-of way be considered wildlife habitat?

HIGHWAY AND HIGHWAY-RIGHTS-OF-WAY AND THEIR USE BY WILDLIFE

Few studies have been conducted of highway rights-of-way as wildlife habitat per se; their value as such should be determined, not only for pheasants, waterfowl and other game birds, but for songbirds and other forms of wildlife as well. Is the presence of grit along the highways really an asset to certain game birds, or could they get along just as well without it? Does salting of highways attract big game to the highways, and can salt blocks located away from the highways help keep the animals away? Do highways pose any real problems in the genetics and evolution of small mammal populations whose territories may be intersected by broad transportation corridors? Should any consideration be given to bridge and other highway structure designs with respect to wildlife usage, either to encourage or discourage such usage? What are the effects on wildlife of concrete barriers in median strips of divided super highways?

EFFECTS OF HIGHWAYS AND HIGHWAY CONSTRUCTION ON FISH AND WILDLIFE

Some writers have written off, as destroyed for wildlife, the lands taken over by highways. How much of the land within the right-of-way <u>is</u> destroyed by the highway; what is left; and what types of new habitat are created? How important are they?

Of what extent, overall, are the streams valuable for fisheries, which are channelized or otherwise altered by highway construction and what are the consequent sedimentation and pollution effects? Of what magnitude is the problem of culverts and other drainage structures used in conjunction with highway construction which impede fish migration? Are the interstate highways which have been constructed a benefit in providing access to hunting and fishing areas, do they fail in <u>not</u> providing access, or do they lead to over-exploitation of the fish and wildlife and recreation resources? What can be done in the planning stages for new highways to reduce ancillary development effects on fish and wildlife resources? Would comprehensive land use plans be helpful? Zoning? Regulations?

EFFECTS OF HIGHWAY MAINTENANCE AND OPERATION ON THE ENVIRONMENT

Although considerable research has been done on various air and water pollutants contributed by the highway system in addition to silt and other sediments, little has been done to evaluate the effect of such pollutants on fish and wildlife. Much more quantitative and definitive information is needed on the effects on fish and wildlife of de-icing chemicals, insecticides, herbicides, soil sterilants, and other pollutants arising from highway maintenance activities, and of the trace metals, rubber, asbestos, oil and grease, noxious gas emissions, and noise pollution stemming from the operation of automotive vehicles on the highways. Much more information exists as to the amounts of such pollutants produced than on their effects with respect to both plants and animals.

Biologists and ecologists should be able to predict some of these effects on fish and wildlife and plants. Information is needed on the amounts of specific pollutants and combinations of pollutants under various environmental conditions which plants and animals can sustain without damage; and the levels at which damage occurs on both short and long-term bases, and at different stages of the life cycle. This is a big order and will require years of concentrated, well designed research.

Some of the effects are not readily apparent. There is conflicting opinion regarding biomagnifications of trace metals in the food chain. This situation should be clarified. Relatively high levels of heavy metals have been found in earthworms and isopods, for example, but little information is available as to the effects of these contaminated organisms on the birds and mammals which consume them. It is known that chlorinated hydrocarbon pesticides build up in food chain organisms with detriment to consuming animals at the top of the food chain; what about lead and other heavy metals?

With respect to salt - so widely used in highway de-icing - more needs to be known regarding the sodium and calcium ion exchange with mercury or other heavy metals associated with the sediments of receiving water and the generation of cyanide in the presence of sunlight when ferric ferrocyanide and sodium ferrocyanide are used as anticaking additives. More needs to be known, also, about the effects of salt, itself, on freshwater lakes and freshwater organisms. We have seen that the chloride content in some waters receiving runoff from highways, towns and cities have reached as high as 11,000 ppm and that although bluegills may tolerate 10,000 ppm sodium chloride, rainbow trout sustained 20 percent mortality at 12,000 ppm. Much more of this type of information is needed on tolerances of various species and on how the buildup of high density saline water in the lower portion of a receiving lake may interfere with the mixing or turnover of the lake water. Also, more information is needed on the effects of salt on freshwater species of algae, bacteria and invertebrates which serve as food for other aquatic organisms.

Again, with respect to the understanding of air pollution effects on fish and wildlife and vegetation, only a start has been made. A member of the staff of the Smithsonian Institution, Mason Hale, has discussed with me some of the interesting, but unpublished, results of his studies on lichens on Plummers Island in the Potomac River near Washington, D. C. This island is crossed at its northern end by the Washington Beltway (Interstate 495) and, down-wind from the beltway, Hale has found lichens polluted with heavy metals as far as 1000 feet. What are the effects on the slugs, springtails and other organisms which feed on the lichens? The lichens themselves are showing bad effects.

Likewise, we know next to nothing about the effects of highway traffic noise on wildlife. Experimental attempts to use sound as a means of repelling or controlling birds and mammals have been somewhat inconclusive or discouraging. Another employee of the Smithsonian Institution working on Plummers Island, however, speculates that some of the birds there which are dependent upon song as a means of defending their nesting territory may be defeated in this by the noise of the beltway traffic. It is time that we find out about such effects. Ideally we should be able to develop predictive models relative to probable pollution effects of highways which can be used by highway planners and builders in designing and routing new highways.

Mortality of wildlife on the highways and animal-vehicle accidents resulting in human deaths and extensive damage to property remain a serious problem. Not only should better methods be developed to reduce the animal-vehicle accident rates, but more should be learned about the importance of the annual traffic toll on the animal populations involved -- particularly on rare and endangered species through whose habitat highways run or are proposed to be constructed. A means for cataloging, mapping and presenting to highway planners, in a usable form, such information would be helpful. To date, most studies would indicate that highway mortality does not constitute a high percentage of the total annual mortality of game species such as rabbits or deer -- probably from one to ten percent -- but what about endangered species, or situations in which superhighways intersect winter deer yards or migration routes of animals unnecessarily? And, how do highways and the amount and speed of the traffic flow affect animal mortality and behavior? What are the factors, climatic and otherwise, that bring animals to the highways and into contact with the vehicles? What is the significance of highways as barriers to the gene flow in a population of small mammals whose range is intersected by a highway?

The millions of acres encompassed by highway rights-of-way would appear to provide much habitat for wildlife; however, little has been done to document its importance. With the increasing demands placed on our land resources for many purposes, including that of highways themselves, why should not more studies be conducted to determine what highway rights-of-way contribute to wildlife production? What do highways take away from wildlife habitat, and what do they contribute? Some sort of balance sheet or check list and data bank should be developed to ascertain effects to date and to serve as baseline and background information for use in future highway route selection and for highway construction and maintenance operations.

It has been estimated that 25 percent of all herbicides sold in the United States for non-agricultural purposes are used in highway and roadway programs. We were unable to obtain an estimate of the amounts of insecticides and other pesticides used, but the total poundage undoubtedly is large. Some assessment of the effects of these chemicals, both on terrestrial and aquatic forms of wildlife, should be made. Herbicides, often applied as blanket sprays, are used extensively to control woody vegetation in lieu of cutting. What are the relative effects, pro and con, on wildlife? Sometimes growth inhibitors are used on grass and weeds to slow growth and reduce the number of times mowing is needed. Which is better for the birds and small mammals which utilize right-of-way vegetation for nesting cover and food? What are the relative contributions of median strips on divided highways to wildlife, the closely mowed sections next to the highways and the brush and trees that often are found on the slopes and outer limits of the rights-of-way? What use is made by wildlife of snags and dead trees that may be found in such areas? Which species of plants preferred by highway landscape architects for highway plantings contribute the most to wildlife? Can plants be identified which serve for erosion control, esthetics and wildlife? I think so.

EFFECTS OF ANIMALS ON PLANTINGS, VEGETATION MANAGEMENT AND OTHER ASPECTS OF THE HIGHWAY SYSTEM: PROBLEMS OF CONTROL

As indicated previously, insects, plant diseases and various wildlife species can have detrimental effects on highway plantings, maintenance of highway vegetation, highway structures such as bridges, and the highway itself. Development of animal control measures is one of the functions of biological and wildlife research, and animal control is a form of wildlife management. Although considerable animal control research has been done by entomologists and by wildlife research biologists, chemists, and physiologists, not a great deal has been directed towards methods specifically designed to solve highway-animal problems. If these problems were identified and brought to the attention of wildlife biologists, or if wildlife biologists communicated more with highway planners and engineers, they should be able to help solve some of the problems such as starlings roosting under bridges, beavers causing the flooding of roads, or muskrats undermining the road bed. Sometimes the problem might be avoided by selecting another route for the highway; sometimes biological control, as being experimented with in California, may serve as well or better than chemical control of insects and avoid undesirable side effects; and, sometimes, selection of different plant species for roadside plantings may prevent their being damaged by deer or other animals. A survey and assessment of animal damage problems with respect to highways should be helpful in acquainting biologists with the problems, and stimulate needed research.

OPPORTUNITIES FOR ENHANCING FISH AND WILDLIFE AND MITIGATING OR REDUCING DAMAGE TO THE RESOURCE

As a sequel to, or an extension of, the assessment of current use of highway rights-of-way and other highway relations with respect to animal-vehicle accidents and problems posed by animals in the operation and maintenance of highways, a careful evaluation of the role of wildlife management might be warranted. Some people would argue that we would be promoting the welfare of wildlife by keeping the highway right-of-way unattractive to wildlife, thus reducing the incidence of animal-vehicle accidents and other problems posed by wildlife; others would argue that highway rights-of-way should be made attractive to wildlife and that every consideration possible should be given to increased production and use of the highway system by wildlife.

Our suggested evaluation, hopefully, would result in recommendations useful to highway administrators, engineers and planners in maintaining current roads and in constructing new ones. It would answer questions as to whether highway rights-of-way ought to be managed in such a way as to encourage use only by birds and the smaller mammals or by all wildlife; whether to discourage as much as possible the use of rights-of-way and highway structures by all wildlife; or whether to encourage use by all wildlife except big game animals which may cause accidents resulting in loss of human life and damage to property. Such an evaluation, it would seem, should consider the esthetic and erosion control value of plants as well as their use by wildlife and the value to motorists of seeing wildlife while driving through the country-side, or even while driving through suburban and urban areas. It should identify the aspects of wildlife management which should receive the most attention.

We know, however, that the problem of how to reduce animal-vehicle accidents and highway mortality of wildlife, especially big game, remains as highly important. Fencing, particularly with one way exits from the highway, has met with some success in reducing the accident rate and research has shown some of the factors conducive to big-game-vehicle accidents. Other measures attempted, such as highway underpasses, traffic warning signs, highway lighting, and roadside mirrors, have had limited success. According to a July 14, 1975 letter from Frank Haberland, Supervisor of Big Game Management for the Wisconsin Department of Natural Resources to my associate, Thomas M. Franklin of the Urban Wildlife Research Center, Wisconsin has experimented, also, with deer repellents applied to roadside vegetation and with special non-palatable roadside seeding mixtures for new highway construction or renovation. According to Mr. Haberland, the repellents were too expensive and required too frequent application to be practical in the Wisconsin climate; and the seeding mixtures were rapidly replaced by more palatable native vegetation. Likewise, not included in our literature summaries, a July 25, 1975 letter from Robert C. Lund, Senior Wildlife Biologist of the New Jersey Department of Environmental Protection, indicated that in the case of one deer underpass under observation in that State, deer activity had been observed at both ends of the tunnel on a part-time basis for eighteen months, but no passage of deer through the tunnel had been noted.

Continued research on how to reduce deer and other big game-vehicle accidents appears to be warranted. At the same time, state game biologists should inform highway officials of areas where construction of new highways would likely result in high mortality rates, such as through deer wintering areas or across migration routes. Attention should be given, also, to ways of reducing highway mortality of other wildlife.

Over thirty-five years ago, Dickerson (1939 - 249) suggested that wildlife managers, landscape engineers, horticulturists and highway engineers pool their knowledge in an attempt to design highways so there would be minimal highway mortality of wildlife. He asked: "In roadside plantings, why not let the escape ability and natural inclination of the native wildlife of the vicinity rather than the width, curvature, and length of tangents of the highway govern the distances between clumps of shrubbery? Why should not the food and cover requirements of wildlife receive consideration in the selection of plant species? Both landscape and wildlife objectives can be achieved with due regard to the safety of the public. May we not soon have a definite program of experimental study undertaken and adequately supported by some progressive highway department that will provide the needed facts on which to base an intelligent effort to make our highways less destructive of both wildlife and humans?" Thus far, except for only partially successful attempts in reducing big-game-vehicle accidents, this has not been accomplished, and even in the exception noted, the horticulturist and landscape architect apparently have not been members of the research team.

More should be learned about the effects on mortality rates of different kinds of wildlife of the type and arrangement of roadside cover and its distance from the pavement. It is generally believed that the closer the cover is to the road surface, the greater the hazard to wildlife. Dambach (1951 - 20) believed if woody plants are used for highway plantings, clumps of them should not be planted opposite each other on both sides of the road, for such an arrangement increases the tendency of animals to cross the road. On the other hand, Hodson (1962 - 259) observed in England that there were much higher numbers of dead animals found opposite gaps and openings in the highway right-of-way vegetation than along stretches of roadway with a uniform border.

Similarly, Dambach (1951 - 20), who, as we have seen, considered roadside vegetation, next to fencerows, to be Ohio's most productive wildlife land, recommended late mowing of roadside cover, not only so first litters and broods of wildlife could be brought off safely, but, presumably, with highway mortality in mind, also "...to reduce the amount of nesting cover next spring." The amount of residual cover found along roadsides has been suggested by several authors as one of the reasons right-of-way vegetation is a favored nesting site for game birds, especially in agricultural areas where cover is often particularly scarce in the early spring. Hence, again, we see that there is a conflict in where to place the emphasis in wildlife management as related to highways. The whole question of wildlife production and highway wildlife mortality in relation to right-of-way vegetation management needs to be thoroughly studied and analyzed so that highway departments can be advised on what is best for wildlife. A study soon to be conducted by the U.S. Fish and Wildlife Service with support from the Federal Highway Administration, may provide some of the needed answers, but there are opportunities for many agencies and individuals to make meaningful contributions in this area.

If it is decided that birds and other smaller forms of wildlife should be encouraged to use highway rights-of-way and deer or other big game should be discouraged from grazing or browsing close to the highway -- and I suspect this will be the case -- wildlife researchers have an almost untouched field to explore. They will have unlimited opportunities -- except, perhaps for financing -- whichever of the alternatives is identified as where to place the research emphasis. Certainly, with their knowledge of the food and cover requirements of wildlife species and of the behavioral characteristics of the different species, they can provide invaluable assistance to highway departments. Carefully designed investigations should be made of existing highway right-of-way situations productive of wildlife to determine why they are productive. Also, experiments in manipulating vegetation for wildlife enhancement, such as have been carried out to a limited extent in some mid-western states in cooperation with highway departments, should be increased in number and tried in other areas.

The advice of wildlife biologists concerning the value of native plant species for wildlife should be helpful, as should their recommendations concerning exotic species which might diversify the cover.

There are opportunities, also, for developing methods for enhancing wildlife in roadside parks where the wildlife can be enjoyed by many people. Median strips, interchange islands, roadside cliffs caused by highway cuts, and odd tracts of land acquired by the highway merit attention. Such tracts should be inventoried, mapped, and evaluated as to their potential for wildlife and recreation. The possible use for hunting in some of the tracts of land acquired at some distance from the highway might merit exploration. The value of artificial structures such as nesting boxes and perches might be assessed. The list of possible research projects in this area could be expanded greatly.

Fishery research biologists working with engineers could develop highly valuable information and methodologies, also, concerning channelized or otherwise altered streams or new streams developed as a result of highway construction. Researchers seem generally agreed that streams should be channelized as a last resort because of detrimental effects on fish spawning beds and on the fish themselves. Although some good research has been done on detrimental effects of sedimentation, stream straightening and shortening, vegetation clearance from stream banks, logging debris, effects of bulldozers in the stream bed, removal of gravel, and other activities, there is still much to be learned. We should be able to convey to road builders information on how better to minimize the detrimental effects, in the first place, and how much siltation and stream alteration there can be without harm to fish and other aquatic organisms, i.e., what are their tolerances? At what stage is the damage irreparable? How soon will a channelized stream, if not maintained, revert back to somewhere near the original condition?

Once a stream is damaged, the researcher needs to work with the engineer on how it can be rehabilitated. Some of the rehabilitation measures that could be developed, hopefully, could be used to improve "undisturbed" streams which are not as productive as they might be. In other words, I think we should emphasize the positive, where possible, and enable the engineers, through use of sound biological and ecological knowledge, to do a better job with the engineering feats they are able to accomplish. Information of this kind is needed in situations where mitigation is attempted in the course of a construction project. Often we do not know enough to assess the trade-offs involved.

There is need also to inspect stream rehabilitation structures such as deflectors, check dams and rip-rap several years after their installation, to determine how durable they are and to suggest ways in which they may be improved.

A review of other sections of this report dealing with soil erosion, sediment, and pollution control will suggest many additional worthy research projects. The primary objective in rehabilitating a once productive stream is to get it back as much as possible into its original state.

Highway structures, such as culverts, may impede the passage of anadromous fish to their spawning areas and thus have a serious effect on the fishery resource. Again, fishery biologists have an opportunity to work with engineers in helping design structures through which the fish can swim on their biological schedule. Research is needed to provide information on the species affected, their swimming ability, timing of the spawning run, what effects a delay in getting through a culvert might have, and identification of the streams and the locations where trouble may be encountered.

Another area much in need of research is the drainage of wetlands, the acceleration of which may be caused by highway drainage ditches, i.e., new highways, particularly township and country roads, constructed through wet areas can place the drainage outlets within reach of adjoining landowners who can then drain their fields with consequent loss of wetlands of much value to waterfowl and other wildlife. The extent of such practices and their impact on wildlife should be further documented and means sought, perhaps through research on institutional arrangements among Federal, State and local organizations, or on ways of implementing environmental safeguards, to remedy the situation.

Again, on the positive side, there are many opportunities to develop methods and guides for rendering impoundments created by highway fills or the digging of borrow pits more productive of fish and wildlife. The decision needs to be made early as to the purposes to be served by these impoundments, and information conveyed to the highway builders in useful forms so the impoundment designs can be made accordingly. Research on costs and benefits, means of financing any extra costs involved, and on how to get local support for these projects might materially enhance their value.

Finally, and perhaps as important as anything mentioned previously, fish and wildlife biologists, botanists, and ecologists have an opportunity to develop better means of assessing the environmental impacts of proposed new highways. To do this effectively will require thorough analysis of existing information and results from the types of studies we have indicated are needed. A better job needs to be done in preparing environmental impact statements, but the problem, in many cases, is simply that the needed information is lacking, including information for better predictive models and more complete ecosystem analyses. Until such information is developed through research, every effort should be made to work with highway planners, landscape architects, engineers and others in the early planning stages of new highways. Such information should include data on rare and endangered species -- both plant and animal -- which might be further endangered by constructing a highway through a particular area. Although some guides are already available, preparation of additional guides or handbooks focused on environmental values of particular, or local, areas might constitute a valuable project.

Certainly any research which would show how to take steps to ensure better communication among agencies at all levels from the planning stages of a new highway through its construction, operation and maintenance; how to pool and make use of information that can be provided only by specialists in various engineering and scientific disciplines; and how to implement, or, if needed, develop new, environmental safeguards, would be worth doing. A project recently completed by the Conservation Foundation and reported on under the titles "Rookery Bay Land Use Studies--Environmental Strategies for the Development of a Mangrove Shoreline", and "Rookery Bay: Ecological Constraints on Coastal Development", was as successful in this regard as any I know. Copies of the reports are available from the Publications Department, the Conservation Foundation, 1717 Massachusetts Avenue, N. W., Washington, D. C., 20036.

PART V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY AND CONCLUSIONS

General Observations

The mileage of rural roads, probably not including many back-country roads and navigable trails, was estimated to be nearly 3.2 million and municipal mileage was reported to be more than .6 million at the end of 1973. Most of the 20 million or more acres encompassed in highway rights-of-way has some form of vegetation on it that produces, or is used by, wildlife. Usually, this large area is not thought of as wildlife habitat; rather, many wildlife resource administrators think of the land occupied by the highway system as wildlife habitat that has been lost. They view, with considerable concern, the development of new highways, not only because of habitat displacement, but because of the many detrimental impacts which highway construction, operation and maintenance can have on fish and wildlife and the environment.

Some limited effort has been made to manage highway right-of-way vegetation for wildlife; some attention has been given to wildlife mortality on the highways and to means of reducing animal-vehicle accidents; and some fish and game administrators have availed themselves of the opportunities to create impoundments through highway construction activities. Otherwise, except for some attempts to rehabilitate streams despoiled by channelization or other activities connected with construction of highways and logging roads, little attention has been given to the highway system with the objective of improved management for fish and wildlife enhancement.

The accent has been on the negative rather than the positive and perhaps, understandably so. Most wildlife research is funded through hunting and fishing license fees or from excise taxes on hunting and fishing equipment. Most of the research is directed to game species that can be harvested by hunters or fishermen. Also, fish and game or conservation agencies and the highway agencies at the local, state and Federal levels have been living and working in separate worlds, in a manner of speaking, and communication among them has been difficult and ineffective.

With the national awakening to the degradation of environmental quality and the need to do something about it, the situation is changing. The National Environmental Policy Act of 1969, and many other environmental laws passed before and after that time -- both at the Federal and state levels -- have paved the way for much closer cooperation and for coordination of effort on highway construction and operation in relation to fish and wildlife and other environmental values. Guidelines, administrative directives, policy statements, and memoranda of understanding among agencies have been formulated to help in carrying out the environmental laws. Even so, there is indication that coordination is not fully effective, particularly at local levels. Many of the Environmental Impact Statements (EIS) required by NEPA are not too helpful or informative, probably because the needed information is not available. It won't be until more well-designed research directed at problems relevant to environmental impacts of highway construction, operation and maintenance is conducted.

Relevant Literature

In connection with our literature search, we found that in most biological, ecological, and fish and wildlife journals, the words, "highway", "roads", "roadsides" and "highway right-of-way" rarely appeared in the indexes of scientific journals or in the various abstracting journals. Computer searches made by several scientific information services for abstracts of relevant literature, although very helpful, did not, we feel certain, uncover some reports that would have been valuable because these terms were not used as key words. Possibly, however, the articles were not there to uncover. Not only did this necessitate going through the journals, article by article, to find relevant material, but it is an indication that highways have been the direct focus or site of very little biological work -- especially fish and wildlife research.

The exception is the extensive research that has been done on vegetation, its establishment and management for soil erosion control and, to a somewhat lesser extent, for its esthetic and landscape values. A high percentage of the articles dealt with use of herbicides for vegetation control, but very few made any reference to wildlife, either in connection with plantings, maintenance or control.

Obviously, there have been many research projects, also, dealing with other methods of erosion control and with air and water pollution stemming from highways and their operation; but, again, few have dealt with effects on fish and wildlife.

With respect to fish and wildlife articles which dealt directly with highways, many consisted of observations on highway wildlife mortality, use of highways by various kinds of wildlife and in various ways, descriptions of attempts to reduce animal-vehicle accidents, and with detrimental effects of highway construction on streams and fish. Some of the relatively numerous articles available in the literature which provide information on plant-wildlife relationships, animal control, wildlife food and cover planting, wildlife food habits, and vegetation management for wildlife were included in the bibliography for their possible relevance and value to highway planners, engineers and landscape architects. Included, also, were selected articles, excerpts from laws and court cases, environmental impact statements and other material related to environmental considerations in highway planning and construction.

Highway-Related Research: Findings and Needs

Rather than summarizing separately some of the research findings, current research, and needed research, we shall treat these together in dealing with selected problem areas involved in highway planning, construction, maintenance and operation, giving special attention to research relevant to fish and wildlife.

Environmental Considerations

With respect to research on planning methodologies that would be helpful to highway planners, engineers and landscape architects in safeguarding fish and wildlife and environmental values, only a beginning has been made in the development of models to predict environmental impacts. Sufficient details and quantitative data are not generally available to do much with ecosystems analysis. Much more attention to these aspects is warranted. Research on methods of collecting, packaging and presenting ecological information in a form in which it can be incorporated with data from economists, lawyers, sociologists, engineers and others in selecting routes and carrying on construction and other highway activities with due consideration to the environment is needed.

Soil Erosion and Control

Research has shown that road construction is a major source of erosion and sedimentation. It is particularly serious when roads are built near streams with no buffer zones of timber or other vegetation. Control efforts have been more successful in connection with Interstate and State highway construction than with county and township road construction. Research has documented serious detrimental effects of road construction activities on fish and other aquatic organisms. Some progress has been made in developing measures to rehabilitate channelized and otherwise altered streams. However, more research is needed to determine overall effects on streams of alterations caused by road construction, and on how to develop more effective rehabilitation and mitigation measures.

Other Pollution Problems

A great deal more is known about the pollutants caused by road construction, maintenance and operation than is known about their effects on fish and wildlife, whether the pollutants are in air or water or whether they are in the form of noxious gases or trace metals, herbicides or insecticides, de-icing chemicals, or noise, Few, if any, researchers are willing to state they they know all that needs to be known on a subject; and despite all the research in the vegetation management area, with new herbicides and insecticides being developed along with growth inhibitors and other materials and application devices, continued research is needed in this area.

Biologists have learned much with respect to effects of chlorinated hydrocarbon pesticides on fish and wildlife, but they have a lot of catching-up to do on effects on animals of trace metals and some of the other materials. Only a beginning has been made with respect to noise pollution effects on wildlife.

Current research efforts in the field of air pollution are of considerable magnitude but, again, research specifically directed to effects on wildlife is limited. Somewhat more is being done on water pollution effects on fish and aquatic organisms, but more details on tolerance levels of different organisms to different toxicants and combinations of toxicants under different conditions would be most helpful in establishing water quality criteria and in developing pollution control programs and guides for highway construction.

Highway Wildlife Mortality and Control

Numerous reports on highway mortality and animal-vehicle accidents have been published, but relatively few of the reports have been based on carefully designed studies to evaluate quantitatively and qualitatively the various factors involved, such as volume and speed of traffic, type of road, type and arrangement of vegetation -- including plantings -- weather conditions, age and sex of the animal victims, breeding and hibernation season effects, and effects of crop harvesting and other activities of man, on the mortality rates.

Although the evidence of highway wildlife mortality in the form of crushed and mangled carcasses looks impressive and is esthetically repulsive, what evidence we have is that the annual toll on most wildlife populations is not critical and does not endanger the populations. In the case of certain already rare and endangered species, the highway mortality, together with destruction of habitat involved in road construction, might be a different story.

Attempts have been made to develop methods for reducing animal-vehicle accidents, particularly deer-vehicle accidents which result in loss of human life and extensive property loss in addition to the deer. Except for some success with fencing, including one-way exits for big game that become trapped between the fence and the highway, these attempts have been relatively unsuccessful, Research on this problem is continuing and is warranted, Some of the problems could be avoided. perhaps, if more attention were given to the routing of highways to avoid, insofar as possible, construction of highways through big game wintering areas and across migration routes. Additional consideration should be given, also, to available food and cover for the animals on and outside the right-of-way, i.e., more research is needed on the requisites of the animals and their behavioral responses to the highway. The Federal Highway Administration and states such as Pennsylvania, Michigan and Colorado have been contributing good information on these matters.

Highway Vegetation Management

As indicated previously, most of the research in this area has been done with minimal attention to possible wildlife benefits. Research has shown that pheasants, certain waterfowl species, and some song birds utilize vegetation for nesting cover. Limited research has been done on manipulating roadside vegetation to improve nesting cover. Much more could be done along this line, not only for game birds, but for song birds, raptors, small mammals and other species. In this respect, some of the methods tested and reported on by Egler (1952 - 569 and 1957 - 518) Niering and Goodwin (1974 - 534), Bramble, et. al., (1958 - 512) and others involving a combination of selective cutting, basal spraying with herbicides, and other methods, warrant further testing on highway rights-of-way over a several-year period.

One of the major questions to be answered is whether it is desirable to manage highway right-of-way vegetation for wildlife generally, including big game, or to manage it for birds and small mammals and other species not likely to cause animal-vehicle accidents of serious consequence to occupants of vehicles or damage to the vehicles. Some attempts in using deer repellents or plants nonpalatable to deer on the roadsides have proven unsuccessful but this approach would appear to warrant further investigation, as would more research on larger underpasses.

Animal Damage and Control Problems

In addition to the problem of animal-vehicle accidents, animals can create other highway-related problems such as interfering with right-of-way reseeding efforts, damaging highway plantings of shrubs and trees or newly laid turf, fouling of bridge structures and interfering with painting operations, flooding of highways (beaver dams), and undermining of roadbeds. Insects and plant diseases can damage roadside vegetation and plantings, also, and efforts to control them with insecticides can have injurious side effects on valuable fish and wildlife.

The U. S. Department of Agriculture has done much research on development of insect control methods and the U. S. Department of the Interior has given much attention to bird and mammal control methods. An assessment of the animal damage problems related to highways and rights-of-way might be helpful in getting some of this continuing research effort focused more specifically on highway animal damage problems. It is encouraging to note that California has been experimenting with biological control of insect pest problems on their highway rights-of-way, an approach that has several benefits with respect to fish and wildlife.

Other Opportunities for Enhancing Fish and Wildlife

Some impoundments valuable for fish and wildlife have been developed in the course of highway construction through fills and the creation of borrow pits by extraction of gravel or other materials needed for the highway. Apparently little bonifide research in the interest of fish and wildlife has been done in connection with these developments. Without such research, and without guides or plans to follow in making the fills or excavations, the impoundments which are created, may not be as productive as they could otherwise be. A lake is not a lake in terms of fish and wildlife; but located in the right place and with the right depth, the right slope of banks, etc., could be created to fill certain fish and/or wildlife needs. Research in this area should be encouraged as it is a means of offsetting some of the detrimental effects of highway construction.

Wetland Drainage

Wetlands are often very productive, biologically, and are valuable for wildlife. Natural wetlands are being reduced in extent every year and highway drainage ditches are, in part, responsible in that they serve as outlets for the drainage of adjoining land. Research on this problem, particularly where the problem is most serious -- in connection with county and township road construction -- should be encouraged. Waterfowl production on some of the area being affected in western Minnesota and in the Dakotas is well documented by research. More research is needed, however, on the role of highway drainage ditches in the drainage of these wetlands and on the institutional, legal or other measures needed to solve the problem.

RECOMMENDATIONS

1. The U.S. Department of Transportation, already funding some of the most relevant highway-wildlife oriented research, especially on ways of reducing animal-vehicle accidents and in increasing our knowledge of highway effects on big game animal

behavior, should continue this type of support. Experimentation with larger highway underpasses for big game in various problem areas of the United States is recommended.

2. The Department should consider the feasibility of developing, in conjunction with the International Association of Game, Fish and Conservation Commissioners, the U.S. Fish and Wildlife Service, the State Departments of Transportation, and other public and private resource and conservation organizations, a policy statement on the management of fish and wildlife as related to highways and highway rights-of-way. This should clarify the role of rights-of-way as wildlife habitat and identify management objectives for fish and wildlife. It should also identify and describe opportunities for improved coordination among concerned agencies in the planning and construction of new highways.

3. Consideration should be given to a survey of State Departments of Highways to determine the extent, types and distribution of problems caused by wild animals with respect to highway vegetation plantings and management, highway structures and to the highway itself through flooding or undermining.

4. Results of this survey and other highway-fish and wildlife related research needs that may be identified should be brought to the attention of wildlife biologists and others who may be able to focus research specifically on these problems. At the same time it would be desirable to provide information on funding possibilities and guides for the submission of research proposals, reporting requirements and the like. Many wildlife biologists are not aware that the Department is funding any wildlife-oriented research.

5. More consideration should be given to the degree to which established environmental safeguards, guidelines and policies are adhered to in local highway construction projects, whether or not they receive Federal funding. Extensive erosion and sedimentation problems exist in some township and county highway construction programs and, in some areas, these projects are accelerating the drainage of wetlands valuable for fish and wildlife. Research, whether of a biological, engineering, or legal-institutional nature, which would help ensure protection of the wetlands and their fish and wildlife resources, is highly desirable.

6. As in the case of "natural" wetlands which are decreasing at an alarming rate, special consideration should be given in highway construction projects to rare and endangered species of both plants and animals. Research into the best means of coordination and information exchange to assure that highway planners and developers know of the location of such rare and endangered species prior to selecting a route through what may be a very restricted habitat, should have high priority.

7. Often, in construction projects sponsored by the Federal Government, an attempt is made to offset environmental damage that may occur in carrying out the project in a certain way because of economic or engineering feasibility, by acquisition or management of another area in such a way as to mitigate the losses. And often, the problem is that insufficient knowledge or inadequate management techniques are available to know whether the "mitigation" measures suggested will be effective i.e., whether the trade will be advantageous or detrimental to fish and wildlife. This situation often occurs in the case of channelization of streams or other alterations of streams as a result of highway construction; or it could happen in the case of bogs or desert areas which constitute special habitats for different species of turtles or tortoises. It is recommended that the Department encourage and support research which will ensure an "even trade" on matters of mitigation and that sufficient research be done to enable those responsible for preparing EIS to have the necessary information to present the facts and alternatives with respect to highway projects.

8. Because management of highway right-of-way vegetation is such an important part of highway maintenance activities, and because right-of-way vegetation management has a direct bearing on wildlife production and use, we recommend that the Department give more attention to wildlife values in such management. In this connection, tests and concurrent research should be conducted on a combination of cutting and selected herbicide treatments that have been found effective in maintaining tree invasion-resistant clones of shrubs over long periods of time in the Northeast. Highway rights-of-way and holdings of excess or odd tracts of land in conjunction therewith should be inventoried and evaluated as to their potential for enhancement and multipurpose management. This approach might help in meeting agency objectives in the areas of wildlife, forestry, recreation, and soil and water management. Consideration should be given to possibilities for integrating the optimum use of highway rights-of-way with railroad and utility rights-of-way, all of which tend to create "edges" in the environment.

9. The U.S. Department of Transportation, in providing funds for research at Universities on highway right-of-way vegetation management and other environmental matters, is urged to encourage the principal investigators of research projects to seek assistance from the wildlife biologists, ecologists, botanists, and other competent investigators present on the same campus. It is felt that this type of interdisciplinary approach will lead to improved research, and generally more useful results.

10. It is recommended that the present report, if approved by the Department, be sent to fish and wildlife agencies at the state and Federal levels; to biological, wildlife and ecological scientific societies; and to universities as a means

of bringing to their attention some of the problems and gaps in knowledge with respect to highway-fish and wildlife relationships. The report describes research needs additional to those listed here.

11. It is suggested that if the Department and other Federal agencies funding research would tighten-up on requirements for research descriptions in Notices of Research Proposals (NRP's) submitted to the Smithsonian Institution's Science Information Exchange and to other information centers, a much better analysis could be made of current research efforts and the national research effort would be made more effective. Likewise, abstracts of research articles often consist largely of project objectives rather than research results. Finally, anything that can be done to encourage the use of the terms "highway", "roadside", "road", and "highway right-of-way" in scientific biological journals and in abstracting journals in the fish and wildlife area would facilitate bibliographic searches and research in the fish and wildlife-highway problem area.

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