Electric fencing for duck and pheasant production in Wisconsin. No. 176 1992

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Cover: Electric fence showing mowed strip to control vegetation.

ABSTRACT

Eight electric fences were constructed and evaluated on 6 public properties in Wisconsin during 1983-85 to determine the feasibility of excluding predators from duck and pheasant nest cover. Flexinet and smooth wire fences were tested on plots ranging in size from 6-47 acres. Problems in maintaining high voltages were encountered due to human error, equipment malfunction, and natural factors. Maintenance problems decreased during the study, but the smooth wire design maintained consistently higher voltages than the Flexinet design. Predator penetration of the fences mainly coincided with instances of low voltages, but red foxes were apparently able to jump the Flexinet fences and opossums were able to penetrate fully-powered fences of either design.

Blue-winged teal and mallards comprised an average 66% and 28%, respectively, of the duck breeding pairs on the study areas and were the most common nesting game bird species. Duck nest density did not appear to increase on the fenced plots over time or relative to controls. Duck and pheasant nest success was related to both fence design and plot size, but the effects could not be clearly separated because Flexinet fence plots averaged smaller than those of smooth wire. Mayfield nest success inside the 4 smooth wire fences (45%) averaged higher than on adjacent control fields outside (27%). Nest success inside the 4 Flexinet fences was not different than on control fields. Nest success averaged higher inside large (> 20 acres) fenced plots (54%) than inside small (< 10 acres) fenced plots (12%). Predator penetration and fence power problems suggest that the smooth wire design was superior to the Flexinet design. Predation by target predators was reduced inside smooth wire fences, but not Flexinet fences.

Construction and maintenance costs were similar for both fence designs. Using labor rates of $10/hour and projecting an operational life of 20 years, smooth wire and Flexinet fences cost $6,402/1,000 ft and $6,232/1,000 ft, respectively. A smooth wire fence enclosing 80 acres would cost $29.88/acre/year and provide 1.7 more young/acre than on unfenced nest cover. The cost of each additional young hatched under these conditions would be $17.37. Costs of additional young could be reduced to $3.65 if fence maintenance problems are resolved. We recommend: (1) the smooth wire fence design, (2) solar panels to extend battery power, (3) large plots, (4) enclosed nest cover that is different from surrounding cover, (5) elimination of den sites within fences, (6) avoidance of severe erosion patterns, (7) a back-up power system, and (8) an experienced person to monitor the fence. Hybrid physical-electrical design alternatives are emerging that make electric fencing a cost-effective management tool for duck production. However, electric fencing should be selectively used.

Key Words: electric fence, predator control, ducks, pheasants, nest success, Wisconsin.

Electric Fencing for Duck and Pheasant Production in Wisconsin

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INTRODUCTION

Intensive management on public lands dedicated to wildlife production has been a major strategy of game bird management. The aim is to increase nest density and success on the remnant habitat of public wildlife properties to offset the widespread decline in habitat quantity and quality on private lands (Nelson and Duebbert 1974, Arnold 1983, Can. Fish Wild. Serv. and U.S. Fish Wildl. Serv. 1986). However, as nesting habitat becomes concentrated, game birds and their predators are forced into close association, resulting in nest success that is often below the level needed to maintain a population (Cowardin and Johnson 1979, Livezey 1981, Sargeant et al. 1984, Wheeler et al. 1984, Cowardin et al. 1985, Fleskes 1986, Greenwood et al. 1987, Klett et al. 1988).

Remedies for this problem include both direct and indirect predator control (Balser et al. 1968, Duebbert and Kantrud 1974, Duebbert and Lokemoen 1980, Madsen 1986, Greenwood 1986). Predator exclusion from nesting fields using electric fencing is one indirect approach that has shown promise from a biological and economical viewpoint (Lokemoen et al. 1982). Electric fences of several designs have been used in North Dakota and Minnesota with mixed results (Madsen 1982, Grunewald 1983, Madsen 1984, Madsen 1986, Lokemoen 1984). Petersen (1990) first tested electric fencing to increase duck production in Wisconsin, using 2 fence designs. His limited success led him to suggest further testing in the state before electric fencing could be recommended as an operational management tool.

Our study was undertaken to test 2 fence designs replicated geographically in Wisconsin. The fences were designed to protect duck and pheasant (*Phasianus colchicus*) nests from 4 major (target) predators: striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), and opossum (*Didelphis marsupialis*). The management problem was to find a cost-effective way to raise game bird nest success on public wildlife lands. Specific objectives were to compare game bird nest density and success within electric fences and adjacent control plots and to document fence construction and maintenance costs. The study was conducted in 1982-85.

STUDY AREAS

Eight fences were constructed and evaluated on 6 state and federal wildlife management properties (Fig. 1). Four fences, 2 on each site, were studied on Erickson Waterfowl Production Area (WPA), St. Croix County, and Horicon Marsh State Wildlife Area, Dodge County. Single fences were studied on Eggleston WPA, Dane County; Ward WPA and Haupt WPA, Columbia County; and Horicon National Wildlife Refuge (NWR), Dodge County.

Erickson WPA adjoins 2 other WPAs to form a 500-acre complex of public wildlife land centered on a 99-acre lacustrine, littoral wetland (Cowardin et al. 1979) described by Evrard and Lillie (1987). An additional 65 acres of palustrine, emergent wetlands lie within 0.5 miles of the nesting fields. The 2 study sites were located on the western half of the property.

Horicon Marsh State Wildlife Area is an 18-mile^2 tract adjoining the Horicon NWR. The southern third of the extensive Horicon Marsh is the dominant wetland on the property and borders the 2 study sites, which were located on the southwest and southeast corners of the property. Horicon Marsh is a palustrine, emergent wetland dominated by common cattail (*Typha latifolia*); it has been described by Linde et al. (1976) and Craven (1978).

Eggleston WPA is a 380-acre tract of public wildlife land with a complex of 56 acres of ditches and diked palustrine, emergent wetlands within 0.5 mile of the nesting fields. The study site was located in the central third of the property. Ward WPA is a 20-acre tract with a single upland field that borders a 61-acre palustrine, emergent wetland.

Haupt WPA is a 100-acre tract where Petersen's (1990) electric fencing study took place in 1980-82. The study site bordered a 135-acre lacustrine, littoral wetland dominated by common cattail. Three additional palustrine, emergent wetlands, totaling 36 acres, lie within 0.5 mile of the nesting fields.

Horicon NWR is a 33-mile^2 federal tract that adjoins Horicon Marsh State Wildlife Area. The northern two-thirds of Horicon Marsh is the dominant wetland on the property. The study site was adjacent to the NWR headquarters, on the east side of the property.

Private lands adjacent to all study areas were intensively farmed, with corn (*Zea mays*), tame hay (*Medicago sativa*), and oats (*Avena sativa*) being the major crops (Wis. Dep. Agric. Trade & Consumer Protection 1987). Soils on the study areas were generally well-drained sandy or silt loams with 0-12% slopes (Glocker and Patzer 1978, Langton 1978, Mitchell 1978). However, both Horicon study areas had poorly drained soils, with silty clays present at the Horicon NWR area (Fox and Lee 1980). The uplands of all study areas were planted to various cool season grasses and/or warm season grasses dominated by switchgrass (*Panicum virgatum*). Annual precipitation ranged from 27-42 inches and averaged 35 inches for all areas during the study (U.S. Dep. Commerce 1983, 1984, 1985).

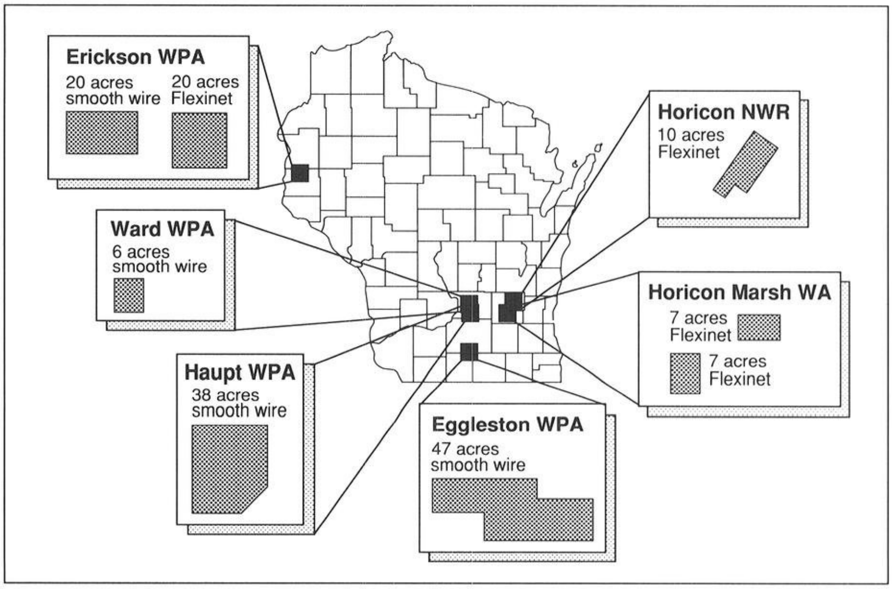


Figure 1. *Locations of study sites and fence plots.*

Electric fences enclosed stands of dense, monotypic switchgrass nest cover.

METHODS

Fence Construction

Fences were constructed during fall of 1982 and spring of 1983 and maintained for 3 nesting seasons. One hundred fifty-five acres were fenced, with individual plots ranging from 6-47 acres (Table 1). Two general fence designs were evaluated: "Flexinet"[1] fencing and "smooth wire." Each design was tested on 4 plots. Comparable (control) acreage of nest cover was studied adjacent to each fence, except at Ward WPA; this fence enclosed the only idle field within miles of the main wetland. Here, the test plot was used to determine if a build-up in nest density over 2 years occurred.

The Flexinet design used a commercial netting of braided stainless steel wire and polythene (plastic). Horizontal Flexinet wires were charged and spaced 3, 6, 8.25, 10.5, 15, 19.5, 24, and 33 inches above ground level in one fence and 3, 6, 9, 12, 16, and 20 inches above ground level in the other 3 fences. All horizontal charged wires were connected electrically every 150 ft. Vertical polythene support wires were spaced every 3 inches and attached to a horizontal polythene support wire that was staked at ground level.

The smooth wire design employed 7 strands of 15.5-gauge, high tensile galvanized wire stretched taut. Wire spacing was 4, 8, 12, 16, 20, 26, and 32 inches above ground level, with wires at 16 and 26 inches grounded and all other wires charged. A 12-inch tall section of one-inch mesh poultry netting was attached to the bottom 3 wires, extending from 3-15 inches above ground level.

Both designs left a 3-inch gap from ground level to the lowest charged wire, to allow ducklings and chicks to pass beneath. Smooth wire fences had fiberglass support posts spaced every 22 ft, and wood corner and brace posts.

Table 1. *Electric fence descriptions.*

Location of Fence[a]	Design	No. Sections[b]	Acres Enclosed	Perimeter (ft)
Eggleston WPA	Smooth Wire	3	47	7,310
Haupt WPA	Smooth Wire	2	38	5,065
Erickson WPA	Smooth Wire	2	20	3,790
Ward WPA	Smooth Wire	1	6	2,160
Erickson WPA	Flexinet	2	20	3,730
Horicon NWR	Flexinet	1	10	3,150
Horicon Marsh WA	Flexinet	1	7	2,250
Horicon Marsh WA	Flexinet[c]	1	7	2,670

[a] WPA=federal waterfowl production area, NWR=national wildlife refuge, WA=state wildlife area.

[b] Each section had a battery and energizer, charging the section separately.

[c] Fence is 33 inches high; all other Flexinet fences 20 inches high.

[1]Reference to trade names does not imply government endorsement of commercial products.

Flexinet fences had attached, fiberglass support posts every 10 ft. Smooth wire fences had a 10-ft wide gate made of 33-inch high Flexinet to allow vehicle access.

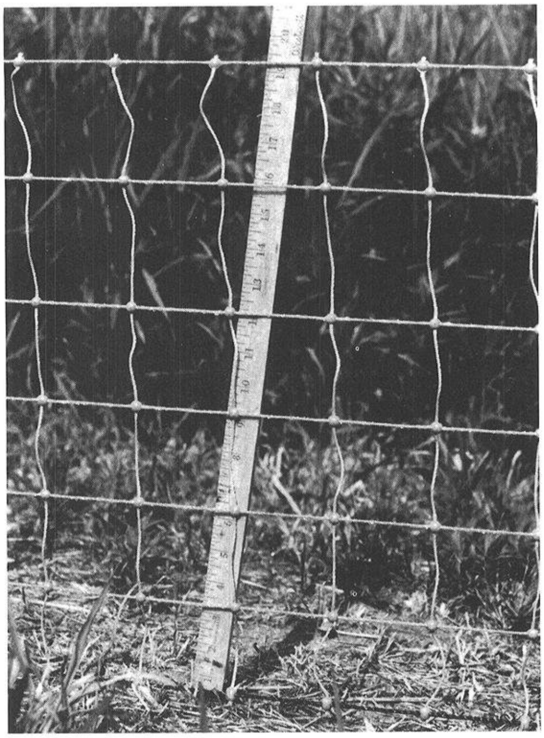
Fence energizers pulsed 4,000-5,000 volts 60 times/minute and were powered by 12-volt wet-cell batteries of 470 amperes. Both energizers and batteries were enclosed within locked wooden boxes (3 ft^3) to protect equipment from weather and vandalism. Some fences were divided into separate sections in which all charged wires were powered by a separate energizer and battery to maintain high voltages (Table 1). All fences were grounded to copper or iron rods sunk 4 ft into the ground.

In 1984-85, the Flexinet fence at Horicon NWR was powered by direct wiring to an AC outlet of the NWR headquarters. Also in 1984-85, a 10-watt solar panel charged the battery of one section of the smooth wire fence at Eggleston WPA. Beginning halfway through the 1984 field season, voltages on all Flexinet fences were boosted by attaching a direct power line (15.5-gauge wire) from the energizer along the entire fence line, with connections to the top horizontal wire every 150 ft.

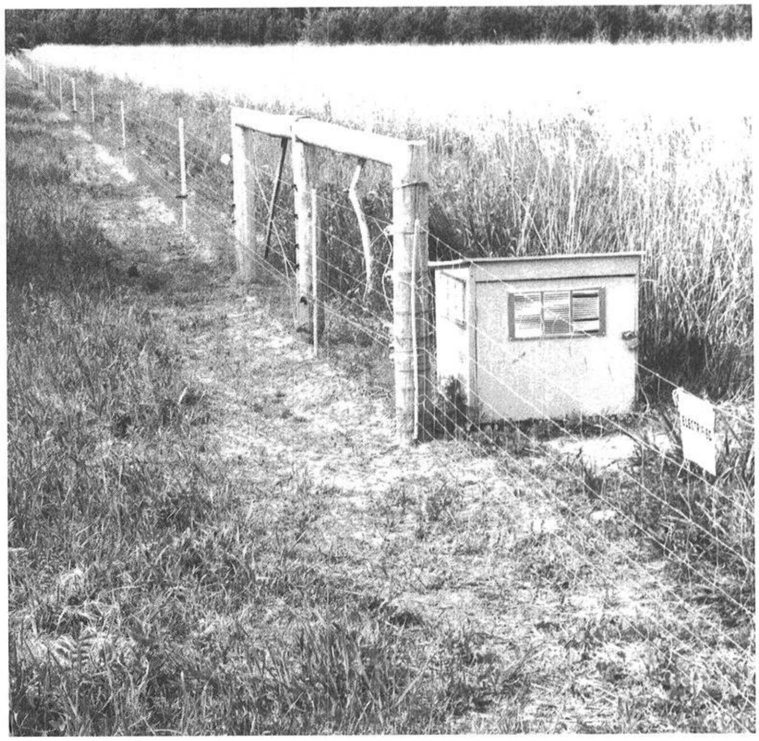
The smooth wire fence at Ward WPA was redesigned in 1985 due to low nest success in the study area during 1983-84. The lowest wire was attached to the bottom of the poultry netting, and both were moved to ground level, anchored, and disconnected from electric power. An electrified smooth wire was offset 2 inches outside the plane of the fence at a height of 11 inches. Additional charged wires occurred at 16, 20, 26, and 32 inches from the ground. This design change tested the exclusion capabilities and maintenance costs of a hybrid physical-electric fence.

Fence Maintenance and Predator Monitoring

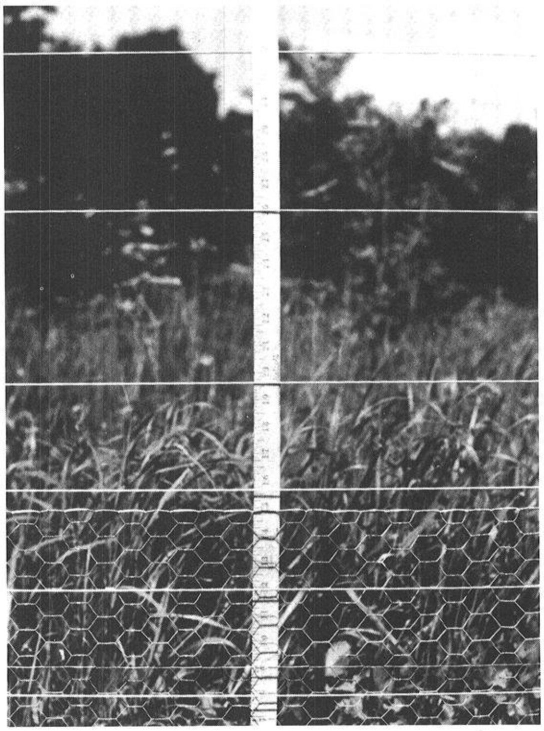
Vegetation was controlled with herbicides on a strip 10 inches wide, centered on the fence line. A pre-emergent soil sterilant (Pramitol 25E) was applied in 1983 to all fence lines at the rate of 12.5 lbs of active ingredient/acre. Another pre-emergent soil sterilant (Urox 5.5) was applied at the Erickson WPA sites in 1984 at the rate of 240 lbs of active ingredient/acre. A post-emergent herbicide (Roundup) was applied to all fence lines in May of each year, except at the Erickson WPA sites in 1985, at the rate of 10.5 lbs of active ingredient/acre. Vegetation within 5 ft of the fence was mowed with a tractor mower prior to the growing season and again during June each year; vegetation within 2 ft of the fence was mowed every 2 weeks with a lawn mower or weed whip. Irregularities in the ground level were smoothed out, and heights of fence posts were adjusted each spring to provide a consistent 3-inch gap under the fences.



The Flexinet design used netting of braided steel wire and polythene with charged horizontal wires.



Fence energizers and batteries were protected from weather and vandalism inside locked wooden shelters.



Smooth wire fences had 7 strands of steel wire and 12-inch steel poultry netting with charged wires at 4, 8, 12, 20, and 32 inches above ground.

Vegetation directly under fences was controlled with herbicides, while vegetation within 5 feet of a fence was kept mowed.

Fences were checked daily for the first 2 weeks of each season and 2-3 days/week thereafter until nesting was completed. The entire length of the fence was walked during each check to note and repair any problems and read end-line voltages. A detailed accounting of maintenance activities, labor hours, and fence performance was kept on standard forms at the fence sites. Smooth wire fences were left intact over winter, but all other equipment, including the Flexinet fencing, was removed and stored each year when nesting was completed.

Predators within the fences were removed using live traps (32- by 10- by 12-inches) at a density of 4-12 traps/fenced plot. Captured predators were marked with fluorescent spray paint and released outside the fence. Traps were positioned along the inside fence perimeter and baited with sardines. Scent stations positioned inside the fence near the perimeter were used as additional indicators of predators within the fences. One scent station was set for every 10 acres fenced. Each station consisted of a 4- by 4-ft plywood sheet, covered with axle grease, dusted with sand, and baited with sardines and fermented egg.

Vegetation Measurements

The vegetation of each field was measured to compare fenced and control nesting fields. The visual obstruction of residual cover was estimated prior to the growing season for 2 or 3 years on all fields. Measurements of the height of 100% visual obstruction of vegetation (Higgins and Barker 1982) were taken every 45 ft on alternate sides along a diagonal transect in each field.

Species composition and coverage of vegetation were estimated in July 1983 for each field using systematic sampling. Quadrants (1- by 2-ft) were placed regularly at a density of one per acre.

Duck Breeding Pair Counts and Nest Searching

Breeding ducks were counted 1-2 times each year from late April to mid-May on wetlands associated with study areas to determine whether their numbers were increasing over time and if nesting hens were concentrating on study sites. Ducks were counted from the ground (Dzubin 1969) on wetlands within 0.5 mile of the nesting fields at the Eggleston, Haupt, Ward, and Erickson WPAs. Ducks were counted at Horicon NWR by refuge personnel, using an air survey of half the marsh and ground surveys to determine species composition and adjust for ducks missed from the air.

Fenced and control fields were searched for duck and pheasant nests 3-4 times annually during May and June, using a cable-chain drag (Higgins et al. 1969) or through intensive searches by ground crews. Clutch size and incubation stage (Weller 1956, Labisky and Opsahl 1958) were determined for each nest. Nest fates were determined after the projected hatch dates. Game bird (duck and pheasant) nest success was calculated for each fenced and control plot using a modified Mayfield success estimator (Miller and Johnson 1978) and compared using a Z statistic (Hensler and Nichols 1981). The total number of nests on each site was also estimated using the nest success estimate and the number of hatched nests found (Miller and Johnson 1978).

Predation at the nest was classified during 1983-84 using the descriptions of Rearden (1951) and Einarsen (1956). Hair-catchers, modified from the "narrow stake" design of Baker (1980), were used to identify nest predators more accurately in 1985. A previous study in southern Wisconsin (R. Gatti, DNR, unpubl. data) documented that hair-catchers had no effect on nest success. Three catchers were placed at every duck nest found on both fenced and control plots, except at the Erickson WPA sites. Each catcher consisted of a 16-inch wooden stake with 3 serrated metal strips stapled as loops at 0, 4, and 8 inches down from the top of the stake. Stakes were hammered 6 inches into the ground, 2-4 inches from the edge of the nest bowl. Captured guard hairs were identified to species using keys of Stains (1958), Adorjan and Kolenosky (1969), and Moore et al. (1974).

The species composition of predations within and outside fenced plots was compared using a χ^2 test; predators were grouped into target (striped skunk, red fox, raccoon, and opossum) or nontarget (all others) groups for evaluations of the fence effectiveness in excluding these major nest predators. The occurrence of predators within fences (captures and indicated tracks at scent stations) was compared to the occurrence of low fence voltages using a χ^2 test among 3 categories of available days of fence operation: < 1 week, 1-2 weeks, and > 2 weeks from an occurrence of low voltage.

RESULTS AND DISCUSSION

Fence Operation

Construction and Annual Set-up

Fence construction was completed before the 1983 nesting season, except for the 38-acre smooth wire fence at Haupt WPA, which was constructed and powered by 8 June 1983 (Table 2). Severe gully erosion at this fence site from 1982 could not be filled until after the 1983 nesting season, so that the fence operated with 4-6 inch gaps below the lowest charged wire along many sections in 1983. This site was susceptible to erosion because of its heavier soils and long drainage pattern, which directed runoff down the exposed soil of the fence line.

The 3 smallest Flexinet fences were not maintained to design specifications in 1983 due to labor shortages. Vegetation at these 3 fences was not mowed as scheduled, and it drained power from the fences. Additionally, the 2 smallest Flexinet fences operated for periods of 1983 with large gaps under the lowest wires, due to human error (fence wires cut by mower, fence left lifted out of the ground after mowing).

Fences were generally powered earlier in 1984 and 1985 than in 1983 (Table 2). Deep snow drifts in 1984 crushed the poultry netting, which required considerable spring maintenance on sections of several smooth wire fences. The 38-acre smooth wire fence line was severely eroded by rainstorms 4 times during the 1984 nesting season. Erosion gullies up to 18 inches deep and running for hundreds of feet were filled with 22 tons of gravel, but gaps under the fence existed for 25 days before they could be repaired.

Power Problems

Numerous problems were encountered in maintaining full power to the fences, although most were corrected in 1-2 days with frequent fence monitoring. Flexinet fences had more than twice as many problems with low voltages as smooth wire fences in 1983, but a similar number of problems in 1984 and 1985. Frequent problems occurred on the 10- and 20-acre Flexinet fences in 1983, the 38- and 20-acre smooth wire fences in 1984, and the tall Flexinet fence in 1984 (Table 2). The numerous voltage problems were scattered over time so that an average of 32% of all fence operational days were within one week after an occurrence of low voltage; this percentage did not differ between fence designs. Fence maintenance was improved each year, and this increased the consistency of higher fence voltages over the study period.

Low fence voltages were caused by equipment malfunction, human error, and natural factors (Table 2). Equipment malfunction was a major cause of problems for low fence voltages, especially at smooth wire fences. Energizers failed 17 times, in spite of the fact that most equipment was purchased new for this study. Most failures resulted from cracks in solder on replaceable circuit boards. Clips on smooth wire fences broke 16 times, causing shorts to corner posts or ground wires; some of these problems may have resulted from white-tailed deer (*Odocoileus virginianus*) collisions, but there was no evidence of this along the fence lines. Low voltages during the first 25 days in 1983 at the 6-acre smooth wire fence were resolved by the installation of a second ground rod.

Failure to monitor and replace the battery before it lost power was the most common human error problem associated with low voltage (15, 6, and 1 instances in 1983, 1984, and 1985, respectively), but this problem was unrelated to fence design. Batteries that were not replaced every 18 days rarely maintained adequate power. The solar panel extended battery life to an average of 42 days of operation. Worker carelessness also resulted in 6 incidents of low voltages.

Natural factors were the major source of problems for Flexinet fences. Flexinet fences did not carry voltages down their lengths as well as smooth wire fences due to their greater resistance. They also experienced low power during periods of rain or heavy dew (21 occurrences) when wet vegetation touched the fence, or water on the vertical wires short-circuited the fence to the ground. The addition of the top power line on Flexinet fences in 1984 resolved many of these problems. The tall Flexinet fence was also short-circuited 6 times when deer or wind knocked it over. The 6-inch stakes that were built into the bottom of the fiberglass support posts of the Flexinet fences were inadequate for supporting the fences in soft ground. This problem was resolved by bracing the fences laterally with guy strings and stakes; however, this made periodic mowing difficult. A known problem from a deer collision occurred only once at the smooth wire fences. Problems from other natural factors (blizzards and a lightning strike) were less common, variable among years, and unrelated to fence design.

Predator Penetration

Predators were captured or indicated by scent station tracks inside all 8 fences in 1983 and 1985, and inside 6 of 8 fences in 1984 (Table 3). Predators appeared to be testing fences frequently because power failures of short duration often resulted in predator penetrations of the fences. Sixty-one predators were captured and 23 additional predators were detected by scent station tracks inside fences over the 3 study years. None of the 61 predators captured and marked inside and released outside the fences were recaptured inside.

Thirty indications of predators (36% of total) occurred in the first 2 weeks after the fences were powered. Thirty-five of the remaining predator visits occurred within 1 week, and usually within 1-3 days, after instances of low fence voltage. The occurrence of predators inside fences was related (χ^2 test; $P < 0.01$) to the occurrence of low fence voltages; more predators occurred within one week of a low voltage instance than expected from the distribution of fence operational days, and fewer predators than expected occurred 1-2 weeks and more than 2 weeks

Table 2. *Electric fence operation and problems, 1983-85.*

Fence Design[a] (acres)	Year	Start Date	No. Days Operated	Voltage Checks (%)[b] Over 3,000	2,000-3,000	500-2,000	0-500	Problems Resulting in Low Fence Voltage[c] Equipment Malfunction[d]	Human Error[e]	Natural Factors[f]
SW (47)	1983	5 Apr	55	37	42	16	5	1	3	0
	1984	9 Apr	87	93	3	0	4	1	1	0
	1985	8 Apr	81	90	0	0	10	3	0	1
SW (38)	1983	8 Jun	40[g]	0	78	22	0	2	2	0
	1984	18 Apr	97[h]	87	0	4	9	4	2	0
	1985	6 May	58	88	4	0	8	2	0	0
SW (20)	1983	28 Apr	76	11	83	3	3	0	2	0
	1984	12 Apr	74	75	3	19	3	0	4	2
	1985	18 Apr	71	90	7	3	0	1	0	0
SW (6)	1983	12 May	54	17	65	17	0	4	0	0
	1984	9 Apr	80	92	0	8	0	1	1	0
	1985	15 Apr	78	86	8	6	0	2	0	0
F (20)	1983	28 Apr	90	0	76	17	7	0	5	5
	1984	11 Apr	71	18	73	9	0	0	0	3
	1985	17 Apr	70	65	19	3	13	4	1	0
F (10)	1983	21 Apr	82	29	37	17	17	6	2	6
	1984	26 Apr	74	80	12	5	2	0	0	3
	1985	6 May	77	100	0	0	0	0	0	0
F (7)	1983	27 May	52[i]	20	68	5	8	0	0	3
	1984	23 Apr	77	65	2	28	5	1	1	1
	1985	10 Apr	89	88	5	2	5	2	1	0
F (7)[j]	1983	21 Apr	82[k]	52	33	14	0	0	3	2
	1984	19 Apr	82	81	0	5	14	2	0	5
	1985	15 Apr	81	97	0	0	3	0	0	1

[a] SW = smooth wire; F = Flexinet.
[b] Voltage checks less than 3,000, 2,000, or 500 v represent increasing potential for predator penetration of fences.
[c] 0-2,000 v.
[d] Number of occurrences of energizer malfunctions, or shorts due to broken fence clips.
[e] Number of occurrences of power failure due to not replacing battery, leaving power off, or damaging fence with mower.
[f] Number of occurrences of shorts caused by dew, snow, lightning strikes, deer collisions, or wind blow-downs.
[g] Fence operated 40 of 40 days with gaps greater than 3 inches under fence.
[h] Fence operated 25 of 100 days with gaps greater then 3 inches under fence.
[i] Fence operated 18 of 52 days with gaps greater than 3 inches under fence.
[j] Fence is 33 inches high; all other Flexinet fences 20 inches high.
[k] Fence operated 6 of 82 days with gaps greater than 3 inches under fence.

Table 3. *Predators detected inside electric fences, 1983-85.*

Fence Design[a] (acres)	Year	Total Trap-nights	Captures	Occurrences of Tracks On Scent Station Board
SW (47)	1983	660	2 opossum, 1 cat, 1 raccoon	1 skunk, 1 cat
	1984	1044	1 opossum, 1 cat, 1 skunk	1 cat[b]
	1985	555	2 opossum	1 skunk, 2 ground squirrel
SW (38)	1983	360	1 skunk, 4 opossum	1 opossum
	1984	873	4 skunk	1 mink
	1985	257	1 skunk, 1 opossum, 1 raccoon	1 mink, 2 ground squirrel
SW (20)	1983	456	2 cats, 1 skunk	0
	1984	444	0	1 cat
	1985	350	0	1 raccoon, 4 ground squirrel
SW (6)	1983	216	1 skunk	0
	1984	320	1 skunk	0
	1985	185	1 opossum, 1 raccoon	1 ground squirrel
F (20)	1983	540	3 skunk	1 skunk
	1984	426	0	1 cat
	1985	417	1 skunk, 1 fox	1 fox
F (10)	1983	324	3 skunk	1 skunk[b]
	1984	296	0	0
	1985	172	1 opossum	0
F (7)	1983	208	2 skunk	0
	1984	308	0	0
	1985	204	1 skunk, 1 opossum	0
F (7)[c]	1983	328	3 opossum, 6 skunk	5 fox, 1 opossum
	1984	328	1 opossum, 1 skunk, 1 raccoon	0
	1985	199	5 opossum	0

[a] SW = smooth wire; F = Flexinet.
[b] Animal that left tracks was presumed captured; all other track occurrences were not accounted for by captured animals.
[c] Fence is 33 inches high; all other Flexinet fences 20 inches high.

after a low voltage instance. Eight of the 19 predators that occurred after one week of full fence power were nontarget species: 6 ground squirrels (*Spermophilus* spp.) and 2 mink (*Mustela vison*) (Table 3). The 11 others were species targeted for exclusion by fencing; they occurred inside fences of both designs. Three striped skunks were caught 9 days after fences registered low volts and may have entered fences during low voltages.

A domestic cat (*Felis catus*) was caught inside a smooth wire fence 28 days after low voltage, and may have entered by jumping onto and over a wood corner post. A red fox track was observed inside the 20-inch high Flexinet fence 23 days after a power problem, but there was no further sign of it, in spite of high fence voltages, for 12 following days. The fox presumably jumped the short Flexinet fence. Patterson (1977) documented red foxes crossing or jumping an 18-inch-high electric fence on 5% of encounters with the fence. Six opossums were captured 15-38 days after power problems on fences of both designs. It is not likely that these opossums entered the fence when there was a power problem and eluded capture or notice that long; hence, they probably penetrated fully-powered fences. One opossum penetrated the hybrid physical-electric smooth wire fence in 1985 by digging under the bottom wire, which was uncharged but taut at ground level.

An opossum was captured outside the 47-acre smooth wire fence after the 1984 nesting season (28 June) and released inside the fence to evaluate capture efficiency. The animal was recaptured after 7 days of normal trapping efforts.

Miscellaneous Observations

Observations during routine fence maintenance documented effects of fences on nontarget animals. On several occasions mink and cottontail rabbits (*Sylvilagus floridanus*) were seen running through fully-powered fences of both designs without hesitation. Numerous recaptures of cottontail rabbits, originally captured and marked inside the fences and released outside, supported these observations of fence penetration. Pheasant and duck broods were also observed running through fully-powered fences of both designs on several occasions.

Table 4. *Dabbling duck breeding pairs counted at study areas, 1983-85.*

Fence Design[a] (acres)	Year	Mallard	Blue-winged Teal	Others[b]	Total
SW (47)[c]	1983[d]	–	–	–	–
	1984	7	24	2	33
	1985	8	26	0	34
SW (38)[c]	1983	28	77	5	110
	1984	18	41	6	65
	1985	35	68	2	105
SW (20) & F (20)[e]	1983	8	14	1	23
	1984	4	18	3	25
	1985	10	21	1	32
SW (6)[c]	1983	6	7	0	13
	1984	4	16	0	20
	1985	4	10	0	14
F (10)[f]	1983	357	628	164	1149
	1984	261	408	112	781
	1985	226	298	36	560

[a] Study area identified by fence; SW = smooth wire design; F = Flexinet design; enclosed fence acreage in (). Refer to Figure 1 for site name.
[b] Includes northern shoveler (*Anas clypeata*), gadwall (*Anas strepera*), green-winged teal (*Anas crecca*), American wigeon (*Anas americana*), northern pintail (*Anas acuta*) and American black duck (*Anas rubripes*).
[c] Counted on wetlands within 0.5 miles of nesting fields.
[d] No counts this year.
[e] Counted only on main wetland of property.
[f] Aerial survey of Horicon NWR, from refuge files.

Adult pheasants with and without broods were observed occasionally running through the fences, but on other occasions they ran along fence lines, apparently reluctant to penetrate. One 10- to 12-week-old pheasant was found entangled in the fence and dead.

Three mallard (*Anas platyrhynchos*) and 2 blue-winged teal (*Anas discors*) hens were captured on nests inside smooth wire fences in 1984 and fitted with back-mounted radio transmitters. All hens successfully hatched their nests, and 2 hens were observed as they exited the fences with their broods. Both hens went through rather than over the fences. Two other marked mallard hens from inside the fences were observed on the water with their entire broods the day after hatch, suggesting few problems with the fence barrier.

Twenty-nine American toads (*Bufo americanus*), 8 painted turtles (*chrysemys picta*), and 3 northern leopard frogs (*Rana pipiens*) were killed as they jumped onto or crawled into the fences of either design. Voltage drops occurred when several turtles were stuck under the fence at 1 time. Six songbirds were killed at fence lines from electrocution or collision: 2 grasshopper sparrows (*Ammodramus savannarum*), 2 red-winged blackbirds (*Agelaius phoeniceus*), one common yellowthroat (*Geothlypis trichas*), and one eastern kingbird (*Tyrannus tyrannus*).

Duck and Pheasant Nesting

Duck Breeding Pairs and Nest Density

Blue-winged teal was the most common duck species associated with study areas, representing an average 66% of the dabbling duck pairs on the 5 properties surveyed during 1983-85 (Table 4). Mallards represented an average 28% of the dabbling duck pairs associated with study areas. Total numbers of breeding dabbling duck pairs fluctuated over the years of study on 3 properties (Eggleston, Haupt, and Ward WPAs), declined each year at Horicon NWR, and increased each year at Erickson WPA. Densities ranged from 0.21-0.64 dabbling duck pairs/acre of wetland among years on the 4 WPAs, and averaged 0.42 pairs/wetland acre for all years and properties. Petersen (1990) counted an average of 26 mallard and 123 blue-winged teal pairs at the Haupt WPA during 1980-82. Our 1983-85 survey of the same wetlands reflects little change in average mallard numbers (27 pairs), but a 50% decline in average blue-winged teal numbers.

There was little evidence of duck nest density increasing on the fenced plots over time or relative to controls. Numbers of duck nests found on study sites (fenced and control) fluctuated during the 3 years of study for most sites (Table 5). Estimated numbers of duck nests present

Table 5. *Numbers of dabbling duck nests found and total estimated at study sites, 1983-85.*

Fence Design[a] (acres)	Year	Treatment		Control		Total	
		Found	Estimated[b]	Found	Estimated[b]	Found	Estimated[b]
SW (47)	1983	5	6	5	–[c]	10	–
	1984	5	7	4	5	9	12
	1985	5	3	5	17	10	20
SW (38)	1983	6	18	9	15	15	33
	1984	6	9	11	32	17	41
	1985	7	13	3	–	10	–
SW (20)[d]	1983	5	5	12	14	22	25
	1984	16	16	18	23	39	43
	1985	9	19	11	25	25	51
SW (6)[e]	1983	2	–	–	–	–	–
	1984	1	–	–	–	–	–
	1985	1	–	–	–	–	–
F (20)[d]	1983	5	6	12	14	22	25
	1984	5	4	18	23	39	43
	1985	5	7	11	25	25	51
F (10)	1983	10	–	16	33	26	–
	1984	9	–	23	16	32	–
	1985	8	9	13	12	21	21
F (7)	1983	10	14	14	22	24	36
	1984	8	–	1	–	9	–
	1985	8	20	5	–	13	–
F (7)[f]	1983	3	–	5	–	8	–
	1984	5	–	5	–	10	–
	1985	10	9	7	6	17	15

[a] Study area identified by fence; SW = smooth wire; F = Flexinet; enclosed fence acreage in (). Refer to Figure 1 for site name.
[b] Estimated no. nests = [No. hatched nests found] ÷ [Mayfield nest success] (Miller and Johnson 1978.)
[c] Nest numbers could not be estimated because no hatched nests were found.
[d] SW (20) and F (20) were at same site so they used the same control; "total" combines both fences and the control.
[e] No control.
[f] Fence is 33 inches high; all other Flexinet fences 20 inches high.

(Miller and Johnson 1978) could only be calculated for every year at Erickson WPA because of extremely low sample sizes and nest success at other properties. More nests were estimated to be present at Erickson WPA each year. The ratio of nest numbers found (or estimated to be present) to breeding pairs did not show any consistent trend over time at any study site. The ratio of nest numbers found inside fences to those found on adjacent control plots also fluctuated over the 3 years of study. There were too few pheasant nests found to examine nest densities separately for pheasants.

Game Bird Nest Success and Predation

The small number of game bird (duck and pheasant) nests available each year made nest success evaluations for individual years and sites difficult. Mayfield nest success estimates ranged from 1-100% inside fences over the 3 years. Pooling years for each fence showed 3 fences with higher nest success inside than outside: the 47- and 20-acre smooth wire fences and the 20-acre Flexinet fence (Table 6). When data were pooled by fenced design, nest success inside the Flexinet fences was not different ($P > 0.20$) than that outside the fences. However, nest success inside the pooled smooth wire fences (45%) was higher ($P = 0.05$) than that outside the fences (27%).

The 3 smallest Flexinet fences and the 38-acre smooth wire fence were not maintained to design standards in 1983. However, even when these site-years were excluded and the data reanalyzed, none of these fences demonstrated higher nest success than controls, nor did the overall results change for Flexinet fences. Petersen (1990) found no difference between nest success inside (41%) and outside (25%) his fences, and no difference between nest success inside Flexinet and smooth wire fences.

Table 6. *Nesting results at electric fence study sites, 1983-85.*

Fence Design[a] (acres)	Plot[b]	1983 No. Nests	1983 Nest Success[c]	1984 No. Nests	1984 Nest Success[c]	1985 No. Nests	1985 Nest Success[c]	1983-85 No. Nests	1983-85 Nest Success[c]	Z*
SW (47)	T	6	71	5	42	3	100	14	64	2.30
	C	5	2	3	40	4	12	12	9	
SW (38)	T	5	5[d]	6	34	6	16	17	18	0.52
	C	8	20	9	9	3	4	20	12	
SW (20)	T	3	100	16	100	9	27	28	73	1.94
	C	12	69	18	57	11	12	41	44	
SW (6)	T[e]	2	1	0	–	1	4	3	2	–
F (20)	T	6	72	4	100	2	14	12	70	1.67
	C	12	69	18	57	11	12	41	44	
F (10)	T	8	3[d]	5	3	6	22	19	7	1.61
	C	14	12	13	6	11	75	38	22	
F (7)	T	9	14[d]	5	26	7	5	21	13	1.04
	C	11	5	1	2	0	–	12	4	
F (7)[f]	T	3	4[d]	4	1	8	64	15	24	1.48
	C	2	0	4	1	4	18	10	5	

* Z test statistic for difference between inside and outside fence; Z=1.96 for (P=0.05); Z=1.64 for (P=0.10).

[a] Study area identified by fence; SW = smooth wire; F = Flexinet; enclosed fence acreage in (). Refer to Figure 1 for site name.

[b] T = treatment plot (i.e. inside fence); C = control (i.e. adjacent outside fence).

[c] Modified Mayfield success estimator (%).

[d] Fence not constructed and maintained to design specifications.

[e] No control acreage searched.

[f] Fence is 33 inches high; all other Flexinet fences 20 inches high.

Nest success was related to the size of the fenced plot, although the influence of plot size and fence design could not be clearly separated because smooth wire fences enclosed an average of 28 acres, over twice that of Flexinet fences (11 acres). All 4 fences (3 Flexinet and 1 smooth wire) that enclosed 10 acres or less had low nest success, averaging 12%. Predators that got inside the small fence plots may have hunted the enclosed cover more intensively than predators inside larger plots. The 4 fences (3 smooth wire and 1 Flexinet) that enclosed 20 acres or more averaged 54% nest success. The only low nest success (18%) on a large-sized smooth wire plot likely resulted from fence gaps caused by extensive erosion; the remaining 2 large-sized smooth wire plots averaged 70% nest success. The only large-sized Flexinet plot had high nest success, but it was in an area of low predation pressure during 1983-84. The success of both large-sized smooth wire plots cannot be explained by low predator pressure; predation outside the 47-acre smooth wire fence was as high as that outside the unsuccessful fences. This, along with other evidence, suggests that smooth wire fences provide better protection than Flexinet fences in spite of fence power problems.

Seventy-two nests were preyed upon inside the fences during the 3 years of study. Evidence indicates that striped skunk and/or opossum and red fox were the major predator species, responsible for 32% and 29%, respectively, of the destroyed nests inside fences. Raccoons were implicated in 15% of the nest destructions inside fences. Predation by non-target species, such as ground squirrels, mink, weasels (*Mustela* spp.), American crow (*Corvus brachyrhynchos*), and an unknown raptor, was indicated for the remaining 24% of the destroyed nests inside fences.

Pooling data for predations inside smooth wire fences showed a predator species composition similar to that of adjacent controls. However, when predators were grouped into target or non-target categories, the proportion of predations attributed to target predators was lower (χ^2; $P < 0.05$) inside smooth wire fences than outside. Pooled predations inside Flexinet fences were attributed to a different (χ^2; $P < 0.01$) composition of predators than on the adjacent controls. The proportion of predations by red fox was higher inside Flexinet fences, while predation by striped skunk and/or opossum was lower inside Flexinet fences than outside. Red fox were apparently able to enter Flexinet fences, and, once inside, remain there long enough to destroy most nests, while skunks and/or opossum appeared to have been somewhat excluded by the fences. When predators were grouped into target or non-target categories, differences among target predators cancelled out; the proportion of predations by target predators was not different inside or outside Flexinet fences.

Table 7. *Mean height of visual obstruction of residual vegetation on study fields.*

Fence Design[a] (acres)	Plot[b]	100% Obstruction Height (cm)		
		1983	1984	1985
SW (47)	Treatment	32**	–	36
	Control	14	–	29
SW (38)	Treatment	37**	–	–
	Control	17	–	–
SW (20)	Treatment	18**	28**	51**
	Control	10	8	28
SW (6)[c]	Treatment	22	–	28
F (20)	Treatment	9	8	25
	Control	10	8	28
F (10)	Treatment	15	–	28
	Control	–	–	25
F (7)	Treatment	19	–	16**
	Control	11	–	11
F (7)[d]	Treatment	10	–	15
	Control	8	–	15

[a] Study area identified by fence; SW = smooth wire; F = Flexinet; enclosed acreage in (). Refer to Figure 1 for site name.
[b] Treatment = inside fence; control = adjacent outside fence.
[c] No control.
[d] Fence is 33 inches high; all other Flexinet fences 20 inches high.
** Treatment different (t-test; $P < 0.01$) than control.

Although 25 predations occurred inside smooth wire fences, most took place shortly after low voltage instances. Seven predations took place during intervals of continuous high voltages on smooth wire fences, but only 2 were by target predators (one red fox and one striped skunk).

Fully-powered Flexinet fences were less successful in excluding target predators. Half of the 47 predations inside Flexinet fences took place during intervals of continuous high voltages, documenting predator penetration of the Flexinet design. Predations by target predators inside Flexinet fences during periods of high voltages included 11 by red fox, 5 by raccoon, and 3 by striped skunk and/or opossum. Target predators penetrated Flexinet fences of both heights.

Vegetation Analyses

Fenced and control fields were selected to provide similar nest cover comparisons. However, vegetation analyses documented differences between nest cover quality inside and outside the fences. The visual obstruction of residual cover was greater inside than outside for 4 of 7 fences in at least one year (Table 7). But nest success did not correlate with visual obstruction of residual cover among control fields, indicating that this was not a major factor. Control fields with visual obstruction averaging less than 20 cm ranged from 0-69% in nest success, while fields with visual obstruction averaging over 20 cm ranged from 1-100% in nest success.

The areas covered by plant genera also differed between fenced and control fields at most sites. Switchgrass coverage was higher on fenced plots than on control fields at 3 smooth wire fences, which explains the taller-denser residual cover inside these fences (Table 8). The 20-acre smooth wire fence plot also contained more *Solidago*, *Aster*, and *Taraxacum*, and less *Poa* and *Bromus* than on its control. The 20-acre Flexinet fence had more *Agropyron* and less *Bromus* inside than outside, while the 10-acre flexinet fence had more *Festuca* and *Poa*, and less *Panicum*, *Solidago*, and *Aster* inside than outside. The differences at these last 2 sites were not reflected in visual obstruction of residual cover. Nest success did not appear to be related to any of these plant genera coverages.

Cost Analysis

Original material costs for the smooth wire fences ($641/1,000 ft) averaged lower than those for the Flexinet fences ($679/1,000 ft) (Table 9). However, smooth wire fences required more labor to construct (52 hours/1,000 ft) than Flexinet fences (11 hours/1,000 ft), and slightly more

Table 8. *Vegetation composition[a] of study fields, 1983-85.*

Plant Genera	SW (47)[b] T	SW (47)[b] C	SW (38) T	SW (38) C	SW (20) T	SW (20) C	SW (6)[c] T	F (20)[b] T	F (20)[b] C	F (10) T	F (10) C	F (7) T	F (7) C	F (7)[d] T	F (7)[d] C
Panicum	69	35	62	41	37	19	58	12	19	35	48	6	14	19	19
Bromus	2	0	3	8	2	13	0	1	13	4	4	23	14	29	24
Cirsium	1	11	6	4	6	2	1	0	0	0	0	0	0	0	0
Taraxacum	1	3	1	2	12	1	4	0	0	0	0	0	0	0	0
Agropyron	1	0	17	18	2	6	0	21	6	2	4	5	6	1	0
Poa	0	0	1	2	4	37	0	39	37	13	2	35	39	0	0
Solidago/Aster	0	0	0	5	19	8	0	10	8	8	25	21	21	10	8
Melilotus	0	0	0	1	0	2	15	0	2	10	4	0	0	1	0
Phleum	0	0	0	0	0	0	0	0	2	2	1	0	0	11	14
Festuca	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0
Medicago	0	0	0	0	0	0	0	0	0	2	1	0	0	12	10
Others	26	51	10	18	18	12	22	17	13	13	11	11	6	17	25
% Grasses	91	61	84	74	47	77	63	73	77	68	61	73	74	64	62
% Forbs	9	39	15	26	50	22	37	27	22	32	39	27	26	36	38
No. Genera	23	24	21	32	37	54	18	33	54	17	19	18	14	18	24
Genera/quadrat	0.4	0.3	0.6	0.7	0.5	0.2	1.8	0.6	0.2	1.7	0.6	0.9	0.7	0.9	1.2

[a] Percent coverage except for diversity indices (no. genera, genera/quadrat).
[b] Study areas identified by fence design; SW = smooth wire design; F = Flexinet design; enclosed acreage in ();
T = treatment plot (i.e. inside fence); C = control (i.e. adjacent outside fence). Refer to Figure 1 for site names.
[c] No control acreage studied.
[d] Fence is 33 inches high; all other Flexinet fences 20 inches high.

labor to set up in subsequent years (11 vs. 8 hours/1,000 ft). Additional materials required in subsequent years were also slightly higher for smooth wire fences ($29/1,000 ft) than for Flexinet fences ($17/1,000 ft). The smooth wire fence material costs included erosion control at the 38-acre Haupt WPA fence, where 22 tons of gravel and extra labor were required to fill gullies in both 1983 and 1984. The other 3 smooth wire fences averaged $20/1,000 ft for materials in subsequent years. Flexinet fences averaged more labor to maintain each year (18 hours/1,000 ft) than smooth wire fences (13 hours/1,000 ft).

Projected material costs over a 20-year life of each fence design are $1,192/1,000 ft of smooth wire fence and $1,002/1,000 ft of Flexinet fence. Labor needs total 521 hours/1,000 ft of smooth wire fence and 523 hours/1,000 ft of Flexinet fence for 20 years. Using current labor rates of $10/hour, 20-year costs would total $6,402/1,000 ft of smooth wire fences and $6,232/1,000 ft of Flexinet fences. Smooth wire fences would only cost $170/1,000 ft more than Flexinet fences over 20 years. Transportation costs were not included because of the potential variability of fence siting relative to labor sources. We did not document transportation costs, but they would add to total costs to some variable degree.

Labor costs would vary depending on whether permanent or seasonal personnel are involved. The fence designs used in this study required regular maintenance checks, which often involved solving problems in the field. Cutting costs by using less skilled or less interested workers may jeopardize the success of the fence. Our work was split between permanent and seasonal workers, and we had numerous problems that were attributed to human error.

Costs/acre enclosed will be optimized for square plots and will decrease as plot size increases. Smooth wire fences around 40- and 80-acre square enclosures would cost $1,690/year and $2,390/year, respectively, for 20 years with labor rates of $10/hour; these costs equate to $42.25/acre/year and $29.88/acre/year for the 2 respective plot sizes.

Petersen (1990) calculated lower original material costs ($564/1,000 ft), higher first-year labor costs ($413/1,000 ft), and lower annual maintenance costs ($136/1,000 ft) for his electric fences of similar designs; his costs totaled $34/acre/year for a 40-acre plot over 20 years, with $11/hour labor rates. Costs of our fences for a comparable situation would total 25% higher than his figure. Lokemoen et al. (1982) reported first-year construction costs of $439-$561/1,000 ft for taller smooth wire fences in North Dakota and Minnesota and later reported annual maintenance costs of $64/1,000 ft of fence (Lokemoen 1984). Construction and maintenance

Table 9. *Electric fence construction and maintenance costs/1,000 ft of fence, 1983-85.*

Fence Design[a] (acres)	1983			1984			1985		
	Material Costs[b]	Labor (hours)		Material Costs[b]	Labor (hours)		Material Costs[b]	Labor (hours)	
		Construct	Maintain		Set-up	Maintain		Set-up	Maintain
SW (47)	$ 647	63	19	$ 18	10	11	$ 16	8	10
SW (38)	598	77	8[c]	88[d]	19[d]	17[d]	16	5	11
SW (20)	634	31	11	18	8	11	31	15	11
SW (6)	685	37	17	19	9	12	42[e]	25[e]	9
Mean	641	52	16	36	12	13	21	9	10
F (20)	688[f]	18	12	16	9	10	19	6	11
F (10)	630[f]	9	11[c]	26	5	19	13	5	16
F (7)	679[f]	7	8[c]	15	15[g]	24	17	5	22
F (7)[h]	720[f]	9	12[c]	13	13[g]	31	19	7	16
Mean	679[f]	11	12	18	10	21	17	6	16

[a] Study area identified by fence; SW = smooth wire; F = Flexinet; enclosed acreage in (). Refer to Figure 1 for site name.
[b] Includes cost of tractor mowing at $9/hr.
[c] Fence not maintained to design specifications; not used in average calculations.
[d] Materials and labor increased by severe gully erosion along fence line.
[e] Modification into new fence design; not used in average calculations.
[f] Includes the additional top power line purchased for all Flexinet fences (actually in 1984).
[g] Labor increased by heavy spring snow during set-up.
[h] Fence is 33 inches high; all other Flexinet fences 20 inches high.

costs of our fences using comparable area and labor rates would be 42% and 48% higher, respectively, than their figures, primarily due to our more frequent maintenance.

Madsen (1985 and pers. comm.) reported construction costs of $860-$937/1,000 ft for hybrid physical-electric barriers in Minnesota; comparable construction costs for our fence designs would be only 5% lower than his figures. Although Madsen did not report annual maintenance costs, these fences were designed for much lower maintenance than our fences.

Cost/benefit ratios were calculated based on nest density and nest success. Only the smooth wire design was used for this evaluation because the Flexinet design did not demonstrate increased nest success. Game bird nest density inside our fences ranged from 0.11-1.43 nests/acre and averaged 0.36 nests/acre for 1983-85; 92% were dabbling duck nests and 8% were pheasant nests. However, these are minimum estimates because cable-chain searching underestimates nest density, especially for pheasants (Higgins et al. 1969). Nest densities on managed fields in Wisconsin have exceeded one duck nest/acre in several locations (Petersen 1990, R. Gatti, DNR, unpubl. data) and exceeded 5 duck nests/acre 1-6 years earlier on our study sites at Horicon Marsh Wildlife Area (G. Bartelt, DNR, pers. comm.). Nest success averaged 45% inside and 27% outside our smooth wire fences. The latter figure is higher than nest success estimates reported from past Wisconsin studies (Livezey 1981, Wheeler et al. 1984, Bartelt pers. comm.), but is not different than estimates outside Flexinet fences (23%) or on other nest cover in the state during 1983-85 (32%; Gatti 1987).

Using our nest success estimates and assuming a density of one nest/acre, a smooth wire fence would produce an additional 0.18 hatched nest/acre over that of unfenced nest cover. Assuming 9.5 young/hatched nest would equate this to 1.7 additional young hatched/acre over that of unfenced nest cover. The cost per additional young hatched ranges from $17.37 to $24.56 (for 80- or 40-acre fences, respectively, enclosing one nest/acre and using $10/hour labor). Resolution of fence power problems that increased nest success to 70% (achieved in 2 of our fences) would reduce the cost per additional young hatched to $7.29-$10.30 for comparable situations. If high nest success can be maintained inside electric fences, nest density should increase over time through homing by successful hens (Lokemoen et al. 1990), and cost-effectiveness can be increased. A density of 2 nests/acre (exceeded historically on several Wisconsin sites) inside a fence with 70% nest success further reduces the cost/additional young hatched to $3.64 or $5.15 for 80- or 40-acre plots, respectively.

SUMMARY AND MANAGEMENT RECOMMENDATIONS

Flexinet Fences

Our initial experience with Flexinet fences indicated that they might better fit management needs than smooth wire fences. Construction costs were comparable to smooth wire fences, they were set up quickly, taken down after field seasons to prevent vandalism or hunter conflicts, and conformed more easily to irregularities of property lines and topography than smooth wire fences. However, there were more problems in maintaining adequate power to Flexinet than smooth wire fences, partly because of the less permanent construction of Flexinet. More importantly, Flexinet fences of both heights did not protect nests from predation. Numerous problems were encountered in maintaining high voltages, and target predator species penetrated Flexinet fences even when fully powered. Red foxes were apparently able to jump over Flexinet fences, especially the 20-inch height, and effectively hunt within them. Although large plots of Flexinet fences were not adequately tested, it is not likely that this would change red fox behavior. Consequently, Flexinet fences are not recommended for predator management to increase game bird production.

Smooth Wire Fences

Problems were also encountered in maintaining high voltages to smooth wire fences due to human error, equipment malfunction, or natural factors. In spite of numerous instances of low voltage allowing predator access, nest success was higher inside smooth wire fences than outside. Predation inside fences coincided with these low voltage instances, indicating that resolution of fence power problems would further improve nest success. Predation by target predator species was reduced inside fences although not eliminated. Some opossums were able to penetrate fully-powered smooth wire fences. Nest success within 2 smooth wire fences averaged much higher than within the other 2 fences. Severe erosion along fence lines and perhaps small plot size were reasons 2 fences failed to protect nests from predation.

Design improvements could reduce or eliminate many of the fence power problems encountered in our study. The solar panel successfully extended battery life; complete conversion to solar panels would reduce maintenance costs as well as reduce fence power problems. Other human error problems should be reduced if a single, experienced person is responsible for fence maintenance. Our study emphasizes that an electric fence must be adequately maintained to be effective. Fence lines should be laid out to reduce drainage patterns with erosion potential along fence lines. A buffer strip of dense grass cover is suggested between active croplands and fence lines to further reduce erosion problems. Equipment malfunctions are more difficult to avoid with our fence design; prevention and detection of malfunctions will necessitate frequent maintenance visits. A backup power system could alleviate malfunctions, but the overall design and costs would change.

Large plots are suggested to reduce fence costs and to reduce the potential for a single predator to destroy all nests on a plot in a brief period. However, as plot size increases it may become difficult to remove predators before each nesting season. Earlier starting dates (mid-March) each year would help, but late snows can temporarily short circuit the fences and negate the effort. Potential den sites (e.g. rock piles) within fences should be eliminated to reduce the attractiveness of the area to predators, but more active predator removal may be necessary. Predation by non-target species was not a major problem in our study. However, compensatory predation by non-target species could occur as predation by target species is reduced (Balser et al. 1968). Fence design changes alone may not be enough to reduce predation by mink and ground squirrels.

We recommend ground cover inside the fence be different from that outside to aid hens in homing to the protected fields in succeeding years (Madsen 1986) although our research did not evaluate this. Active croplands, food plots, or at least very different nest cover should surround the fenced plots.

Our smooth wire fence design has potential for cost-effectively increasing game bird production immediately in situations of high nest density or low nest success, or over time by building up nest densities. Costs and benefits depend upon labor rates, plot size, nest density, and nest success. We documented $10.30/additional young hatched over that of unfenced cover for the best conditions of our study. Cost/benefit could realistically be reduced to $3.64/additional young hatched with resolution of smooth wire fence power problems that increases nest success.

Hybrid Physical-Electrical Barriers

Hybrid physical-electric barriers offer the advantage of using fewer electric wires and rely on physical barriers to direct predators into electric wires. These barriers have reduced problems of maintenance and have recently provided dependably high game bird nest success (Madsen 1986, P. Arnold, USFWS, pers. comm., Greenwood et al. 1990). These fences were more substantial in structure with higher initial costs, but lower maintenance and overall cost/benefit than our smooth wire design. Hybrid fences have a 2-inch wire mesh physical barrier for the first 2 ft above ground and electric barriers above this up to 4 ft above ground. Predators were discouraged from digging under the fence by either burying 1 ft of fence, folding 1 ft of fence away from the fence at ground level, or constructing electric wires outside the fence near ground level. Earlier starting dates are possible with hybrid fences because electric wires are above potential snow drifts of late winter. Some fences also had a "backup" of poison bait inside the fence to kill any predator that penetrated the fence.

Our study included only a single-year test of a physical-electrical barrier. However, our experience and information from other studies allow us to make some general recommendations regarding their construction. We recommend consideration of a different hybrid fence design than we tested, as illustrated in Figure 2. The physical barrier should extend at least 3 ft above ground level to avoid problems with growing vegetation shorting electric wires. A physical barrier of 2-inch mesh wire allows duckling or chick exit, but may prevent the exit of accompanying hens (Greenwood et al. 1990, J. Lokemoen and G. Krapu, USFWS, pers. comm.). Additional research will determine the severity of this problem and test solutions. Our experience with a physical-electric barrier indicated that digging under the fence needs to be prevented. Extending the fence underground rather than maintaining outside electric wires at ground level would eliminate the need for spraying or mowing maintenance and therefore erosion problems. However, plastic-coated wire is needed for the buried barrier so that wire corrosion does not shorten effective life of the fence (P. Arnold, USFWS, pers. comm.).

Two pairs of charged wires offset from the plane of the fence just before the top of the physical barrier would prevent predators from climbing over. Smooth wires extending above the physical barrier would give visual

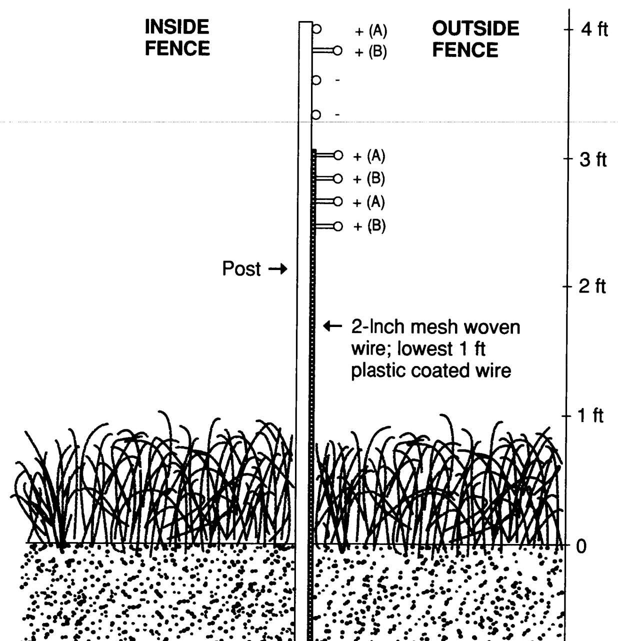


Figure 2. *Suggested design for a hybrid physical-electrical barrier in Wisconsin.*

discouragement to jumping over, but electrifying upper wires is of questionable value, except for the top wire of the fence. Electric wires should be paired, with 2 separate power systems (Fig. 2). An electric barrier would still be maintained if one system failed. This duplication of power could be justified by fewer problems and fence maintenance visits.

General Considerations

Poison baits inside fences would likely solve the problems of predator removal at the beginning of each field season, for occasional predator penetration, and for non-target predator penetration. However, their importance to fence success may be underestimated by referring to them as a "back-up". Less secure fence designs with poison baits inside may also demonstrate high nest success. Such poison baits are currently illegal in Wisconsin. Live-trapping inside fences for removal of problem animals may be desirable. However, the back-up power system and hybrid physical-electric design reduce fence maintenance visits to one per week or less; unattended live-traps have the potential for conflicts with humane captive animal policies in the state.

Lokemoen (1984) reviewed the economic effectiveness of several management practices for duck production. He found electric fences more cost-effective ($2.38-$8.86/fledged young) than nest cover establishment, or construction of nest structures, islands, level ditch ponds, and impoundments ($7.89-$580.52/fledged young); only lethal predator removal was more cost-effective ($1.88-$3.37/fledged young) than electric fences, and the difference was minor. Our fences demonstrated reasonable returns on management dollars, and future designs improve the economics of electric fencing. There appears to be a reluctance to accept electric fencing as a management tool in Wisconsin because of high initial costs and maintenance commitments. However, the high return on these costs compared with the poor return on less intensive management is what makes electric fencing cost-effective. A concurrent study on managed but unfenced nest cover in Wisconsin documented an average nest density of 0.14 game birds/acre and 26% Mayfield nest success (R. Gatti, unpubl. data). Over 20 years, 7.16 fledged young would be produced on unfenced cover at a cost of $1,200 (R. Gatti unpubl. data) or $168/fledged young.

Electric fences, particularly our suggested fence design, are intensive management efforts that are not suitable for all wildlife production lands. They will be most cost-effective on properties where densities of duck breeding-pairs and nests are high and nest success is low (i.e. population "sinks"). Electric fencing allows co-existence of predators and high game bird populations, which should be socially more acceptable than lethal removal of predators. Electric fences, like artificial nest structures, give clear visual reminders of management that may be distasteful to some. But self-sustaining populations of ducks and pheasants may not be possible in an intensively managed agricultural environment without such intensive management efforts.

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Approximate Metric-English Equivalents	
1 ha = 2.48 acres	1 L = 1.06 qt
1 m = 3.28 ft	1g = 0.035 oz
1 cm = 0.39 inches	1kg = 2.21 lb
1 km = 0.62 miles	1 metric ton = 1.10 tons
1 m^2 = 1.20 yd^2	

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