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ABSTRACT: The development of exclusion fencing has been extensive in Australia in attempts to reduce losses of crops and livestock to rabbits (Oryctolagus cuniculus), dingos (Canis familiaris Var. dingo) and other species. Restrictions on other damage control methods have led to increased efforts in the United States to utilize such fences for protection of crops and livestock from dogs (Canis familiaris), coyotes (Canis latrans) and other species. Electric fences have occasionally been used to protect apiaries from black bears (Ursus americanus) and to protect some wildlife species from carnivores.

Varied fence types include conventional netwire or combinations of net and barbed wire, high-voltage electric wires and conventional fences modified by addition of electric wires. Fences appear to be most useful and cost-effective on small open pastures with intensive production and appear to be least successful on large pastures with low production and high vegetative cover, which restricts removal of predators. Fences may be helpful in directing predator travel to areas where other control methods can be applied.

Limitations on the use of exclusion fences include construction costs and the inability to exclude some predators or to remove them from fenced areas. Regulations related to protection of wild species such as pronghorn antelope (Antilocapra americana) may prohibit construction of effective exclusion fences, particularly on public lands. Difficulties and costs of fence maintenance are related to terrain, soil types, dense vegetation, fence damage by livestock and other animals, heavy snows, flood-waters and other causes.

Predators gain access through damaged fences, malfunctioning electric fences, or by jumping over or digging under. Data indicate that where predators tend to be contained within such enclosures, fences may serve to increase losses to predation rather than to reduce them.

INTRODUCTION

The use of barrier fences to protect humans, domestic animals and some wildlife species from depredation began long before written history, perhaps with primitive man blocking the entrances of his caves for security from large carnivores. In various forms, barrier fences were developed and persist worldwide.

Barriers developed for protection from human predators include, among others, The Great Wall of China, moats surrounding medieval European castles, and the stockades which surrounded early forts in North America. Current examples are the barbed concertina and other fences routinely used by modern armies to repel invaders.

Fitzwater (1972) reviewed the use of barrier fencing for more prosaic purposes in protection of livestock and crops and described numerous types, from earthen barriers to modern electric fences. Barriers of thorny shrubs, although ancient, are still commonly used for this purpose in many countries.

Perhaps the most extensive efforts at fencing to protect crops and livestock have been carried out in Australia in attempts to exclude European rabbits, dingos and some marsupials. McKnight (1969) reported that more than 5600 miles of dingo fencing existed in Australia by 1908 and Ritchie (undated, ca. 1980) stated that "The most striking example is the dog-proof fence which stretches through South Australia, New South Wales and Queensland for approximately 5000 kilometers." Recent experimental trials of electric fencing to exclude dingos were also reviewed by Ritchie.

In general, these and other authors indicate that attempts to exclude rabbits through fencing were of limited value, and that, although dingo fencing could be useful, sound construction and maintenance were critical to its effective use (McKnight 1969, Whitehouse 1979, Ritchie, undated, CD. Gooding, personal communication, March 17, 1980). Experimental trials of electric fences in Australia to protect lambs from predation by feral pigs produced similar findings (Mitchell et al. 1977, Plant 1980).

While Australia may be unique in its extensive efforts to utilize exclusion fencing, the concept itself is common. McKee (1913) cited the use of fencing in South Africa to protect cattle and ostriches from carnivores and urged the use of jackal-proof netwire fences and kraals to protect sheep and goats. Spencer (1928) pointed out similar advantages to the use of netwire fences and corrals for protection of sheep in Canada. Young (1944) stated that "What seems to be the first recorded...proposal of a wolf-proof fence in the colonies was in the year 1717, in the Cape Cod region of Massachusetts." Young commented that "In later times exclusion of wolves by fencing was tried by stockmen and finally by the Federal Government; however, none of the plans proved practicable."

EARLY U.S. FENCES

Young (1951) stated that "In the authors opinion, prevention of coyote depredations by the construction of a coyote-proof fence involving large acreages is not economical or practical. Where smaller enclosures are required, it can be made fairly effective in small pastures... " Young described a fence built to enclose a 5000-acre sheep ranch near Petaluma, California "in the early 1890's" which was constructed of split redwood pickets five feet long woven into strands of wire, with a barb wire stretched 8 inches above the top of the pickets "to make it dog proof." However, some dogs and coyotes were not excluded by the fence since "the catch on this farm during 1891 was eighteen dogs, and ten coyotes..."

Lantz (1905) reported on a series of 14 fence designs which he had tested with coyotes in 1904 and concluded that additional testing was necessary. He speculated that "a fence … of woven wire with a triangular mesh not over 6 inches across, and of a height of 28 to 42 inches, supplemented by two or three tightly stretched barbed wires, would prove to be coyote-proof." Jardine (1908, 1909, 1910) tested fence configurations to protect sheep and indicated that fences 59 inches high were generally sufficient to exclude coyotes. The U.S. Department of Agriculture (1909) reported that experimental use of coyote-proof fencing on 2560 acres in Northeastern Oregon was highly successful in protecting ewes and lambs from coyote predation during the summer of 1908. No losses to predators, increased lamb weights, more efficient use of range and increased carrying capacity of the range were cited as advantages in the use of such fences.

Shaw (1914) recommended net and barbed-wire pasture fences five feet in height and the use of corrals to protect sheep, but without specifications on corral construction. McWhorter(1915) cited USDA Forest Service recommendations for "coyote proof" fences in suggesting that "they would be even better suited for turning dogs….for dogs, as well as coyotes, are very shy of barbed wire." Dixon (1920) cited relatively successful use of two fence types over a ten-year period on a 5600-acre sheep ranch in Mendocino County, California. One fence found to be effective consisted of 6-foot redwood stakes driven 12 inches into the soil, spaced three inches apart and lashed near the top to a heavy wire, with two barbed wires above for a total height of 66 inches. The second utilized a heavy barbed wire three inches underground, 52-inch triangular netwire from the ground level upward, and two barbed wires 3 inches and 9 inches above the netwire for a total height of 61 inches. Dixon stated, however, that coyotes did gain access through these fences at times, that fires were a hazard to the stake fence, and that "Fencing against coyotes is impracticable on the open sheep range in most parts on California...."

EARLY U.S. FOREST SERVICE RECOMMENDATIONS FOR FENCES

Simmons (1935) suggested use of USDA Forest Service recommendations for dog and wolf-proof fence construction. These included one barbed wire stretched flat on the ground, 32-inch netwire above, four barbed wires above the netwire, and one barbed wire held on "offsets" extending 5 inches to the outside from the top of the fence. Total height of the fence was 60 inches. Simmons suggested using 56 to 58-inch woven wire with one barbed wire offset at the top as an alternate fence for protection from dogs and wolves (Canis spp.). In both cases, the offset barbed wire was intended to prevent coyotes, dogs and wolves from climbing over fences.

EARLY "WOLF-PROOF" FENCES IN TEXAS

Jones (1938) stated that "It may be conservatively estimated that 95 percent of the 8,920,000 sheep and 3,040,000 Angora goats are grazed 'loose' within wolf-proof pastures in the great permanent ranching area in southwestern Texas." He commented that the most common type of "wolf-proof" fence in this area was constructed of mesh wire approximately 51 inches high with stays six to nine inches apart and mesh openings from one inch at the bottom to four inches at the top. The bottom of the mesh wire was stapled to wood posts at ground level and one or two barbed wires at three or four-inch intervals were stretched above the mesh. Jones also indicated that a common practice was to stretch one barbed wire at ground level on the opposite side of the posts from the mesh wire to prevent wild animals from digging under and those rocks were often tamped into the soil at the fence to further reduce this possibility. Jones described some of the difficulties in fence maintenance due to floods and the need to use "water gaps" (independent sections of fence) to span "draws and dips". Jones commented that:

> "The construction of wolf-proof fencing constitutes the most expensive of the general ranch improvements in southwestern Texas. The claim has been set forth by some leading ranchers that a ranch properly watered and enclosed by a wolf-proof fence is worth twice as much as a similar holding which does not possess these improvements. The principle advantages claimed for the wolf-proof fence by the sheep and goat raisers in southwestern Texas are:
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> "1. That herding is eliminated, thus entailing a saving of from $50 to $100 per month in herders' wages for each 1,000 to 1,200 sheep grazed on the respective ranches.
>
> "2. That flocks free to graze at will within the wolf-proof pastures are not only healthier but in addition they produce larger yield of lighter shrinkage and more desirable wool than is produced by flocks under herd.
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> "3. That the carrying capacity of the ranges are increased due to the fact that less vegetation is trampled out when the sheep and goats are allowed to graze at will.
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> "4. The lambs develop into more growthy animals during the suckling period when developed under this system of management and are consequently worth more money at weaning time.

"5. That herds are healthier and freer from such parasitic infestations as scabies, internal parasites, etc., due to the fact that the different owners' herds are prevented from contacting and mixing under this system of management.

"6. That ranches are enabled to more adequately control or preserve their range vegetation."

Wentworth (1948) also indicated these advantages of fencing. Caroline (1973) described the "eradication of wolves" from Texas' Edwards Plateau and stated that "removal of wolves (from the Texas Hill Country) was half due to fencing and half due to organized control." Caroline pointed to deterioration of "wolf-proof" fences as a significant factor in reinvasion of the Texas Hill country by coyotes beginning in the 1950s.

RECENT EXPERIMENTAL NETWIRE FENCES

Shelton (1973) described the general requirements for combination net and barbed-wire fences to be effective in excluding coyotes. He suggested that, although some coyotes will scale fences up to 6 feet in height, recommendations for fences 6 feet high would be unrealistic for the extensive sheep and goat production areas of Texas. He indicated that a fence "as little as 4 feet high...will cause most coyotes to look for a hole in the net or a slide[1/] under."

For Southwestern Oregon, Cannon (1975) recommended 59-inch high woven wire with vertical stays 6 inches apart and horizontal wires spaced 1 1/2 inches apart at the bottom with spacing gradually increasing to 4 inches at the top. In addition he recommended a woven-wire apron, 24 inches wide or wider, attached to the outside of the 59-inch upright wire with hog rings to prevent dogs and coyotes from digging under. Cannon also stated that:

"Predation fencing doesn't replace the government trappers but aids him in his control work. Without the trapping program the fence is ineffective...natural forces, slides, washouts, windstorms will cause breaks in the fence and these must be repaired regularly if the fence is to be effective. The fence is a tool in the control of predatory animals and serves best when ranchers and trappers work together to make the total program effective."

DeCalesta (1976) reported on pen tests of exclusion fencing. His comments are particularly useful because of the extensive observations and the number of fence configurations tested:

"Tests were conducted on 34 electric and non-electric fences to evaluate their effectiveness in deterring crossing by coyotes. All tests were conducted inside a 16-acre chain link-fenced enclosure northwest of Corvallis, Oregon. The test period extended from April, 1975, through March, 1976.

"Coyotes crossed test fences 567 times by climbing over, jumping over, passing through meshes or between wires, and crawling under. The percent frequency of occurrence for each method of crossing was 29.6, 36.4, 29.4, and 33.9, respectively (0.7 percent not observed). No digging under was observed, probably because of the short test periods (10-15 minutes). Coyotes crossed fences significantly more often at or within 2 meters of corners when corners were not obstructed. Coyotes appeared to have difficulty jumping over fences that were higher than 66 inches. Adult coyotes were able to crawl through meshes with unstretched dimensions as small as 6 by 4 inches.

"A woven wire fence 67 inches high, including an overhang, was a significantly greater deterrent to coyotes than the standard livestock fence, but a woven wire fence with electric wires placed in front of it was not significantly better than any standard livestock fence. Coyotes crossed the test fence with an overhang 14 times, all of which involved crawling through woven wire meshes.

"When the woven wire fence with overhang was exposed to coyotes during overnight test periods, one coyote was successful in crawling under the test fence. A woven wire apron was added to the fence, and one coyote was able to cross the fence three times during additional testing, apparently by crawling through meshes.

"Electric fences generally were not effective in deterring coyotes under test conditions. Electric wires could not be positioned in a manner that insured coyotes would receive a shock. In 466 tests of 18 different electric fences, coyotes were observed receiving a shock only 13 times.

"Results of all tests indicated that an effective fence for deterring coyotes should be at least 66 inches high, be constructed of mesh no larger than 6 by 4 inches, have at least a 15-inch inclined overhang, and have a woven wire apron extending at least 12 inches from the base of the fence. A fence constructed in this manner is considered minimal to deter coyotes; however, absolute effectiveness is not insured. Cost per mile for materials to construct a fence of this type is estimated to be $2500."

[1/] Passages under fences are variously termed as "slides", "crawls", "digs", etc., depending on local terminology.

Thompson (1978) described fence-crossing behavior by coyotes in these tests and stated that:

> "I did not use V-mesh for test fences...as originally described by Jardine because it was not easily obtained during my tests. I believe that V-mesh would preclude coyotes from crawling through, but excessive cost ($3 per meter) and limited production reduce its utility."

DeLorenzo (1977) further described two fence types found most effective in the Oregon tests as follows:

> "Two fence designs tested in Oregon are the predator-directing fence and the predator-deterrent fence. The directing fence is not designed to be 'coyote proof, but rather to discourage some coyotes from crossing, and to direct other coyotes to cross at identifiable locations, making the job of trapping these coyotes easier. The fence causes predators to leave signs (hairs rubbed off on fence, holes dug under fence) when crossing the fence, allowing trappers to be more effective when placing traps and snares. This fence has been used by a number of western Oregon sheep growers who say it has significantly reduced their losses.
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> "The deterrent fence forms a physical barrier between sheep and coyotes. Only an exceptional coyote could cross it. The fence, though not an absolute deterrent, should provide a high degree of protection to livestock. It also functions as a directing fence. It was more effective than the predator-directing fence when tested with coyotes in penned tests at Oregon State University. The deterrent fence is currently being field tested on sheep ranches in Oregon, and at time of printing, lacks a field-tested stamp of approval.
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> "The fences are similar in design and appearance. Both are attached to wooden posts at approximately 15-foot intervals. Both have a woven wire apron attached to the bottom, extending outward from the fence, which prevents coyotes from digging under. Horizontal wires of the woven wire for the upright portion of the fence are 1 1/2 inches at ground level, progressing to 4 inches at the top of the fence. The upright woven wire for the directing fence is 59 inches high, and a single strand of barbed wire is stretched 6 inches above it. Upright woven wire for the deterrent fence is 72 inches high. The top 16 inches of this fence are bent outward to fit upon the outriggers placed on each fence post. This overhang deters coyotes from jumping or climbing over the fence.
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> "Efficiency of these fences may be improved by: increasing the fence height, increasing the width of the apron, reducing mesh size, and burying the apron. Some coyotes use corner braces in climbing over fences, so it is necessary to keep corner braces as low to ground level as possible. Increasing the width of the overhang, especially at fence corners, will help deter coyotes from crossing the deterrent fence.
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> "Materials and costs are similar for both fences....
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> "Predator fencing is an alternative method of protecting livestock from coyotes, but fencing must be evaluated for each livestock operation. Fencing is not applicable to all operations, but has been economically justifiable to some sheep producers in Oregon."

Sands (1977), de Calesta and Cropsey (1978), and Thompson (1979) indicated that although the best fence designs found in the Oregon tests were costly to construct, they were effective in excluding most coyotes. DeCalesta and Cropsey commented regarding field tests of a 72-inch high woven-wire fence with overhang as follows:

> "Coyotes were unable to cross the fences and large animals encountering the fences did not damage them. Deer (Odocoileus spp.) were able to leap over the fence, but occasionally hit the top, flipping the overhang toward the interior of the fence. Flipping the overhang back to the exterior side of the fence restored its configuration. A black bear (Ursus americanus) climbed over the fence in Coos County without damaging it; the overhang section merely doubled over on the upright portion, which buckled slightly. The original configuration was easily restored.
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> "The 1-year test results of the fence to prevent loss of sheep to coyotes were encouraging. Whether the fences will continue to prevent coyote crossings will be evaluated for an additional 5 to 10 years."

FENCE DAMAGE BY ANIMALS

Although deCalesta and Cropsey did not observe significant damage to these fences by large animals, it is quite common to encounter such damage caused by livestock, deer and black bears. Whitetail deer (Odocoileus hemionus) are noted in many areas as a major cause of fence damage through their habit of stretching and breaking openings in netwire mesh in order to pass through, thus providing ready access for other species, including coyotes. Javelina (Dicotyles tajacu) and wild hogs (Sus scrofa) are also a common cause of damage to netwire fences in some areas. Armadillos (Dasypus novemcinctus) are noted for burrowing under netwire fences, thus encouraging access by dogs and coyotes. Stoner et al. (1938)

commented that it was impossible for beekeepers to exclude black bears from apiaries in the Sierra Nevada mountains of California by using stockades due to the expense for labor and materials. Black bears are noted for their ability to defeat netwire and other fences apparently whenever they choose. Bears frequently damage net fences to the extent that they must be repaired in order to hold livestock and to exclude coyotes and dogs (J. Carman, personal communication, August 21, 1980; R.C. Geaney, personal communication, August 20, 1980; V.E. Pifer, personal communication, August 19-20, 1980; R.A. Thompson, personal communication, January 21, 1982).

EXPERIMENTAL ELECTRIC FENCES TO REPEL BEARS

Difficulties encountered in excluding deer, bears, coyotes, dogs and other species with conventional exclusion fencing led to experimental use of electrically charged fences for this purpose in the United States. Early attempts employed systems with relatively low secondary voltages to protect apiaries from black bears (Stoner et al. 1938). Stoner et al. indicated the need for a grounded poultry-netting apron to ensure that bears would not escape being shocked when they touched these fences. Floyd (1960) indicated that electric fences were not consistently effective if bears had entered apiaries and discovered honey. Johnson (1975) stated that high-voltage electric fences are generally effective in excluding black bears from apiaries if vegetation is not permitted to grow around the wires and a 24-inch "chicken netting" apron is used at the bottom of the fences. Gunson (1977) found electric fences to be 88.7 percent effective in protecting apiaries from black bears, although Ford (1979) commented that these fences were only 80 to 85 percent effective. Later findings by Gunson (1979) that fences were 81 percent effective over a 3-year test period in excluding black bears agree closely with those of Ford.

EXPERIMENTAL ELECTRIC FENCES TO PROTECT WILD ANIMALS

Other attempts to utilize electric fences have included efforts to protect wildlife species in the United States. Wilson (1975) indicated that exclusion fences were successful for a 14-year period in protecting desert bighorn sheep (Ovis canadensis) from predation in Texas. He further commented that an electric wire around the top of these fences would keep mountain lions (Felis concolor) and bobcats (Lynx rufus) from climbing over them and that burying the fence at the bottom would keep most predators from digging under. However, Parsons (1976) commented that "We thought it (the exclusion fence around the desert bighorn pasture) was predator-proof, but since we quit trapping lions, we found out that it wasn't." Winkler (1978) further indicated that:

> "Since 1974, the Texas Parks and Wildlife Department's bighorn sheep restoration program has been in constant jeopardy from predators, specifically cougars. Documented losses of 7 adult sheep and 11 lambs in the brood pasture at the Black Gap Wildlife Management Area in Brewster County have occurred since May 1974. A band of 20 bighorns released from the pasture in 1971 has all but disappeared, although it was estimated that their numbers had doubled by 1974. On the Sierra Diablo Wildlife Management Area, where mountain lions have not been a problem, lamb production and survival has been excellent."

Limited use of a high-voltage electric fence to exclude small mammalian predators from waterfowl nesting areas was described by Lokemoen (1979) who stated that the fence worked well during the test period but that wet vegetation would ground out the lower wire. Fence construction and the number of wires were not described by Lokemoen but, apparently, at least 7 wires were used. Minsky (1980) reported that a 3-wire electric fence was effective in excluding red foxes (Vulpes fulva) from a nesting colony of Least terns (Sterna albifrons).

RECENT EXPERIMENTAL ELECTRIC FENCES

Low-voltage electric fences were used in the past with relative success to contain livestock but many attempts, largely unreported, to develop effective low-voltage fences to repel dogs and coyotes met with relatively poor success. Major reasons for these failures appear to include, among others, inadequate fence construction, dry soil conditions in many instances, grounding of fences by extraneous wires and vegetation, damage by livestock, the insulating quality of animals furs, and limitations inherent in low-voltage systems.

Although many elements have been important to renewed interest in electric fencing to exclude carnivores, the spiralling cost-price squeeze in agriculture, difficulty in securing competent herders, labor costs, and restrictions imposed on other methods of damage control are major factors. Development of high-voltage systems in Australia and New Zealand with more reliable components and their capability of charging many miles of wire provided additional impetus. As a consequence, numerous pen and field tests of a variety of fence types have been carried out within the past five years in the United States and Canada. Most of these have been directed to exclusion of dogs and coyotes from sheep and goat herds.

Henderson (1974) indicated that in Kansas successful use of electric fences required that "yearly rainfall should exceed 28 inches. Teaching the sheep to respect the fence is of primary importance" and that "sources of electricity other than batteries are needed." Henderson suggested the use of a single charged wire 8 to 10 inches above the soil surface to exclude coyotes, or a similar wire strung 5 feet outside of existing fences to prevent coyotes from digging under or jumping over fences. Shelton (1977) described several fence configurations of 1 to 13 wires which presented potentials for excluding coyotes. He also listed some of the limitations of these fences due to coyote behavior. Shelton (1978) reported partial success in excluding coyotes from experimental pastures in Texas with the use of 2 charged wires on the outside of existing netwire fences.

Whiteman (1978) indicated that, for temporary electric fencing in Oklahoma, 2 or 3 smooth charged wires should be adequate to contain sheep and to repel dogs and coyotes. He suggested 5 to 9 wires for permanent electric fences, the bottom wire being a grounded wire 3 inches above ground level, with alternating charged and grounded wires at 6-inch intervals above the first wire to a height of 51 inches for a 9-wire fence. Whiteman also indicated that insulators to prevent grounding of charged wires were not required with the new high-voltage fence charger if hardwood posts and stays were used to support these fences. Whiteman (personal communication, August 23, 1979; 1980) commented further regarding the possibility that in some areas of Oklahoma, where coyotes were regularly exposed to barbed wires in conventional fences and smooth wires in electric fences, smooth wires would be more likely to repel coyotes than would barbed wires. At present, there do not appear to be definitive data to support or refute this hypothesis, although the ability of coyotes to learn and adapt is well documented. Shelton (1978, 1980) indicated that in some tests in Texas coyotes appeared to be capable of determining whether or not electric fences were charged and would pass through such fences when they were not charged. It is possible that this capability must be learned, since Thompson (1978), Shelton (1981) and others have found that some coyotes at least appeared unaware that fences were charged.

Gates et al. (1978) found in a series of tests that captive wild coyotes were consistently excluded from a 13-wire electric-fenced sheep enclosure constructed within a 150-acre coyote-proof test pasture. Another sheep enclosure within the test pasture, enclosed by a conventional netwire fence with two barbed wires above the netwire, consistently failed to exclude coyotes. Gates et al. concluded that "Results from this investigation clearly show that properly designed electric fencing can effectively protect sheep from coyotes and thus contradict conclusions from previous reports." Gates (1978) described in detail the electric fence used in these tests but commented that coyotes could dig under the fence and that cattle in adjacent pastures could cause fence maintenance problems. Thus, the premise that the fence design developed by Gates is 100% effective in protecting sheep from coyotes (Anonymous 1979, page 27) may not be accurate.

Dorrance and Bourne (1980) reported trials on five farms in northwestern Alberta where existing fences were modified or 7-wire electric fences were constructed to prevent coyote predation on sheep. The sheep pastures enclosed varied from about 13 to 140 acres. The authors stated that "These fences eliminated or sharply reduced predation and appear to be an economical, effective, nonlethal method for preventing coyote predation of domestic livestock." The authors indicated further that "We have found no evidence to suggest that a coyote will attempt to dig under an electric fence to get into a pasture, and...observations suggest that a coyote can dig out only with some difficulty." They suggested that, since coyotes are more likely to crawl through bottom wires rather than to jump through or over the electric fences used, only the first and third wires, 6 inches and 18 inches above ground level, need to be charged. They also suggested the addition of a barbed, grounded wire about one inch above ground level, and that the bottom charged wire should also be barbed, to reduce the chance of a coyote crawling under without being shocked.

In addition to the more or less permanent electric fences used to enclose pastures, temporary electric fences of 1 to 3 wires are often used to restrict livestock to specific pasture areas for better utilization of forage. They are much more commonly used where land is highly productive and intensive management is practical.

There is also some use of electrically charged plastic-metal ribbon and plastic-metal mesh fencing material for temporary enclosures. These can be installed to manage the use of pasture forage and the mesh is also advertised for temporary corrals to exclude predators from livestock which are confined at night.

COOPERATIVE FENCE TRIALS

Cooperative rancher efforts to fence large land tracts have occurred in several areas. One in New Mexico may be one of the more extensive of these projects (Anonymous 1978, Linhart et al. 1979). This group of ranchers modified existing netwire sheep fences by adding charged wires at the top and bottom and added sections of 5 to 9-wire electric fences in an attempt to enclose some 400,000 acres. (Linhart et al. 1979). Their intent was to reduce access by coyotes and to enhance the effectiveness of other control methods. However, B.M. Corn (personal communication, February 10, 1982) indicated that grading of fence lines and construction of new fences would be necessary for most effective exclusion of coyotes. He pointed out that damaged netwire, extraneous wire from old fences which shorted out charged wires, difficult or inadequate maintenance, and washouts due to floods were problems encountered with this project in New Mexico. Corn commented that exclusion of coyotes had been more successful with use of 220-volt chargers than with 110-volt chargers. Corn also indicated that construction of effective exclusion fences is prohibited on federal lands interspersed with private lands in that area and that, as a consequence, coyotes have easy access through the fences on these federal lands. Opposition to construction of predator exclusion fences on federal lands in this area of New Mexico was reported earlier by Worthington (1977) and others.

EFFECTS OF FENCES ON GAME ANIMALS AND RESTRICTIONS ON PUBLIC LANDS

Opposition such as reported by Worthington is at least partially due to the restriction of pronghorn antelope (Antilocapra americana) movement by predator exclusion fences. The fences recommended by the Bureau of Land Management (Williamson 1975) include replacement of sections of netwire fences, 50 to 200 yards long, with barbed wire fences 42 inches high, with a barbless bottom wire 10 to 16 inches above the ground (Worthington 1977). These fencing criteria were upheld on appeal to the U.S. Department of Interior (Williamson 1978). However, since such fences are completely ineffective in excluding coyotes and other predators, the comments by Corn (1982) that coyotes find easy access through these fences are not surprising.

Spillett et al. (1967), Bear (1969), Oakley (1973) and others have commented on the effects of netwire sheep fences in restricting movement of pronghorns. Spillett et al. and Bear recommended various fence modifications, including fences no higher than 32 inches, to permit pronghorns to cross them. The Wildlife Society (1974) recommended that livestock fences in pronghorn habitat (including both public and private land), have only three or four wires with a maximum height of 38 inches and a barbless bottom wire at least 10 inches above the ground. The Wildlife Society further recommended that "Aesthetic criteria should be established to minimize the visual impact of fences." The Wyoming Game and Fish Department (1978) adopted similar recommendations on fence types, on both public and private lands in pronghorn and deer ranges, except where exclusion fences might be essential for human safety, including highway fences, railroad right-of-way fences, etc. Netwire fences are required by Wyoming state law on some highway rights-of-way but are opposed by the Wyoming Game and Fish Department, where not required by law, for most circumstances in pronghorn and deer range. Yoakum (1978) suggested similar fence modifications for pronghorn range in Texas.

All of these recommendations on fencing as related to pronghorn movement referred to conventional fences, but Gates et al. (1978) commented in regard to the electric fence they developed that, "With regard to environmental acceptability, the electric fence could not be used where it would interfere with antelope movement." Gates also expressed some reservations related to restriction of deer movement by these fences. Presumably, similar concerns would be encountered if electric fences restricted movement of other wild species as well, other than the common carnivores, since the Wyoming Game and Fish Department (1979) has made specific recommendations on fences to benefit deer and elk (Cervus canadensis) and the Bureau of Land Management has specific recommendations related to fencing which might affect desert bighorn (Williamson 1975).

From these and other reports, including many of those from the news media, it is clear that, in addition to federal and state regulations, there is substantial opposition to use of effective predator exclusion fences. As a consequence, such fences do not appear to be a viable alternative to protect livestock on public lands and may also be vigorously opposed on some areas of privately owned land where they may restrict movement of pronghorn, deer, elk, or certain other wild species.

OTHER FACTORS WHICH LIMIT EFFECTIVE USE OF FENCES

There are other limitations to the effective use of exclusion fences. Parsons (1976) and Winkler (1978) found that such fences did not exclude mountain lions from a bighorn sheep brood pasture. Observations by Shelton (1979, 1980) of mountain lions gaining access to pastures surrounded by netwire and electric fencing to protect sheep further describe the difficulty of excluding this species by fences.

There are numerous physical factors which may decrease effectiveness of electric fences. Grounding of charged wires by heavy or wet vegetation and by extraneous wires are reported by numerous investigators and ranchers (Shelton 1979; T. Connelly, personal communication, February 19, 1980; A.H. Murphy, personal communication, February 9, 1981). Heavy rains tend to cause soil erosion and washouts under fences, particularly at trails, gullies and creeks. Falling timber and windblown dirt and vegetation frequently damage fences. Drifting snow may ground out electric fences and frequently covers them, particularly on the lee side of slopes, hills and high vegetation, to provide both livestock and other species easy passage over them. P.S. Gipson (personal communication, January 18, 1982) reported such difficulties with electric fencing in Alaska. Shelton (1979) reported that lightning and ice storms caused failure of some electric test fences in Texas.

Damage to fences and grounding of electric wires by livestock, bears and deer is relatively common (Shelton 1979; J. Carman, personal communication, August 21, 1980; R.C. Geaney, personal communication, August 20, 1980; V.E. Pifer, personal communication, August 19-20, 1980; R.A. Thompson, personal communication, January 21, 1982). Shelton (1979) also reported that coyotes gained access to kill sheep by jumping electric fences. Murphy (1981) commented that coyotes gained access and killed sheep which were inside a "deer-proof" pasture, although the coyotes' access routes could not be determined. Connelly (1980) and Murphy (1981) reported very high maintenance costs for electric fences and both indicated that the fences were not sufficiently cost-effective. Shelton (1981) indicated that in some instances coyotes gained access to goats through electric fences and remained inside, apparently due to being shocked in passing through into the pastures. He speculated that extensive killing of goats may have been partially due to the coyotes being confined. Others have also observed this to occur, including Dorrance and Bourne (1980). Shelton (1981) commented that:

> "The most obvious conclusion from this experience is that even electrified fences should provide some degree of physical barrier to coyote passage. The charged wires would then serve to deter attempts such as digging or climbing to defeat the fence. Theoretically, once the predators learned to fear the fence they avoid subsequent attempts at passage."

The most common netwire used for sheep and goat fences has vertical stays at 6 or 12-inch intervals. Both sheep and goats often attempt to feed on vegetation adjacent to fence lines by reaching through the mesh. As a result, 12-inch spacing between vertical stays is preferred for goat fences since their horns frequently catch and prevent them from backing out of netwire. With stays at 12-inch intervals goats can usually turn their heads so their horns are roughly parallel to the horizontal wires and pull out of the mesh. In many instances they cannot do so with vertical stays at 6-inch intervals and such fences must be checked regularly to free them. This causes additional labor and goats will die if they are not found and released, thus the preference for 12-inch mesh. However, this also has a direct bearing on predator exclusion since the larger mesh is less effective in preventing access by dogs and coyotes.

Also, some of the small carnivores which may prey on small livestock and poultry are not easily excluded by fences. These include bobcats, red foxes (Vulpes fulva), gray foxes (Urocyon cinereoargenteus), raccoons (Procyon lotor), mink (Mustela vison), badgers (Taxidea taxus), hognose skunks (Conepatus leuconotus) and others.

An additional factor affecting the use of fences is the ownership of grazing lands. Current land prices are inflated by recreational and other developmental demands. In addition, low livestock prices and high interest rates, as well as other operating costs, have caused low or negative livestock profit margins. Because of high costs many livestock producers are forced to lease rather than purchase land and may be unable either to afford fence construction and maintenance costs, or to maintain a profit margin even if they could construct fences. Thus, it may be difficult economically to justify fence construction, particularly for producers who lease land, even if fences were completely effective in preventing predation on livestock.

SUMMARY AND CONCLUSIONS

In general, netwire fences of appropriate mesh size, or combination net and barbed-wire fences with netwire at least 48 inches in height and barbed wires above, to a height of 5 feet or more appear to be the most effective conventional fences for exclusion of dogs and coyotes.

There appears to be general agreement that electric predator exclusion fences require high-voltage chargers (5000 or higher secondary volts). The most effective electric fence tested to date (Gates et al. 1978) was 5 feet high with 12 alternately charged and grounded wires in the vertical plane and one charged wire 8 inches outside the fence and 6 inches above ground level. Under pen test conditions where it could be correctly maintained, this fence was consistently effective in excluding coyotes.

There are sufficient data available from rancher use and experimental trials of conventional and electric fences to indicate that properly constructed predator exclusion fences can be efficient for some livestock operations. Fences are most useful and cost-effective on small, open pastures, without dense brush cover or timber, so that predators can be easily removed. Cost-effectiveness of fences is related to land productivity, construction and maintenance costs, adverse weather and other conditions that may cause extensive maintenance or other problems.

Conventional fences are relatively ineffective in preventing access by mountain lions and bears, but if well constructed and maintained are reasonably effective in excluding dogs and coyotes. Conventional netwire fences modified by adding electrically charged wires and all-electric fences may be more effective in excluding predators but must be carefully maintained. Some are easily grounded and rendered ineffective by wet vegetation, extraneous wires, damage by animals and other causes.

Predators may gain access through fences by jumping, crawling through or digging under. If they are contained within fences, they may resort to excessive killing of livestock. As a consequence of these factors, exclusion fences are not consistently effective in preventing or reducing predation.

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